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# Development and characterization of a new sweet egg-based dessert formulation ☆

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**Abstract**

The purpose of this work was to develop and characterise a new low-cholesterol formulation of a semisolid dessert made with egg yolks and sucrose. Basing on preliminary tests, two formulations were prepared, one according to the traditional recipe (TCY) and the other one as a low-cholesterol product (TCGR). TCY ingredients were water, egg yolk and sucrose; whereas in TCGR egg yolk was substituted by a combination of egg yolk granules, sunflower oil and hydrocolloids. The new recipe showed 83% less cholesterol content per serving unit and also lower calorie value than the typical recipe. These formulations were compared by means of rheological, textural and sensorial analyses. Colour and microstructure analyses were also developed. Sensory data indicated that, beyond differences regarding physical characteristics, there were not significantly differences between samples in texture and flavour acceptance. Finally, in order to provide a culinary point of view of the new recipe, a final dish was created by a trained chef using the new sweet egg-based formulation.


*Keywords:* Egg yolk granules; Low-cholesterol dessert; Rheology; Texture; Sensory evaluation

## Introduction

Hen egg is one of the most versatile foods, containing high-quality proteins and lipids (Anton, 2007). Furthermore, egg is widely employed as an ingredient in the food industry, due to their thickening, gelling, emulsifying, foaming, colouring, and flavouring properties, it contributes to the texture and sensory characteristics of food products (Rossi et al., 2010). Along with changes in egg-processing technology, there has been a continuous growth of further-processed egg products. In fact, today, approximately 30% of the total eggs consumption is in the form of processed products (Froning, 2008). Many of these egg products are used as ingredients in several food applications such as pasta, mayonnaise, pastry, and baked foods.

Desserts are known in many cultures of the world as courses that typically come at the end of a meal. They usually consist of sweet and creamy food and, consequently, high in sugar and fat levels (Alija and Talents, 2012). However, and since changing dietary habits and sedentary lifestyles have led to an increase in worldwide obesity, as a result, people have come to expect something different from their diet in recent decades (Seuss-Baum, 2007). Thus, largely influenced by health related concerns, there has been pressure on the food industry to reduce the amount of fat (specifically cholesterol), sugar, salt and certain additives in the diet (Alija and Talents, 2012; Nikzade et al., 2012). There are different strategies to transform traditional recipes into low fat versions for the food industry: by reducing its content and/or by using ingredients

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(such as starch, inulin, pectin, carrageenan, etc.) that mimic their functional properties (Alija and Talents, 2012).

In addition to its nutritional value, fat influences rheological properties and sensory characteristics of foods such as flavour, mouthfeel and texture. These sensory properties are very hard to reproduce in formulations without fat. Therefore it is rather difficult to imitate traditional product quality when preparing low-fat foods (Liu et al., 2007). For instance, chefs have been working on the reduction of fat in desserts but keeping same texture. Collaboration between chefs and food technologists would lead to preserve the original sensory attributes of a traditional dessert while still achieving reduced calorie contents (Alija and Talents, 2012).

This work covers the general characteristics of a semisolid sweet egg-based dessert. Despite this work is based on a Spanish product, its formulation is similar to other egg products found worldwide such as custard dessert or crème caramel; in fact, it could be described as a pudding made with egg yolks and syrup. The aim of this work was to develop a low-cholesterol product (TCGR) achieving an appearance, and aroma and texture profiles substantially as good as those of typical product (TCY). Since the egg yolk granules present interesting nutritional composition (34% lipid and 60% protein on a moisture-free basis) and functional properties (gelling, emulsifying, etc.) to be employed as ingredient in food industry (Laca et al., 2014), instead of yolk used in traditional product, low-cholesterol dessert was formulated employing yolk granules and hydrocolloids (potato starch and carrageenan) as ingredients. Both formulations were compared by means of rheological and textural measurements, as well as of their colour, microstructure and sensorial properties. Finally and, with the purpose of integrating technological advances in food science with gastronomes' vision, this study also included a final dish created by a trained chef using the new recipe.

## Material and methods

### *Yolk and egg yolk granules preparation*

Egg yolk granules were obtained according to Laca et al. (2010). Egg yolks were prepared from fresh eggs by performing manually the shelling of the eggs and the separation of the yolk from the albumen, the vitelline membrane was removed using tweezers. Granules and yolk were freeze-dried at −70 °C and 0.1 mbar in a Telstar Cryodos Lyophilizer. They were frozen at −80 °C previous to lyophilisation.

### *Recipes and products development*

Sweet egg-based desserts were prepared based on preliminary tests. Two formulations, one according to traditional recipe (TCY) and the other one as a low-cholesterol product (TCGR) were developed. Starch and carrageenan were chosen as texturing agents since these hydrocolloids properties had been evaluated in desserts based on gelled systems by Nunes et al. (2006). For the sensory test TCGR sample with colourant (β-carotene) was also evaluated. The products were prepared by weighing the ingredients, and then, they were successively added in the order shown in Table 1 under blending for 5 min at 20,000 rpm with a Heidolph SilentCrusher Homogenizer. The dough were put in moulds and cooked at 105 °C during 15 min in a steam sterilizer AES-75 (Raypa).

Table 1
Formula of experimental desserts.

| Ingredient | TCY (g) | TCGR (g) | TCGR with colourant |
|---|---|---|---|
| Distilled water | 17 | 17 | 17 g |
| Sucrose | 30 | 27.5 | 27.5 g |
| Liophilized yolk | 10 | – | – |
| Sunflower oil | – | 2 | 2 g |
| β-carotene | – | – | 6 mg |
| Potato starch | – | 0.5 | 0.5 g |
| Carrageenan | – | 0.3 | 0.3 g |
| Liophilized granules | – | 6 | 6 g |
| **Serving unit total weight** | 57 | 53.3 | 53.3 g |

Total energy value from each formulation was obtained from energy equivalents for available carbohydrate, fat, and protein, 4 kcal/g, 9 kcal/g, and 4 kcal/g, respectively (FAO, 2003; Komatsu et al., 2013).

### *Rheological measurements*

The un-cooked dough was rheologically characterised. The rheological tests were carried out with a Haake MARS II rotational rheometer with a Haake UTC Peltier temperature control unit. All the analysis were developed at 20 ± 0.1 °C (except the temperature ramp) employing a parallel-plate sensor systems (PP60Ti) with a gap of 1 mm. The rheological measurements were performed on the samples the same day of preparation and tests were developed at least in duplicate.

Flow curves were carried out in CS (Controlled Stress) mode from 0.01 to 100 Pa in 100 s. For thixotropy evaluation, shear stress was maintained at this rate during 60 s and then was reduced to 0.01 Pa in 100 s.

Power law (1), Herschel–Bulkley (2) and simplified Carreau (3), viscous flow models commonly used to characterise different hydrocolloid dispersions and food emulsions (Razavi et al., 2011; Bortnowska et al., 2014), were selected to fit the experimental upstream flow curves obtained:

$$\tau = K_p \dot{\gamma}^{n_p} \tag{1}$$

where $\tau$ is the shear stress (Pa), $\dot{\gamma}$ is the shear rate ($s^{-1}$), $K_p$ is the power law consistency coefficient (Pa $s^n$) and $n_P$ is the power law flow behaviour index (dimensionless).

$$\tau = \tau_0 + K\dot{\gamma}^{n} \tag{2}$$

where $\tau$ is the shear stress (Pa), $\tau_0$ is the yield point (Pa), $\dot{\gamma}$ is the shear rate ($s^{-1}$), $K$ is the consistency coefficient (Pa $s^n$) and $n$ is the flow behaviour index (dimensionless).

$$\eta = \frac{\eta_0}{\left[1 + \left(\dot{\gamma}/\dot{\gamma}_c\right)^2\right]^s} \tag{3}$$

where $\eta_0$ is the limiting viscosity for the first Newtonian region (Pa s), $\dot{\gamma}_c$ is the critical shear rate for the onset of the shear thinning behaviour ($s^{-1}$) and $s$ is a parameter related to the slope of this region (dimensionless).

Hysteresis loop area values (obtained from the area between the upstream and downstream data) and flow models parameters were calculated using the Haake Rheowin 4.0 Software.

In dynamic conditions, analyses were carried out in CD (Controlled Deformation) mode at a constant deformation of 0.1%. Temperature sweeps were developed at a frequency of 1 Hz and a glass hood and silicone oil were employed to avoid sample desiccation during the analyses. In order to simulate product cooking, temperature sweeps were carried out from 20 to 90 °C at a heating rate of 3 °C/min, then this temperature was maintained during 300 s and was reduced to 5 °C at a cooling rate of 3 °C/min, this final temperature was maintained during 300 s. The un-cooked dough was analysed by means of frequency sweeps carried out from 0.1 to 10 Hz. Additionally, the sample was load in the rheometer and the temperature was maintained at 90 °C during 10 min, afterwards the temperature was maintained at 5 °C during 5 min, finally this gelled sample was also analysed employing frequency sweeps. Storage (elastic) modulus ($G'$, Pa), loss (viscous) modulus ($G''$, Pa), complex modulus ($G^*=(G'^2+G''^2)^{1/2}$, Pa) and loss tangent angle (tan $\delta$, dimensionless) were obtained as a function of frequency ($v$). The $G'$ and $G''$ moduli were modelled as a power function of the oscillatory frequency (Eqs. (4) and (5)), as commonly used to describe the viscoelastic behaviour of food and dispersions (Augusto et al., 2013):

$$G' = k' v^{n'} \quad (4)$$

$$G'' = k'' v^{n''} \quad (5)$$

where $k'$ (Pa s$^{n'}$), $k''$ (Pa s$^{n''}$) and $n'$ (dimensionless), $n''$ (dimensionless) are consistency coefficients and behaviour indexes, respectively.

Bohlin's parameters were assessed from the following relation (Bortnowska et al., 2014):

$$G^* = A v^{1/z} \quad (6)$$

where $z$ is coordination number (dimensionless) and $A$ the proportional coefficient (Pa s$^{1/z}$). According to Bohlin's theory of flow as a cooperative phenomenon, $z$ is a measure of the number of rheological units correlated with one another in the three-dimensional structure, while the parameter $A$ is related to the strength of the interaction between those units.

### *Texture analysis*

Tests were performed with a TA.XT.plus Texture Analyzer (Stable Micro Systems). A penetration test with a load cell of 5000 g was performed to determine the gel force. A 5-mm penetration was made with a 0.5-in. diameter probe (S/0.5) at a speed of 2 mm/s. The force versus time was recorded: the “peak” or maximum force is taken as a measurement of firmness, while the maximum negative force is taken as an indication of the cohesiveness of the sample. Desserts were prepared and stored at 4 °C overnight. Measurements were developed at least in duplicate.

### *Colour measurement*

The colour of the dough formulations and cooked products were measured in terms of CIELAB parameters $L^*$ (whiteness or brightness), $a^*$ (redness or greenness) and $b^*$ (yellowness or blueness) (Wei et al., 2012). Measurements were carried out using an UltraScan VIS spectrophotometer (HunterLab). It was standardized with a light trap and a white title, and the green title was used to verify the instrument long-term performance. A fixed amount of sample was load into the measurement cell and analyses were conducted in specular exclusion mode. This mode is used to measure colour including the effects of gloss and texture, so the evaluation of colour is closer to human-eye perception. Analyses were carried out at least in duplicate.

The colour changes due to the cooking process are expressed as follows:

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (7)$$

where $\Delta E$ is the total colour change due to the cooking process.

### *Microstructure analysis*

The microstructure of the different dough formulations was examined using optical microscopy (Olympus BX61). A small aliquot of each sample was placed on a microscope slide and covered with a cover slip prior to analysis.

Cooked samples were also analysed employing scanning electron microscopy SEM. Once samples were cooled at 4 °C, they were fixed overnight in 3% glutaraldehyde in 25 mM phosphate buffer (pH 6.8). Then they were rinsed in several changes of buffer. Afterwards, samples were dehydrated in a graded ethanol series and once 100% ethanol was achieved, they were moved in a graded acetone series, so samples were finally in 100% acetone. The samples were critical point dried through $CO_2$ in a Bal-Tec CPD 030 Critical Point Dryer. Dry fractions were fractured and torn with a blade and fragments were mounted on aluminium SEM stubs, and coated with gold in a Sputtering Balzers SCD 004. The microscope used was the JEOL-6610LV SEM.

### *Sensory evaluation*

The dessert samples were prepared in the laboratory by the method described in section “Recipes and products development” the day before the tests. Products were conserved in a refrigerator at 4 °C. The procedures used in the organoleptic assessment were based on UNE Standards and two different trials were carried out.

The panel was made up of eight healthy subjects between 20 and 30 years of age without any sensorial defects. None of them took any medication. The panel was duly instructed about the methodology to use in the organoleptic assessment of the attributes (basic tasting procedures including sampling times, mouth washes, time intervals between samples, and presentation of the data on the scoring sheet) and how to avoid physiological and environmental factors that might condition the results. The tests were conducted in a room next to the laboratory with artificial lighting, during the early afternoon, with a room temperature of 20 °C and 80% humidity and in isolated work stations free from noise. The samples were presented in numbered containers. The final score was obtained by averaging the results for each attribute across all panel members.

For the first trial (*paired comparison test*), two samples (TCY and TCGR) were given to the panel. Each judge was asked to identify which was the firmer, sweeter, more coloured and more cohesive sample.

The second trial was a test to obtain a first approaching to the TCGR dessert acceptability (*preliminary preference test*). In order to evaluate the colour effect on panel behaviour, three samples (TCY, TCGR and TCGR with β-carotene colourant) were given to the panel. In this case, each judge was asked to point appearance, texture and flavour attributes of each sample employing a 9-point scale (9: like extremely and 1: dislike extremely).

### *Statistical analyses*

Experimental data were evaluated by running *t*-tests to compare means at a 95.0% confidence level. Standardized skewness and standardized kurtosis were used to assess if the samples came from normal distributions. Sensorial evaluation data were assessed by running analysis of variance (ANOVA) tests, which determine whether there are any significant differences amongst the means at a 95.0% confidence level. Multiple range test was used to distinguish which means were significantly different from which others. These analyses were performed using STATGRAPHICS PLUS for Windows 3.0© Package (Statistical Graphics,Washington, USA).

## Results and discussion

### *Nutritional profile*

Table 2 shows the composition and nutritional value of the traditional recipe (TCY) and the low-cholesterol product (TCGR). As can be seen, dry matter content was very similar in both products and carbohydrates content was nearly the same, whereas TCY presented higher lipid content and lower protein content than TCGR. It is remarkable the difference in cholesterol content (more than 5 times higher in case of TCY).

Regarding nutritional value, as can be seen in Table 2, TCGR recipe showed a pronounced reduction in total energy compared with the traditional formulation (TCY). Since dessert serving is usually taken as unit in diets development, it is important to remark that most desserts are within a range from 180 to 599 kcal (total mean value of 315.5 kcal) per dessert serving (McCarty et al., 2007). According to that, nutritional values of both recipes serving units were lower than this mean value. In addition, TCY value was within the reported range for dessert serving, whereas TCGR value was below this range.

Table 2
Composition and nutritional value of experimental desserts.

| | TCY | TCGR |
|---|---|---|
| **Dry matter (% w/w)** | 70.2 | 68.1 |
| **Carbohydrates (% w/w)** | 52.6 | 53.1 |
| **Proteins (% w/w)** | 5.5 | 6.5 |
| **Total lipids (% w/w)** | 12.4 | 8.3 |
| **Cholesterol (mg/serving unit)** | 247 | 42 |
| **Cholesterol (mg/100 g sample)** | 433 | 79 |
| **Nutritional value (kcal/serving unit)** | 196 | 167 |
| **Nutritional value (kcal/100 g sample)** | 344 | 313 |

Values were calculated according to data from Laca et al. (2010).

### *Rheological behaviour*

Many semisolid desserts, like custard or yoghurt, exhibit thixotropy (Arcia et al., 2010; Cruz et al., 2013), a time dependent behaviour which means that viscosity decreased with the shearing time. The area of hysteresis loops could be considered as an estimation of the degree of thixotropy, and it was generally admitted that the greater the hysteresis area, the stronger the thixotropic properties would be (Ma et al., 2014). Fig. 1 shows that both samples presented a clockwise hysteresis loop (shear stress values recorded by the downward curves were lower than the upward curves values).

Therefore, the loop area designates the energy required to break down the structure that is not recovered during the experimentation period (Alvarez and Canet, 2013). As it is shown in Table 3, there were significant differences between hysteresis loop values of samples; hence, thixotropic behaviour was less pronounced in TCY in relation to TCGR.

The complex rheological behaviour of thixotropic materials can be understood on the basis of a microstructure that also depends on the shear history (Mewis and Wagner, 2009). The TCY emulsion (very homogeneous, see Fig. 5), showed the lower hysteresis loop value. On the opposite, in TCGR emulsion (much more heterogeneous than TCY sample, see Fig. 5) the existing sugar–hydrocolloids interactions that made the gel network less destroyed by shear strain could be responsible of a more thixotropic behaviour.

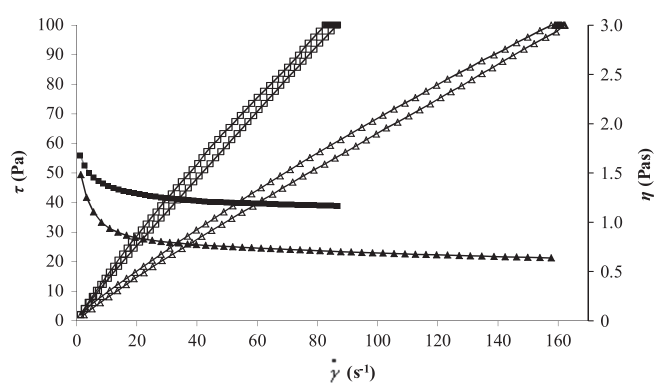


Fig. 1. Steady shear flow (TCY: □; TCGR: Δ) (primary *Y* axis) and viscosity (TCY: ■; TCGR: ▲) (secondary *Y* axis) curves.

Table 3
Power Law, Herschel–Bulkley and Carreau models fitting data for both formulation desserts. Average values ± SD are reported.

| | Hysteresis loop area (Pa s$^{-1}$) | Power law | | | Herschel–Bulkley | | | | Carreau | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $K_p$ (Pa s$^n$) | $n_p$ (-) | $r^2$ | $\tau_0$ (Pa) | $K$ (Pa s$^n$) | $n$ (-) | $r^2$ | $\eta_0$ (Pa s) | $\dot{\gamma}_c$ (s$^{-1}$) | $s$ (-) | $r^2$ |
| **TCY** | $625 \pm 107^a$ | $1.69 \pm 0.30^a$ | $0.90 \pm 0.03^a$ | 1.00 | $0.46 \pm 0.26^a$ | $1.62 \pm 0.33^a$ | $0.93 \pm 0.03^a$ | 1.00 | $2.26 \pm 0.41^a$ | $0.310 \pm 0.486^a$ | $0.048 \pm 0.007^a$ | 0.99 |
| **TCGR** | $901 \pm 33^b$ | $1.33 \pm 0.05^a$ | $0.86 \pm 0.02^b$ | 1.00 | $-0.16 \pm 0.34^b$ | $1.35 \pm 0.00^a$ | $0.85 \pm 0.02^b$ | 1.00 | $3.59 \pm 0.99^b$ | $-0.005 \pm 0.009^a$ | $0.085 \pm 0.029^b$ | 0.99 |

Within columns values followed by the same letter do not differ significantly from each other (95% confidence level).

Concerning viscosity values, it can be observed in Fig. 1 that TCY sample showed higher values than TCGR. In addition, TCGR achieved higher shear rate values applying the same shear stress range (0.01–100 Pa) in the same time (100 s). So TCGR exhibited less resistance to flow.

The steady flow characteristics of the dessert formulations are presented in Fig. 1. The upward flow curves were fitted by Eqs. (1)–(3) and the parameters are shown in Table 3. Significant differences were found between TCY and TCGR flow behaviour indices ($n_p$, $n$); however, their values were almost 1.0, indicating a slightly pseudo-plastic and shear-thinning behaviour of both samples. The behaviour index values were similar to those described by Bortnowska et al. (2014) for dried egg yolk-stabilized emulsions (0.83). There were not significant differences between samples regarding consistence coefficients ($K_p$, $K$). However, TCY consistence coefficient values were slightly higher than TCGR ones, that is in accordance with Zhang et al. (2013) who reported that addition of sugar in tapioca starch dispersions increased consistency coefficient value. Yield stress ($\tau_0$) values were significantly different in TCY and TCGR, although they were very low or even negative, which agrees with the “almost” Newtonian character of the samples. Regarding Carreau model, significant differences in this model parameters' values were observed among samples. Despite these differences, and according with Power law and Herschel–Bulkley parameters values, low $s$ index values reflected again the reduced pseudoplastic character of both formulations.

The gel point occurs at the time at which $G'$ and $G''$ cross each other at a given frequency (Cordobés et al., 2004), so gelation temperature was obtained in this way from temperate sweeps shown in Fig. 2. The values were 89.7 ± 0.5 °C and 43.1 ± 0.1 °C for TCY and TCGR samples, respectively. Hence, the gelation seems to take place more quickly in TCGR than in TCY. This difference is due to composition, potato starch is known to gelatinize between 58 and 65 °C (Oh et al., 2007), whereas Wang et al. (2005) described gelling temperatures of approximately 37 °C for 2% carrageenan aqueous solutions. Furthermore, Laca et al. (2010) reported gel point temperature of around 82 °C for egg yolk granules. This is in accordance with TCGR results, as starch and carrageenan could be responsible of TCGR sample lower gelation temperature. In addition, it is well known that egg yolk coagulation temperature is about 65–70 °C, so in case of TCY sucrose increased the gelation temperature. Once the samples were gelled, $G'$ and $G''$ moduli values increased until their stabilisation at 5 °C. Loss modulus values were very similar in both samples, while elastic modulus values were slightly higher in case of TCY sample. These different moduli values can be explained as yolk and granules show a different gelation process and network characteristics (Anton, 2013).

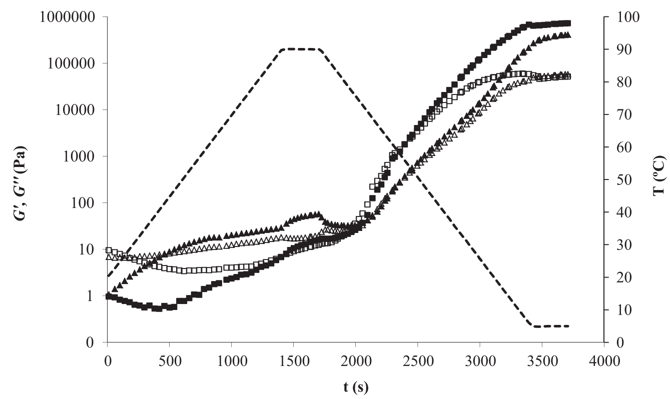


Fig. 2. Temperature sweeps for TCY ($G'$: ■; $G''$: □) and TCGR ($G'$: ▲; $G''$: Δ). Broken line represents temperature ramp.

The mechanical spectra of samples, before and after coagulation, are shown in Fig. 3. In case of samples before gelation, $G''$ values higher than $G'$ ones indicated a more fluid-like behaviour. Additionally, in both samples, $G'$ and $G''$ values increased with frequency reflecting that in non-gelled samples these moduli are strong function of frequency (Steffe, 1996). Tárrega and Costell (2006) observed that addition of carrageenan in dairy desserts produced an important increase in the viscoelastic functions $G'$ and $G''$. This is in accordance with results before gelation found in this work, since TCGR sample (that includes among its ingredients carrageenan) moduli values were notably higher than TCY ones. After gelation process, TCY moduli values increased in approximately hundred times, whereas TCGR $G'$ and $G''$ values increased only in around 10 times, this reflects a harder gel in case of TCY sample. Gelled samples showed little variation with frequency and for TCGR sample $G'$ values were higher than $G''$ ones, reflecting the behaviour of a typical gelled material. This was also observed in case of TCY for low frequency values (below 7 Hz), but at higher frequencies viscoelastic moduli showed a nonlinear behaviour.

For comparison purposes, tan $\delta$ values of both samples before and after gelation are presented in Fig. 4. At low frequencies (below 1 Hz) tan $\delta$ remained quite constant and, moreover, values of non-gelled samples were very similar; likewise values of gelled samples were also alike. Thus, at low

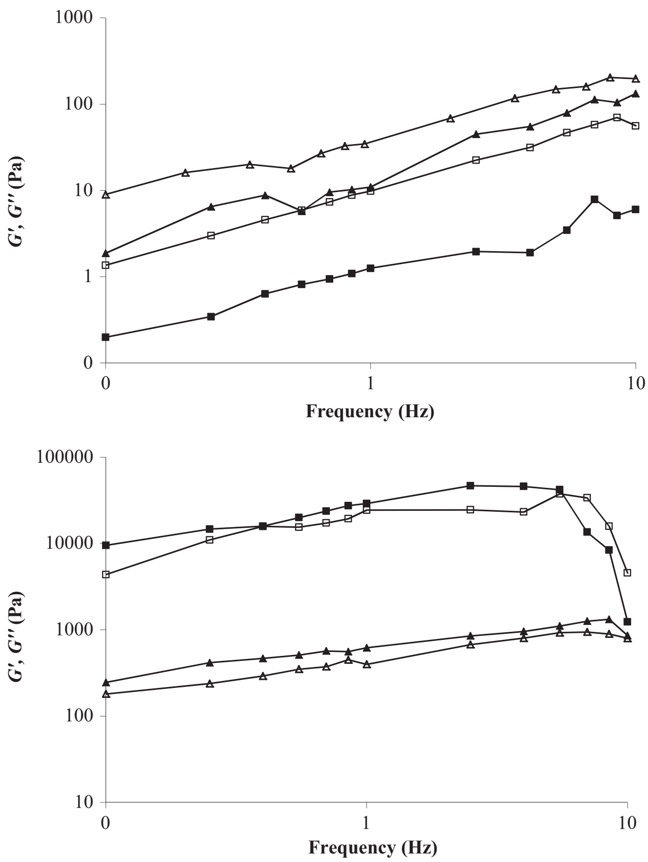


Fig. 3. Mechanical spectra for TCY ($G'$: ■; $G''$: □) and TCGR ($G'$: ▲; $G''$: Δ), before (up) and after (down) gelation.

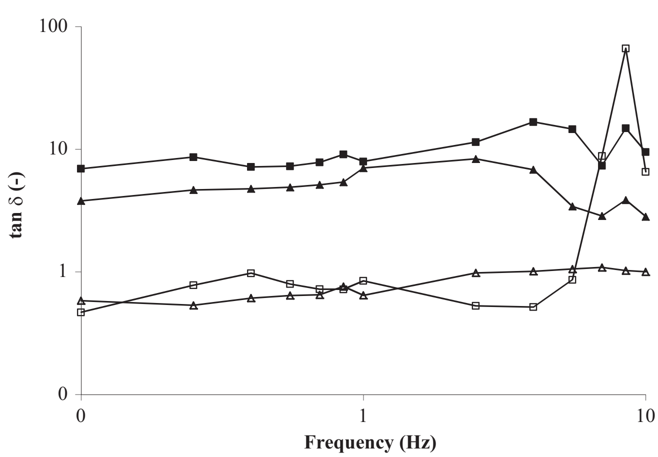


Fig. 4. Frequency sweeps loss tangents of both formulations before (TCY: ■; TCGR: ▲) and after (TCY: □; TCGR: Δ) coagulation process.

frequency values, relative elastic and viscous contributions is almost the same for both formulations. At higher frequencies, tan $\delta$ of non-gelled samples decreased with increasing frequency. On the opposite, in case of TCGR gelled sample tan $\delta$ values slightly increased with increasing frequency, whereas at high frequencies tan $\delta$ of TCY gelled sample behaviour was more irregular. It is important to remark that, in general, tan $\delta$ values of both formulations decreased with gelation process, which indicates a more elastic character of gelled samples. The relative elastic and viscous contributions to the samples viscoelasticity is different in gelled and non-gelled samples; in non-gelled samples $G''$ prevailed, on the opposite, in gelled samples $G'$ predominated.

It was possible to model the storage and loss moduli as a power function of the oscillatory frequency (Eqs. (4)–(6)) (Table 4) from 0.1 to 5.5 Hz (at higher frequencies the gelled TCY sample showed a nonlinear behaviour). In general, all samples showed low values of $n'$ and $n''$ of a similar magnitude indicating a weak gel structure. Excepting for non-gelled TCGR, the values for $n''$ were slightly higher than those for $n'$, which demonstrates that the viscous behaviour of these samples became more important at high frequencies. On the contrary in non-gelled TCGR, $n'$ and $n''$ values were very alike, so in this case viscous and elastic behaviour have similar importance in the frequency range studied. Additionally, gelled samples values were of the same order of magnitude as the range (0.15–0.40 for $n'$ and 0.36–0.41 for $n''$) reported by Bortnowska et al. (2014) for dried egg yolk-stabilized emulsions with 3–4% of pregelatinized waxy maize starch.

The weak gel structure was also corroborated by Bohlin's parameters. Values of coordination number ($z$) indicated little number of rheological units correlated with one another in the three-dimensional structure, while the proportional coefficient ($A$) values reflected low strength of the interaction between those units. It is important to take into account that, cooking process increased considerably the number (in approximately 2500 and 35 times for TCY and TCGR, respectively) and strength (in more than twice in both samples) of these interactions. However, these gels were still weaker than those described by Gabriele et al. (2001) for different food systems (yogurt, dough and jam). Low values of $z$ and $A$ also mean the tendency of dispersed droplets to coalesce when the system undergoes mechanical stress (Laca et al., 2012), hence gelled sample was more stable than non-cooked one. Finally, it is important to point out that there were not significant differences in case of parameter $z$ between TCY and TCGR non-gelled and gelled samples. On the contrary, parameter $A$ is significantly different in case of TCY and TCGR gelled samples. Thus, the number of rheological units was similar in both samples, whereas the three-dimensional network linkages are stronger in case of egg yolk proteins regarding granules proteins. According to Anton (2013), LDLs proteins have a determinant role in egg yolk gelation process; since granules are mainly constituted by HDLs proteins, differences in protein interactions are responsible of TCY and TCGR networks characteristics.

### *Textural properties*

As it is shown in Table 5, there were no significant differences between samples regarding cohesiveness, whereas TCY exhibited significantly lower gel firmness compared to TCGR. This result contradicts rheological data. Since $G'$ is the energy stored per deformation cycle during an oscillatory test, it is related to the stiffness/consistency of the network. And consistency relates to the firmness of a liquid or semi-solid

Table 4
Oscillatory frequency Power-law and Bohlin's parameters. Average values ± SD are reported.

| | Bohlin's parameters | | | Power-law | | | |
|---|---|---|---|---|---|---|---|
| | **$A$ (kPa)** | **$z$** | **$r^2$** | **$n'$** | **$r^2$** | **$n''$** | **$r^2$** |
| **TCY** | $0.010 \pm 0.001^a$ | $1.15 \pm 0.02^a$ | 0.99 | $0.66 \pm 0.06^a$ | 0.92 | $0.87 \pm 0.02^a$ | 0.99 |
| **Gelled TCY** | $25.02 \pm 0.73^b$ | $2.38 \pm 0.25^b$ | 0.94 | $0.42 \pm 0.08^b$ | 0.92 | $0.49 \pm 0.05^b$ | 0.92 |
| **TCGR** | $0.008 \pm 0.003^a$ | $1.17 \pm 0.16^a$ | 0.97 | $0.86 \pm 0.07^c$ | 0.93 | $0.84 \pm 0.15^a$ | 0.97 |
| **Gelled TCGR** | $0.289 \pm 0.036^c$ | $2.78 \pm 0.54^b$ | 0.97 | $0.30 \pm 0.08^b$ | 0.97 | $0.48 \pm 0.12^b$ | 0.98 |

Within columns values followed by the same letter do not differ significantly from each other (95% confidence level).

Table 5
Mechanical parameters obtained from texture analysis. Average values ± SD are reported.

| | **Firmness (g)** | **Cohesiveness (g)** |
|---|---|---|
| **TCY** | $79.9 \pm 0.9^a$ | $-10.9 \pm 7.1^a$ |
| **TCGR** | $134.0 \pm 21.8^b$ | $-19.3 \pm 6.6^a$ |

Within columns values followed by the same letter do not differ significantly from each other (95% confidence level).

fluid. According to this, once gelled, TCGR should have shown the highest $G'$ value as it showed the highest value in firmness, and it did not (Figs. 2 and 3). Additionally, it is important to remark than sensory evaluation results were in accordance with rheological data.

For a firmness reading, the panellist compresses the sample between the tongue and the hard palate. Carrageenan gels hardness decrease rapidly as a consequence of melting of the gel structure by elevated mouth cavity temperatures, whereas starch-containing foods undergo enzymatic break-down that will reduce its firmness (Pascua et al., 2013). Hence, as TCGR recipe contains carrageenan and also starch, the information provided by texture analyzer may not relate to what was perceived by a person actually chewing the product (Chen and Opara, 2013).

## *Colour*

The lightness/darkness ($L^*$), redness/greenness ($a^*$) and yellowness/blueness ($b^*$) values for TCY and TCGR, both before and after cooking process, are shown in Table 6. There were not significant differences between non-gelled samples in the $L^*$ values, while $a^*$ and $b^*$ values were significantly different. Concerning cooked samples, all parameters were significantly different in both samples. Thus, not only non-gelled TCY, but also cooked one, were clearly redder and yellower than TCGR sample. The colour of egg yolk is attributed to fat-soluble carotenoids (xanthophylls; including lutein, zeaxanthin, β-cryptoxanthin and minor amounts of β-carotene) (Li-Chan and Kim, 2008), but only some of these pigments appear in small amounts in egg granules (Laca et al., 2012), hence this is the main reason of colour differences between samples TCY and TCGR.

Table 6
Values of $L^*$, $a^*$ and $b^*$ colour parameters for TCY and TCGR before and after cooking process. Average values ± SD are reported. The colour changes are expressed as Δ.

| | **$L^*$** | **$a^*$** | **$b^*$** |
|---|---|---|---|
| **TCY** | $70.04 \pm 0.69^a$ | $13.41 \pm 0.15^a$ | $44.11 \pm 1.11^a$ |
| **Gelled TCY** | $53.36 \pm 1.29^b$ | $14.19 \pm 1.24^a$ | $49.51 \pm 4.02^b$ |
| **Δ** | −16.69 | 0.78 | 5.41 |
| **Δ*E*** | | 17.56 | |
| **TCGR** | $69.62 \pm 0.13^a$ | $8.50 \pm 0.18^b$ | $37.41 \pm 1.19^c$ |
| **Gelled TCGR** | $58.80 \pm 1.04^c$ | $5.74 \pm 1.09^c$ | $35.28 \pm 2.69^c$ |
| **Δ** | −10.82 | −2.76 | −2.14 |
| **Δ*E*** | | 11.36 | |

Within columns values followed by the same letter do not differ significantly from each other (95% confidence level).

With regard to the differences before and after cooking process, significant differences were detected for $L^*$ and $b^*$ values in case of TCY sample and for parameters $L^*$ and $a^*$ in TCGR sample. It is noticeable that in both samples gelation reduced lightness; however, in case of TCY increased yellowness and in case of TCGR decreased redness. The possible influence of non-enzymatic reaction (maillard reaction) between the proteins and the carbohydrates, as well as the egg yolk pigments, has been described in other cooked products (Marcet et al., in press). Hence, although TCY sample presents less carbohydrate content, it presents highest sucrose content (+2.5 g) which could have been hydrolysed by heat acting as a reducing sugar and helping in colour (yellowness) generation. It is well known that the thermal processing can result in some undesirable detrimental effects such as decolouration (Huang et al., 2013), the total colour change ($\Delta E$) indicates the magnitude of colour difference between processed and unprocessed desserts. Although this parameter was higher in TCY than in TCGR, in both cases differences in perceivable colour can be classified analytically as “great” according to Barba et al. (2012).

## *Microstructure*

As it is shown in Fig. 5, TCY emulsion appearance was much more uniform than TCGR emulsion. For instance, in TCGR sample carrageenan structures, starch granules and oil droplets can be easily appreciated (see arrows). The unheated

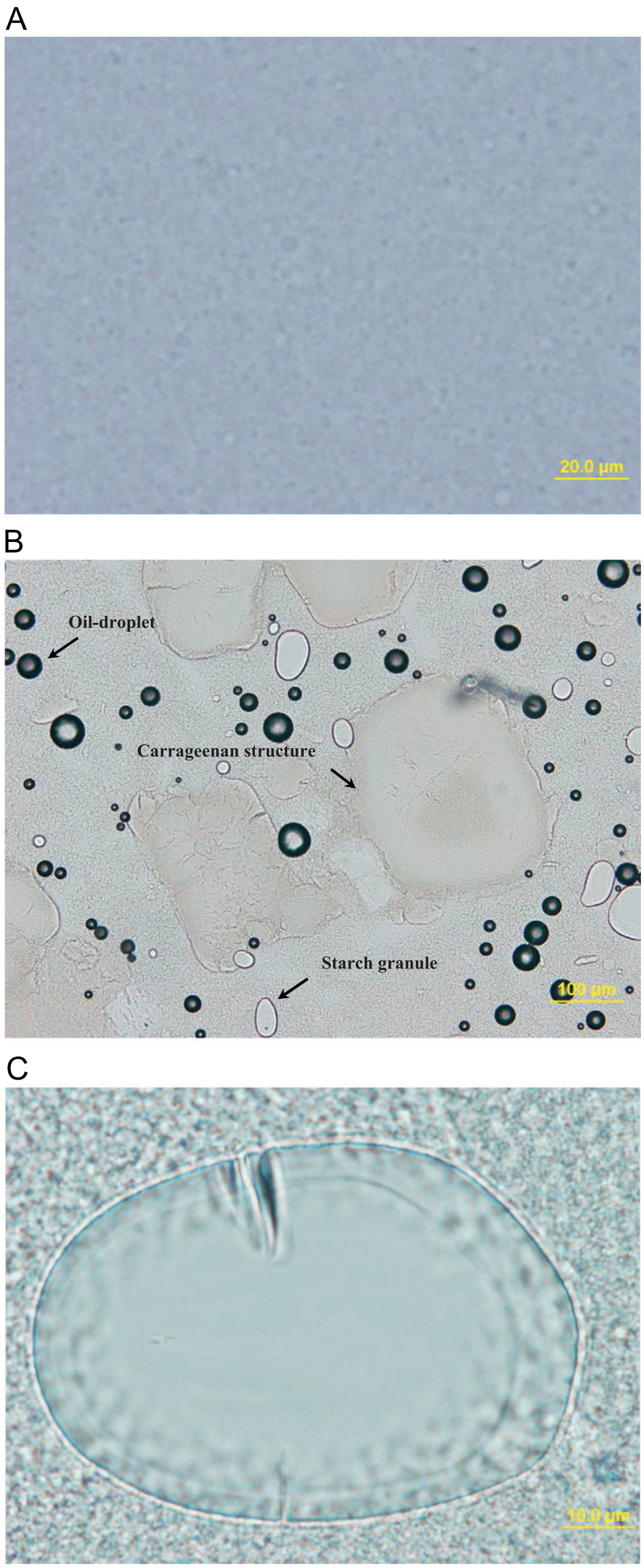

Fig. 5. Micrographs of non-gelled TCY (A: 40 × magnification) and TCGR (B: 10 × magnification and C: 100 × magnification).

potato starch appeared as a mixed group of irregularly shaped granules ranging in size between 10 and 100 μm. In SEM micrographs (Fig. 6) these morphological differences can also be observed in cooked samples. TCY appeared again as a homogeneous protein matrix, whereas TCGR showed a dense three-dimensional network where carrageenan was uniformly distributed (Núñez-Santiago et al., 2011; Espinosa-Dzib et al., 2012). In addition, interspersed potato starch granules similar to those reported by Kaur et al. (2007) appeared in this network.

### Sensory evaluation

A wide variety of food products can be considered to consist either entirely or partially as emulsions, or (as it happens in this work) have been in an emulsified state sometime during their production. The emulsified components of these foods play important roles in determining their distinct functional attributes, such as appearance, texture and flavour (Chung and McClements, 2014).

In Table 7, sensorial evaluation results are shown. According to the paired preference test results, TCY dessert was marked as the more coloured sample by 100% of panellists. Rheological test identified TCY as the firmest product, as it was also verified by the majority of the panel (75%). Despite the total percentage of carbohydrates was very similar in both recipes, most panellists (87.5%) were able to identify TCGR (with 0.5% more carbohydrates than TCY) as the sweetest sample. Concerning cohesiveness, although textural analyses did not find significant differences between samples, values were slightly higher in case of TCGR, as it was also recognised by 75% of panel members.

In regard to preliminary preference test, three attributes were evaluated: appearance, texture and flavour. In appearance evaluation, colour seems to be determinant to the panel since most coloured sample (TCY) obtained the highest punctuation. Furthermore, the only difference between TCGR and TCGR with β-carotene samples was the use of this colourant and, although there were not significant differences between these samples, TCGR with β-carotene was higher scored. Finally, it is important to notice that there were not significant differences between samples in texture and flavour evaluation.

### Case studies

Once the new recipe was compared with the traditional product, not only by means of instrumental measurements, but also by sensory evaluation, the new sweet egg-based formulation was assessed from a culinary point of view. In Fig. 7 the TCY and TCGR “bare” products are shown. In the case study reported in this paper, an experienced chef employed the new formula to create his own dish (Fig. 8).

In the chef opinion, the new product can be prepared in the same way as the traditional recipe (mixing the ingredients and cooking in a bane-marie), as well the low-cholesterol dessert is as easy to handle as the typical product. Since the TCGR appearance was the attribute with the lower score in the sensory evaluation, the chef employed colourant (β-carotene) to enhance the new formulation colour. On the side, and according with the chef gastronomic perspective, different food elements (such as those shown in the dish photograph)

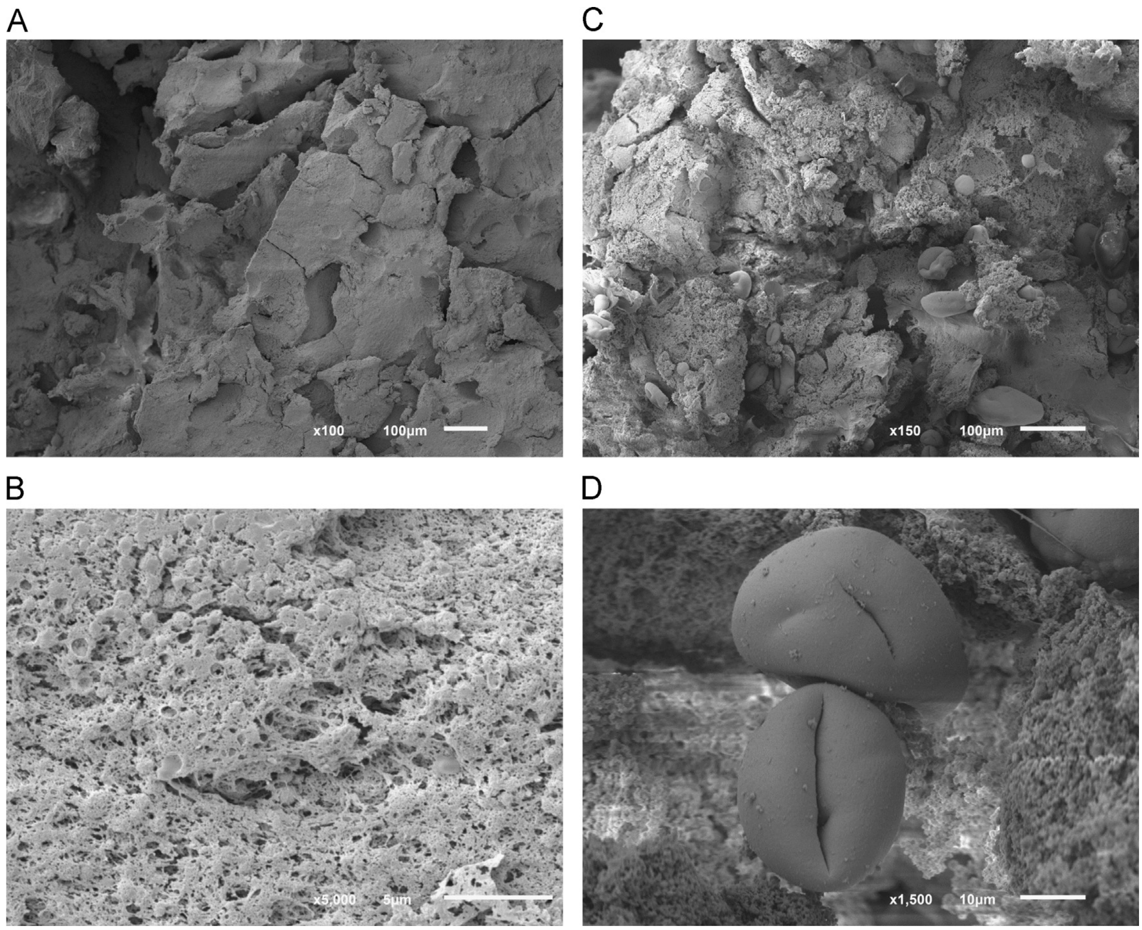


Fig. 6. Scanning electron micrographs (SEM) of gelled TCY (A and B) and gelled TCGR (C and D).

Table 7
Sensorial evaluation results. Average values ± SD are reported.

| | *Paired comparison test* | | | **More cohesive** | *Preliminary preference test* | | |
|---|---|---|---|---|---|---|---|
| | **Firmer** | **Sweeter** | **More coloured** | | **Appearance** | **Texture** | **Flavour** |
| **TCY** | 6 | 1 | 8 | 2 | $7.25 \pm 1.16^{a}$ | $6.75 \pm 1.04^{a}$ | $5.88 \pm 1.81^{a}$ |
| **TCGR** | 2 | 7 | 0 | 6 | $4.75 \pm 1.28^{b}$ | $6.00 \pm 1.41^{a}$ | $7.25 \pm 1.28^{a}$ |
| **TCGR with β-carotene** | – | – | – | – | $5.88 \pm 1.13^{b}$ | $5.63 \pm 1.51^{a}$ | $7.25 \pm 1.16^{a}$ |

Within columns values followed by the same letter do not differ significantly from each other (95% confidence level).

and also a black background can be employed to highlight the new recipe appearance.

## Conclusions

The purpose of this work was to develop a low-cholesterol product (TCGR) achieving sensorial properties similar to those of a typical Spanish dessert made with egg yolks and syrup (TCY). Regarding nutritional value, TCGR showed 83% less cholesterol content than typical formulation, additionally, this product achieved a reduction in total energy content of approximately 15% compared with traditional recipe (TCY).

Rheological tests showed thixotropic and reduced pseudoplastic behaviour of both formulations and also reflected different gel properties of both samples, such as different gelation point. In addition, these measurements indicated lower firmness of TCGR in relation to TCY; this was confirmed by sensory evaluation, whereas micrographs revealed clearly more uniform microstructure in case of TCGR than in TCY sample.

The panellists detected significant differences between samples regarding colour, as it was also showed by colour measurements. Finally, it should be taken into account that sensorial evaluation demonstrated that there were not significant differences between samples in texture and flavour evaluation.

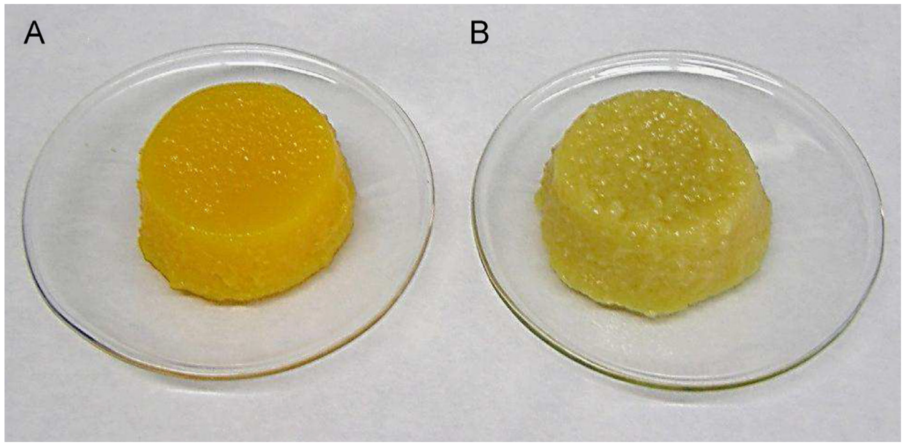


Fig. 7. “Bare” products (A: TCY and B: TCGR).

Fig. 8. New expression of TCGR dessert.

To sum up, egg yolk granules in combination with texturing agents have proved to be exceptionally promising for the development of healthier egg yolk based desserts, keeping similar characteristics to those of traditional products. This work represents only a first investigation about the potential use of egg yolk granules as ingredient in patisserie; nevertheless, the concept opens a new line for new low-cholesterol dessert creations.

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