LWT - Food Science and Technology 43 (2010) 436–441

Contents lists available at ScienceDirect

LWT - Food Science and Technology

journal homepage: www.elsevier.com/locate/lwt

Functional properties of pasteurised liquid whole egg products as affected by the hygienic quality of the raw eggs

Margherita Rossi*, Ernestina Casiraghi, Laura Primavesi [1], Carlo Pompei, Alyssa Hidalgo

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

ARTICLE INFO

Article history:
Received 15 December 2008
Received in revised form
27 August 2009
Accepted 10 September 2009

Keywords:
Cake volume
Foam consistency
Foam stability
Hygienic quality
Overrun
Viscosity
Whole egg product

ABSTRACT

The viscosity, foaming and baking performances of pasteurised liquid whole egg products were investigated to study the influence of raw egg hygienic quality on egg product functional performances. Uracil, lactic acid and 3OH-butyric acid measured in the pasteurised egg products were taken as chemical indices of the hygienic quality of the raw material. A high variability in the functional properties was observed, especially for overrun and foam stability, as well as in the chemical indices of hygiene. Many interesting correlations were found between variables, for example between overrun and cake volume ($p < 0.001$). Instead, no significant correlations were found between the chemical indices and the different functional properties. However, the application of Principal Component Analysis demonstrated that a good hygienic quality of the raw material used to prepare the liquid whole egg products is a prerequisite needed to develop good functional performances, although other factors pertaining to composition or processing also have a role.

1. Introduction

Egg is a polyfunctional ingredient, because its thickening, gelling, emulsifying, foaming, colouring, and flavouring properties contribute to the texture and sensory characteristics of foods. Food industries chiefly make use of the liquid egg products obtained through the shelling and pasteurisation of shell eggs, whole egg products being employed as ingredients for the manufacture of egg pasta, mayonnaise, pastry, and baked foods. In bakery products, both albumen and yolk proteins of whole egg contribute to the formation and stabilization of the aerated structure (Kiosseoglou & Paraskevopoulou, 2006). In particular, whole egg foaming properties are of primary importance in sponge cakes or Génoise cakes, in which aeration is mainly obtained in the beating phase of eggs with sugar, or in the industrial mixing process of batter using high-speed mixers (Bennion & Bamford, 1973; Conforti, 2006; Rossi, Hidalgo, & Clerici, 2008). Even if the final cake structure is based on gluten development, the network system is modulated by the heat-setting ability of the egg proteins, resulting in a more brittle and less elastic structure (Davies, 1986).

Food manufacturers often complain about a certain variability of functional properties in egg products, which can seriously hamper the standardization of processes and of final food quality. Actually, many factors have been identified as sources of variation for these functional properties (Rossi, 1999). Some of them are related to the quality of the raw material in terms of egg freshness and composition (Donovan, 1977; Hammershoj, Larsen, Andersen, & Qvist, 2002; Jones, 2007; Meehan, Sugihara, & Kline, 1962; Rossi, Fessas, & Pompei, 2001), others are linked to processing treatments such as homogenisation, pasteurisation and freezing (Allais, Edoura-Gaena, Gros, & Trystram, 2006; Dawson, 1996; Garibaldi, Donovan, Davis, & Cimino, 1968; Guilmineau & Kulozik, 2007; Hamid-Samimi & Swartzel, 1984; Jaekel, Dautel, & Ternes, 2008; Lechevalier et al., 2005; Rossi, Pompei, & Casiraghi, 1997; Yang & Cotteril, 1989). Studying the industrial processing of pasteurised liquid egg white, Lechevalier et al. (2005) tried to quantify the influence of the different factors on functional properties, concluding that the quality of the raw material is the main source of variation, accounting for 70% of variability.

In Europe, egg products for the food industry can be produced with both grade A (fresh eggs) and B (second quality) eggs, fit for human consumption (EU, 2003). Their shells must be clean, dry, fully developed, and with no cracks; cracked eggs however can be used provided they are processed as soon as possible. Eggs must be broken in a manner that minimises contamination, from shells in particular, thus egg contents may not be obtained by the

* Corresponding author. Tel.: +39 02 50319188; fax: +39 02 50319190.
E-mail address: margherita.rossi@unimi.it (M. Rossi).
[1] Present address: Unità di Allergologia e Immunologia Clinica, Fondazione IRCCS Ospedale Maggiore Policlinico, Mangiagalli e Regina Elena, via Pace 9, 20122 Milan, Italy.

0023-6438/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.lwt.2009.09.008

centrifuging or crushing of eggs (EU, 2004). Practically, the hygienic quality and the physical characteristics of the raw material are highly variable depending on shell soundness and storage times before breaking (refrigerated shell eggs can be stored for months before processing). Moreover, illegal practices such as centrifuging, used to recover the contents of broken, undersized or very old eggs, may contribute to microbial contamination and mechanical stress of the raw material. The EU legislation establishes that the pasteurised egg products shall not contain *Salmonella* (in 25 g), and limits the presence of Enterobacteriaceae to a maximum of 100 cfu/g (EU, 2005) at the end of the pasteurisation treatment; limits are also given for 3OH-butyric acid (10 mg/kg dry matter), an index of the presence of incubator reject eggs, and for lactic acid (1000 mg/kg dry matter), a chemical index of hygienic quality of the raw material to be measured before treatments (EU, 2004). Hidalgo, Franzetti, Rossi, and Pompei (2008a) suggested uracil as a marker for assessing raw material hygienic quality in pasteurised egg products. The Authors stated that uracil, absent in sound whole eggs, is formed as a consequence of high microbial contamination ($>10^6$ cfu/g) after a sufficient lag time.

Despite the outstanding role of whole egg as a food ingredient, the literature pertaining to the factors affecting its functional properties is relatively scarce, in comparison with that concerning the single fractions albumen and yolk. Moreover, because of the interactions between albumen and yolk components, the results obtained for the individual fractions cannot be extrapolated to whole egg.

The aim of the present work was to study the influence of the raw material hygienic quality, indicated by uracil and by the legal indices 3OH-butyric and lactic acids on the viscosity, foaming and baking performances of pasteurised liquid whole egg products. The study was carried out on several industrial egg products and on experimental samples obtained from the pasteurisation at laboratory scale of fresh and long-term stored eggs.

2. Materials and methods

2.1. Experimental and industrial whole egg products

Three whole egg product samples were prepared at laboratory scale using three different lots of shell eggs, namely, grade A-extra eggs (EU, 2003) from the commercial channel (sample A); newly-laid eggs obtained directly from the farm (sample B); grade B eggs (EU, 2003) stored at 4 °C for 6 months (sample C).

For the preparation of these experimental samples, 80 eggs per sample were manually broken and, after removing the *chalazae*, manually mixed. The mixes obtained were homogenised (frequency 50 Hz, pressure 30 bar) using a Niro Soavi homogeniser (mod. Panda, Parma, Italy) and then pasteurised (63.5 °C for 210 s) in a lab scale tubular heat exchanger, equipped with an aseptic stainless steel bottling system.

Sixteen samples (I1–I16) of commercial liquid pasteurised whole egg products produced by different manufacturers were kept at 4 °C and analysed two days after production.

2.2. Analytical methods

The total mesophilic aerobic bacteria count (cfu/g) was determined following method 966.23 (AOAC, 1995a). The pH was assessed potentiometrically using a PHM62 standard pH meter (Radiometer, Copenhagen, Holland); dry matter was determined gravimetrically according to method 925.30 (AOAC, 1995b); protein content was calculated as total nitrogen, following the method 925.31 (AOAC, 1995b), multiplied by the factor 6.25.

Lipid content was determined by the rapid Gerber-method fat analysis for dairy products, using 12% size butyrometers with 1% fat subdivisions. The method was modified as follows: 10 ml sulphuric acid (density: 1.82 g/ml), 11 ml whole egg and 1 ml amyl alcohol (density: 0.815 g/ml) were added consecutively to the butyrometers. The tubes were then gently shaken, placed in a 70 °C water bath for 15 min and finally centrifuged at 800 rpm for 10 min in a heated specific centrifuge (Pool Bioanalysis, Italy). After centrifuging, the volume of fat was immediately read on the graduated scale of the butyrometer. Method repeatability was assessed on ten replicates of analysis on a whole egg sample (average lipid value: 9.4 ± 0.05 g/100 g) giving a coefficient of variation (CV) of 0.53%. For comparison, the same sample was also analysed (ten replicates) following the official method 925.32 (AOAC, 1995b) for the analysis of fat in eggs and egg products obtaining a slightly higher average lipid content (10.0 ± 0.05 g/100 g) and a similar CV of 0.50%.

Lactic acid and uracil were determined by HPLC as described by Hidalgo et al. (2008a); 3OH-butyric acid was evaluated using the Boehringer Mannheim enzymatic kit (R-Biopharm GmbH, Darmstadt, Germany), following the method suggested by the producer for egg analysis.

All chemical analyses were performed in duplicate and results are expressed as g/100 g dry matter (DM).

Whole egg whipping capacity was measured using the Cream tester CT II (Gerber Instruments, Effretikon, Switzerland), as reported by Hidalgo, Rossi, Clerici, and Ratti (2008b). The whipping capacity was calculated as overrun (%) expressing the percent volume increase as follows: $\text{Overrun}(\%) = [(V - Vo)/Vo]100$, where V is the foam volume and Vo is the whole egg sample volume before whipping. The registered electric current value (mA) was taken as an index of foam consistency.

Foam stability was evaluated immediately after whipping. Foam was gently poured into a 250 ml graduated plastic cone and the weight of the transferred foam registered. The cone was covered with a transparent film and kept at 4 °C for 2 h, then the volume of the liquid separated at the cone bottom was registered. Foam stability was calculated as follows: $\text{Stability}(\%) = 100 - V_{LS}/V_{LWE}100$, where V_{LS} is the volume of the liquid separated and V_{LWE} is the volume of the liquid whole egg, corresponding to the

Table 1
Dry matter, protein, lipid contents and pH (mean ± standard deviation) of experimental (A–C) and industrial (I1–I16) whole egg products.

Sample	Dry matter (g/100 g)	Protein (g/100 g)	Lipid (g/100 g)	pH[l]
A	23.5 ± 0.20^{fgh}	12.2 ± 0.24^{ef}	9.1 ± 0.14^{cde}	7.6^{d}
B	23.4 ± 0.12^{efg}	11.9 ± 0.23^{de}	8.8 ± 0.35^{bc}	7.3^{a}
C	23.4 ± 0.13^{efg}	12.9 ± 0.09^{hi}	8.0 ± 0.10^{a}	7.9^{g}
I1	22.6 ± 0.26^{c}	11.4 ± 0.21^{b}	9.4 ± 0.28^{de}	7.6^{d}
I2	20.9 ± 0.14^{a}	11.5 ± 0.10^{bc}	8.0 ± 0.05^{a}	7.8^{f}
I3	23.2 ± 0.47^{def}	12.0 ± 0.22^{def}	9.5 ± 0.00^{e}	7.6^{d}
I4	21.6 ± 0.15^{b}	10.4 ± 0.12^{a}	8.7 ± 0.14^{bc}	7.7^{e}
I5	24.5 ± 0.42^{jk}	12.1 ± 0.29^{def}	11.0 ± 0.42^{i}	7.3^{a}
I6	22.6 ± 0.41^{c}	12.6 ± 0.27^{gh}	8.6 ± 0.07^{b}	7.6^{d}
I7	24.3 ± 0.13^{ijk}	13.1 ± 0.21^{i}	10.3 ± 0.46^{f}	7.4^{b}
I8	23.7 ± 0.31^{fghi}	12.7 ± 0.23^{h}	10.4 ± 0.20^{fg}	7.3^{a}
I9	24.8 ± 0.23^{k}	12.0 ± 0.24^{def}	11.8 ± 0.09^{l}	7.3^{a}
I10	23.5 ± 0.57^{fgh}	11.8 ± 0.12^{cd}	10.9 ± 0.12^{hi}	7.4^{b}
I11	22.9 ± 0.22^{cde}	11.8 ± 0.19^{cd}	10.5 ± 0.39^{fgh}	7.4^{b}
I12	25.5 ± 0.13^{l}	12.3 ± 0.17^{fg}	8.8 ± 0.09^{bc}	7.5^{c}
I13	23.9 ± 0.41^{ghi}	12.3 ± 0.19^{fg}	10.3 ± 0.10^{f}	7.4^{b}
I14	22.7 ± 0.18^{cd}	11.5 ± 0.18^{bc}	10.4 ± 0.07^{fg}	7.4^{b}
I15	21.2 ± 0.22^{ab}	10.7 ± 0.09^{a}	9.0 ± 0.15^{bcd}	7.4^{b}
I16	24.0 ± 0.62^{hij}	12.2 ± 0.14^{ef}	10.8 ± 0.40^{ghi}	7.4^{b}
Average	23.3	12.0	9.7	7.5
CV (%)	5.1	5.7	11.3	2.4

[a–k]Values bearing different letters in the same column are significantly different ($p \leq 0.05$).
[l] Standard deviation approximates 0.00.

Table 2
3OH-butyric acid, lactic acid and uracil contents (mean ± standard deviation) of experimental (A–C) and industrial (I1–I16) whole egg products.

Sample	3OH-butyric acid[h] (mg/kg DM)	Lactic acid[i] (mg/kg DM)	Uracil (mg/kg DM)
A	nd	nd	nd
B	nd	nd	nd
C	nd	nd	nd
I1	nd	nd	5.0 ± 0.21^{a}
I2	6.0 ± 1.56^{cde}	nd	nd
I3	3.0 ± 0.23^{a}	nd	nd
I4	14.2 ± 1.44^{g}	4684.8 ± 265.43^{e}	60.0 ± 6.12^{e}
I5	3.9 ± 1.13^{ab}	nd	nd
I6	3.9 ± 1.06^{ab}	398.0 ± 25.33^{abc}	nd
I7	5.6 ± 0.86^{cde}	nd	nd
I8	7.6 ± 0.99^{ef}	nd	nd
I9	7.2 ± 1.80^{def}	447.0 ± 16.11^{c}	7.0 ± 0.40^{b}
I10	5.0 ± 1.12^{bcd}	421.0 ± 42.22^{bc}	14.0 ± 0.00^{d}
I11	6.0 ± 1.10^{cde}	353.0 ± 65.10^{ab}	nd
I12	nd	337.8 ± 38.21^{a}	nd
I13	4.8 ± 0.02^{bc}	$381. \pm 61.00^{abc}$	nd
I14	9.0 ± 2.47^{f}	1014.0 ± 48.31^{d}	15.0 ± 2.20^{d}
I15	nd	nd	10.0 ± 0.13^{c}
I16	4.4 ± 0.45^{bc}	350.0 ± 54.14^{ab}	nd

[a–g]Values bearing different letters in the same column are significantly different ($p \leq 0.05$) according to LSD test carried out after variance stabilization through log transformation of the original data (Neter et al., 1989).
[h] Legal limit: 10 mg/kg DM (EU, 2004).
[i] Legal limit: 1000 mg/kg DM (EU, 2004); nd: non detectable.

equivalent volume of the transferred foam and calculated dividing initial foam weight by whole egg density. These tests were performed in triplicate.

Baking performance, expressed as final cake volume, was evaluated preparing a high-ratio cake of standard formulation, as proposed by Rosenthal (1995), containing 29.1% sugar, 25.3% flour, 21.5% whole egg, 12.7% hydrogenated-fat margarine, 8.9% water, 1.3% skim-milk powder, 0.9% baking powder, and 0.3% salt. A batter (500 g) was prepared with a mixer (Hobart Co., Troy, OH, USA) supplied with a bowl and a whisk and operating at three fixed speeds. The dry ingredients were first mixed at speed 1 for 1 min, then the liquid ones (pre-conditioned at 20 °C) were added and the mixture was treated at speed 1 for 3 min, then at speed 3 for other 3 min. Aliquots (10 ml each) of the dough were poured, with the aid of a silicon tube mounted on a syringe, into fifteen 50 ml graduated glass cylinders and baked in a microwave oven, equipped with a rotating plate and a timer, at 450 W for 210 s. Each cooking session was performed on 5 cylinders at a time, placed at equal distance from the centre of the microwave plate. Three cooking sessions were performed, for a total of 15 replicates per sample. After cooling, cake volume (ml) was directly read on the cylinder graduation and the value recorded. Results are reported as the average value of the 15 replicates.

Viscosity was determined at room temperature using a Bohlin VOR Rheometer (Bohlin Reologi AB, Lund, Sweden), supported by a dedicated software (Bohlin VOR Rheometer Software, version 4.05). Tests were carried out with a C25 measuring element and torsion bar of 4.13 g cm. Results (mPa s) were expressed as apparent viscosity, at a shear rate of 232 s^{-1}, and represent the average of three determinations.

2.3. Statistical analysis

The ANOVA and the Least Significant Difference (LSD) test were calculated by Systat 5.03 software for Windows (Systat Inc., San Jose, CA, USA) to evidence significant differences among the values. LSD test was performed on the original data, except those reported in Table 2, for which a log transformation was applied to stabilize the variance (Neter, Wasserman, & Kutner, 1989). The Pearson correlation matrix was also calculated by Systat 5.03. The Principal Component Analysis (PCA) was carried out by The Unscrambler 9.2 (Camo, Oslo, Norway).

3. Results and discussion

3.1. Composition of egg products

Chemical composition and pH of experimental (A–C) and industrial whole egg products (I1-I16) are shown in Table 1. Dry matter (20.9–25.5 g/100 g), protein (10.4–13.1 g/100 g DM), and lipid (8.0–11.8 g/100 g DM) contents of industrial liquid egg products showed ranges of variation wider than those observed for experimental samples. This was due to the variability of albumen to yolk ratios in industrial egg products, according to the different food industries requirements. Instead, the values of pH in the industrial

Table 3
Functional properties (mean ± standard deviation) of experimental (A–C) and industrial (I1–I16) whole egg products.

Sample	Viscosity (mPa s)	Overrun (%)	Foam consistency (mA)	Foam stability (%)	Cake volume (ml)
A	10.90 ± 0.351^{f}	516 ± 0.5^{k}	272 ± 1.5^{e}	26.2 ± 1.72^{hi}	30.2 ± 0.92^{f}
B	8.23 ± 0.067^{c}	508 ± 0.7^{ijk}	270 ± 1.5^{e}	10.5 ± 1.09^{ab}	29.7 ± 1.09^{cdef}
C	12.4 ± 0.755^{h}	516 ± 0.7^{k}	285 ± 3.1^{fghi}	19.3 ± 2.02^{ef}	28.7 ± 1.07^{abcde}
I1	7.83 ± 0.028^{b}	404 ± 25.6^{g}	230 ± 20.5^{d}	13.7 ± 4.91^{bcd}	29.2 ± 0.27^{bcdef}
I2	6.36 ± 0.123^{a}	207 ± 0.2^{c}	166 ± 1.5^{a}	9.0 ± 0.64^{a}	28.3 ± 0.88^{ab}
I3	11.66 ± 0.065^{g}	505 ± 0.8^{ij}	280 ± 3.1^{efgh}	28.3 ± 1.30^{ij}	29.8 ± 0.80^{ef}
I4	13.90 ± 0.000^{j}	263 ± 6.2^{d}	191 ± 15.6^{c}	15.9 ± 5.71^{cde}	28.3 ± 0.67^{ab}
I5	10.17 ± 0.058^{e}	509 ± 5.6^{jk}	277 ± 0.6^{efg}	22.7 ± 0.41^{fgh}	29.9 ± 0.74^{ef}
I6	9.62 ± 0.020^{d}	181 ± 0.3^{a}	171 ± 1.0^{ab}	24.7 ± 1.33^{ghi}	28.2 ± 0.64^{ab}
I7	13.10 ± 0.000^{i}	498 ± 1.0^{i}	287 ± 1.2^{ghi}	36.6 ± 1.02^{l}	29.7 ± 1.09^{cdef}
I8	9.36 ± 0.067^{d}	506 ± 1.4^{ijk}	270 ± 2.1^{e}	21.9 ± 1.68^{fg}	29.3 ± 0.82^{bcdef}
I9	11.40 ± 0.000^{g}	198 ± 0.3^{bc}	180 ± 1.5^{b}	15.9 ± 0.83^{cde}	28.4 ± 0.94^{abc}
I10	8.07 ± 0.036^{bc}	315 ± 0.4^{f}	274 ± 0.6^{e}	17.1 ± 1.15^{de}	28.4 ± 0.62^{abc}
I11	7.95 ± 0.114^{bc}	188 ± 5.0^{ab}	167 ± 1.5^{a}	23.8 ± 2.01^{gh}	28.8 ± 1.00^{abcdf}
I12	11.70 ± 0.071^{g}	516 ± 0.2^{k}	291 ± 3.8^{ij}	30.0 ± 3.01^{jk}	29.9 ± 0.63^{ef}
I13	15.00 ± 0.100^{k}	516 ± 0.7^{k}	300 ± 3.2^{j}	30.2 ± 0.34^{jk}	29.3 ± 0.70^{bcdef}
I14	10.90 ± 0.100^{f}	298 ± 5.35^{e}	284 ± 0.6^{fghi}	21.8 ± 0.58^{fg}	27.8 ± 1.10^{a}
I15	6.68 ± 0.080^{a}	198 ± 0.2^{bc}	167 ± 1.0^{a}	12.7 ± 1.26^{bc}	28.6 ± 0.94^{abcde}
I16	13.17 ± 0.208^{i}	477 ± 5.6^{h}	288 ± 0.6^{hi}	32.4 ± 0.47^{k}	29.7 ± 0.97^{cdef}
Average	10.44 ± 2.492	385 ± 141.3	245 ± 51.7	21.7 ± 7.75	29.1 ± 0.72
CV (%)	23.9	36.7	21.1	35.7	2.5

[a–l]Values bearing different letters in the same column are significantly different ($p \leq 0.05$).

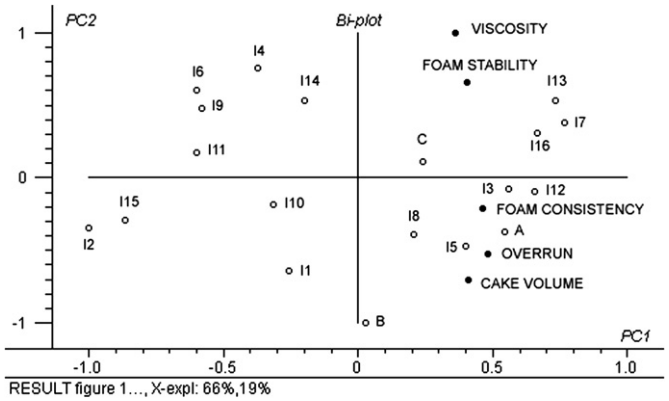

Fig. 1. Principal Component Analysis of experimental (A–C) and industrial (I1–I16) whole egg products for functional property variables: bi-plot of scores and loadings on the PC1–PC2 plane.

products had a narrow range between 7.3 and 7.8, while the highest pH value observed in the experimental sample C reflected the long-term storage of shell eggs used as the raw material, which leads to a pH increase (Rossi, Pompei, & Hidalgo, 1995)

3.2. Hygienic quality of egg products

As regards microbial quality of experimental samples, raw whole eggs used for the production of samples A, B and C all presented counts of the same order of magnitude (10^4 cfu/g), which were reduced to values below 100 cfu/g after the pasteurisation treatment, indicating the efficacy of the lab sanitization process. The good hygienic quality of the raw materials used for samples A, B, and C was also confirmed by the values of the chemical indices reported in Table 2, even for sample C obtained from sound shell eggs stored for 6 months before processing. Actually, no detectable uracil, 3OH-butyric and lactic acids were found in samples A–C.

Instead, six industrial samples out of sixteen (I1, I4, I9, I10, I14, I15) presented detectable uracil levels (Table 2), and two of them also exceeded the legal limits for lactic acid (I4, I14), thus revealing the low hygienic quality of the raw material used for their production, in accordance with the findings of Hidalgo et al. (2008a). Furthermore, sample I4 also showed an illegal level of 3OH-butyric acid, indicating the fraudulent use of incubator reject eggs. These results suggest a wide variability of the hygienic quality of the raw material used for the production of these industrial whole egg products.

3.3. Functional properties of egg products

Table 3 shows the results obtained for the viscosity, the foaming properties, and the baking performance of the experimental and industrial liquid egg products. A wide variability of foaming properties was observed among samples, especially for overrun and foam stability that bear coefficients of variation of 37% and 36%, respectively. A minor variation was instead observed for cake volume (CV = 2.5%). The PCA of sample functional properties evidenced the scatter plot reported in Figure 1, with the two first PCs explaining 85% of total variability. From the left side to the right, samples are roughly distributed along the PC1 axis with increasing overrun and foam consistency, these two variables having the highest loadings on PC1, which explains 66% of total variability. Considering the distribution and the values reported in Table 3, three main groups of samples, characterized by similar foaming properties, can be argued. A group with positive PC1 values (A, B, C, I3, I5, I7, I8, I12, I13, I16) developed high foam volumes with overrun values of about 500% and high foam consistencies (≥270 mA); another group (I1, I4, I10, I14) had intermediate overrun values (about 260–400%); the third group (I2, I6, I9, I11, I15) developed the lowest foam volumes (overrun about 200%) and foam consistencies (≤180 mA). The three experimental samples (A, B, C), in particular, lay in the right part of the plot together with the best performing industrial whole egg products.

3.4. Correlation analysis

Functional and compositional characteristics of industrial liquid egg products and experimental pasteurised whole egg products were jointly processed in a Pearson correlation matrix (Table 4). Both the dry matter and protein contents proved to affect positively the whole egg functional properties. The dry matter in particular was found to be directly correlated with whole egg overrun, foam consistency and stability ($p < 0.01$), and with viscosity and cake volume ($p < 0.05$). As a general rule, the functional properties were all correlated with each other. This was true for overrun, foam consistency and foam stability. Furthermore, viscosity was directly correlated with all the foaming properties, thus indicating that a more viscous whole egg product tends to develop higher volumes ($p < 0.05$) of more consistent ($p < 0.05$) and stable ($p < 0.01$) foam. Notwithstanding the small variability observed in cake volume development (Table 3), this last property was positively correlated with the foaming variables, overrun in particular ($p < 0.001$). This correlation justifies the practice of performing in-house whipping tests of whole egg products in quality control laboratory of baking industry.

Differently from Chang and Chen (2000), who modified whole egg pH in the range 6.5–9.0, no correlations were found between pH and the functional performances, probably due to the narrow

Table 4
Pearson correlation matrix of functional and compositional characteristics of whole egg products.

	3OH-butyric acid	Lactic acid	Uracil	Dry matter	Protein	Lipid	pH	Viscosity	Overrun	Foam consistency	Foam stability
Lactic acid	0.722***										
Uracil	0.663**	0.995***									
Dry matter	−0.209	−0.302	−0.398								
Protein	−0.293	−0.570*	−0.695***	0.670**							
Lipid	0.324	−0.111	−0.093	0.516*	0.145						
pH	−0.079	0.186	0.154	−0.514*	−0.065	−0.814***					
Viscosity	0.285	0.377	0.217	0.475*	0.316	0.175	−0.014				
Overrun	−0.394	−0.296	−0.356	0.596**	0.552*	0.002	−0.090	0.460*			
Foam consistency	−0.234	−0.236	−0.270	0.631**	0.526*	0.194	−0.214	0.514*	0.890***		
Foam stability	−0.005	−0.136	−0.299	0.594**	0.605**	0.307	−0.183	0.667**	0.486*	0.547*	
Cake volume	−0.502*	−0.373	−0.442	0.566*	0.405	0.060	−0.204	0.253	0.809***	0.572**	0.502*

*$p \leq 0.05$; **$p \leq 0.01$; ***$p \leq 0.001$.

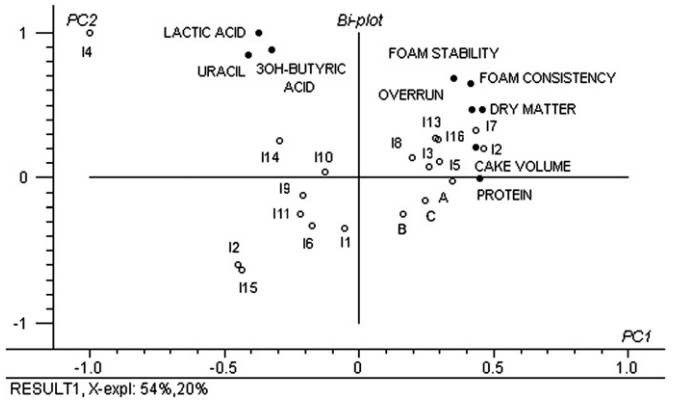

Fig. 2. Principal Component Analysis of experimental (A–C) and industrial (I1–I16) whole egg products for functional property variables plus hygienic quality indices: bi-plot of loadings and scores of component 1 and 2 calculated using nine variables.

pH range (natural pHs) in our study. No correlations were found between the chemical indices of hygiene and the functional properties. This result was to be expected because the chemical indices of hygiene, presenting frequent non detectable values, feature as semi-continuous variables, differently from the functional properties that behave instead as continuous variables. However, negative relations, although not significant, can be observed between the chemical indices of hygiene and foaming properties and cake volume. In fact, comparing the results reported in Tables 2 and 3, to samples presenting poor hygienic quality generally correspond low functional properties values. A highly significant correlation ($p < 0.001$) was found between uracil and lactic acid. This is consistent with the findings of Hidalgo et al. (2008a) who observed similar kinetics of formation for these two compounds as a consequence of microbial metabolism in whole egg. Lactic acid and uracil were also correlated with 3OH-butyric acid. These correlations can been explained by the fact that, although 3OH-butyric acid does not develop from microbial activity but only from embryonic metabolism (Salwin, Staruszkiewicz, & Bond, 1972), lactic acid and uracil are also formed during embryo development (Rossi, Hidalgo, Pompei, & Giuffrida, 1999).

3.5. Comprehensive multivariate approach

The functional and compositional characteristics and the indices of raw material hygienic quality of experimental and industrial pasteurised whole egg products were jointly processed by PCA. The original twelve-variable model was optimised selecting the nine variables reported in Figure 2. The figure represents the bi-plot of loadings and scores of components 1 and 2, which together explain 74% of variance. On the bi-plot, uracil and the legal indices lactic and 3OH-butyric acids lay close to each other in the left upper part of the plot, well separated from the functional characteristics which, in turn, are close to protein and dry matter contents. Variables distribution on the first component indicates opposite directions for the functional properties and the indices of poor hygienic quality of the raw material, suggesting that good functional properties are not generally associated with poor hygiene of the raw material. Moreover, considering the distribution of samples on the plot, the ones on the left side ($PC1 < 0$) showed unsatisfactory functional performances (Table 3), independently of the hygienic quality. In fact, on the left side, besides samples with the worst hygienic quality of the raw material (Table 2), samples I2, I6, and I11 are also found. Yet, these latter samples do not contain uracil and comply with present European regulations for lactic and 3OH-butyric acids.

4. Conclusions

In conclusion, this research demonstrates that a good hygienic quality of the raw material is a necessary prerequisite, but not sufficient, to achieve good functional performances of liquid whole egg products. Actually, besides hygiene, many other factors related to the processing and the quality of eggs may affect whole egg performances. Further investigations should be carried out to evaluate the contribution of these factors to the variability of functional performances found in the commercial whole egg products. This is a key point in keeping the performances under control and contributing to the standardization of the egg-containing foods.

Acknowledgements

The authors would like to thank Valentina Barone for her contribution to the experimental part.

References

Allais, I., Edoura-Gaena, R. B., Gros, J. B., & Trystram, G. (2006). Influence of egg type, pressure and mode of incorporation on density and bubble distribution of a lady finger batter. *Journal of Food Engineering, 74*, 198–210.
AOAC International. (1995a). Microbiological methods. In P. Cunnif (Ed.), *Official methods of analysis of AOAC International*. Gaithersburg, MD: AOAC International.
AOAC International. (1995b). Egg and egg products. In P. Cunnif (Ed.), *Official methods of analysis of AOAC International*. Gaithersburg, MD: AOAC International.
Bennion, E. B., & Bamford, G. S. T. (1973). *Eggs and egg products.* In, *The technology of cake making*. London: Leonard Hill Books.
Chang, Y. I., & Chen, T. C. (2000). Functional and gel characteristics of liquid whole egg as affected by pH alteration. *Journal of Food Engineering, 45*, 237–241.
Conforti, F. D. (2006). Cake manufacture. In Y. H. Hui (Ed.), *Bakery products. Science and technology*. Oxford: Blackwell Publishing Ltd.
Davies, A. P. (1986). Protein functionality in bakery products. In J. M. V. Blanshard, P. J. Frazier, & T. Gaillard (Eds.), *Chemistry and physics of baking. Materials, processing and products* (pp. 89–102). London: The Royal Society of Chemistry.
Dawson, P. L. (1996). Effects of freezing, frozen storage, and thawing on eggs and egg products. In L. E. Jeremiah (Ed.), *Freezing effects on food quality* (pp. 337–366). New York: Marcel Dekker, Inc.
Donovan, J. W. (1977). A study of the baking process by differential scanning calorimetry. *Journal of the Science of Food and Agriculture, 28*, 571–578.
EU (European Union). (2003). Commission Regulation No 2295/2003, 23 December 2003. *Official Journal of the European Union, L 340*, 16–34.
EU (European Union). (2004). Regulation (EC) No 853/2004 of the European Parliament and of the Council, 29 April 2004. *Official Journal of the European Union, L 226*, 22–82.
EU (European Union). (2005). Commission Regulation (EC) No 2073/2005, 15 November 2005. *Official Journal of the European Union, L 338*, 1–26.
Garibaldi, J. A., Donovan, J. W., Davis, J. G., & Cimino, S. L. (1968). Heat denaturation of the ovomucin-lysozyme electrostatic complex: a source of damage to the whipping properties of pasteurized egg white. *Journal of Food Science, 33*, 514–524.
Guilmineau, F., & Kulozik, U. (2007). Influence of a thermal treatment on the functionality of hen's egg yolk in mayonnaise. *Journal of Food Engineering, 78*, 648–654.
Hamid-Samimi, M. H., & Swartzel, K. R. (1984). Pasteurization design criteria for production of extended shelf-life refrigerated liquid whole egg. *Journal of Food Processing and Preservation, 8*, 219–224.
Hammershoj, M., Larsen, L. B., Andersen, A. B., & Qvist, K. B. (2002). Storage of shell eggs influences the albumen gelling properties. *Lebensmittel Wissenschaft und Technologie, 35*, 62–69.
Hidalgo, A., Franzetti, L., Rossi, M., & Pompei, C. (2008a). Chemical markers for the evaluation of raw material hygienic quality in egg products. *Journal of Agricultural and Food Chemistry, 56*, 1289–1297.
Hidalgo, A., Rossi, M., Clerici, F., & Ratti, S. (2008b). A market study on the quality characteristics of eggs from different housing systems. *Food Chemistry, 106*, 1031–1038.
Jaekel, T., Dautel, K., & Ternes, W. (2008). Preserving functional properties of hen's egg yolk during freeze-drying. *Journal of Food Engineering, 87*, 522–526.
Jones, D. R. (2007). Egg functionality and quality during long-term storage. *International Journal of Poultry Science, 6*(3), 157–162.

Kiosseoglou, V., & Paraskevopoulou, A. (2006). Eggs. In Y. H. Hui (Ed.), *Bakery products. Science and technology* (pp. 161–172). Oxford: Blackwell Publishing Ltd.

Lechevalier, V., Périnel, E., Jeantet, R., Lesaffre, C., Croguennec, T., Guérin-Dubiard, C., et al. (2005). Statistical analysis of effects of industrial processing steps on functional properties of pasteurised liquid egg white. *Journal of the Science of Food and Agriculture, 85*, 757–769.

Meehan, J. J., Sugihara, T. F., & Kline, L. (1962). Relationship between shell egg handling factors and egg products properties. *Poultry Science, 41*, 892–900.

Neter, J., Wasserman, W., & Kutner, M. H. (1989). *Applied linear statistical models*. Boston: Irwin.

Rosenthal, A. J. (1995). Application of aged eggs in enabling increased substitution of sucrose by Litesse (polydextrose) in high-ratio cakes. *Journal of the Science of Food and Agriculture, 68*, 127–131.

Rossi, M. (1999). Egg products functional properties. In *Proceedings of VIII European Symposium on the Quality of Eggs and Egg Products* (pp. 303–312), Bologna, Italy, September 19–23: WPSA Italian Branch.

Rossi, M., Fessas, D., & Pompei, C. (2001). Effects of egg aging on the baking properties of raw and pasteurised whole egg. In *Proceedings of IX European Symposium on the quality of eggs and egg products* (pp. 363–367), Kusadasi, Turkey, September 9–12: WPSA Turkish Branch.

Rossi, M., Hidalgo, A., & Clerici, F. (2008). Whole egg whipping properties as affected by albumen and yolk fraction changes. In *Proceeding of the 1st Mediterranean Summit of WPSA* (pp. 229–233), Porto Carras, Greece, May 7–10: WPSA Greek Branch.

Rossi, M., Hidalgo, A., Pompei, C., & Giuffrida, F. (1999). A new approach to the identification of incubator reject eggs in pasteurized whole egg products obtained from fresh eggs. In *Proceedings of VIII European Symposium on the quality of eggs and egg products* (pp. 451–456), Bologna, Italy, September 19–23: WPSA Italian Branch.

Rossi, M., Pompei, C., & Casiraghi, E. (1997). The chemical physical and functional properties of pasteurized and frozen egg products. In *Proceedings of VII European Symposium on the quality of eggs and egg products* (pp. 299–306), Poznan, Poland, September 21–26: Boleslaw Matylla.

Rossi, M., Pompei, C., & Hidalgo, A. (1995). Freshness criteria based on physical and chemical modifications occurring in eggs during aging. *Italian Journal of Food Science, 7*, 147–156.

Salwin, H., Staruszkiewicz, W. F., & Bond, J. F. (1972). Formation of β-hydroxybutyric acid in eggs during incubation. *Journal of the Association of the Official Analytical Chemists, 55*, 458–460.

Yang, S., & Cotteril, O. J. (1989). Physical and functional properties of 10% salted egg yolk mayonnaise. *Journal of Food Science, 54*, 210–213.