Optimization of low-cholesterol—low-fat mayonnaise formulation: Effect of using soy milk and some stabilizer by a mixture design approach

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Abstract
In the present study, the optimized mixture proportions of low cholesterol-low fat mayonnaise contained soy milk as an egg yolk substitute (10%) with different composition of xanthan gum (XG), guar gum (GG) and mono- & diglycerides emulsifier (MDG) (0–0.36% of each component) were determined by applying the simplex-centroid mixture design method to achieve the desired stability, textural and rheological properties and sensory characteristics for effective formulation process. Results revealed that the best mixture was the formulation contained 6.7% mono- & diglycerides, 36.7% guar gum and 56.7% xanthan gum. The xanthan gum was the component showing the highest effect on all the properties of mayonnaise samples. In addition, an increase of xanthan gum followed by guar gum caused greater values for the stability, heat stability, consistency coefficient, viscosity, firmness, adhesiveness, adhesive force and overall acceptance and lower value for flow behavior index. Depending on the desirable level of xanthan gum, guar gum and mono- & diglycerides, creation of low cholesterol-low fat mayonnaise with properties closely matching those of commercial ones is possible.

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1. Introduction

Mayonnaise is a kind of semi-solid oil-in-water emulsion containing 70–80% fat. It is traditionally prepared by carefully mixing egg yolk, vinegar, oil, and spices (especially mustard). Largely influenced by health related concerns, there has been pressure on the food industry to reduce the amount of fat, sugar, cholesterol, salt and certain additives in the diet (Liu, Xu, & Guo, 2007). Among mayonnaise ingredients, egg yolk is most critical for the stability of the product (Hasenhuettl, 2008). Nevertheless, one main problem with egg yolk is its high cholesterol content, so different attempts have been carried out to develop low cholesterol sauces with similar characteristic to real mayonnaise (Laca, Sáenz, Paredes, & Díaz, 2010).

Using of another emulsifier in addition to egg yolk, or completely replace this important ingredient provides several advantages, like a decrease in cholesterol content and, generally, in fat content, an increase in microbiological stability and, in some cases, lower costs of manufacture (Riscardo, Franco, & Gallegos, 2003). For that reason, the emulsification properties of animal proteins such as whey protein, casein and meat protein have been extensively investigated by a number of researchers (Raymundoa, Francob, Empisc, & Sousad, 2002; Riscardo et al., 2003). Moreover, vegetable protein isolates can be used effectively as food emulsion stabilizers because of their capacity to lower the interfacial tension between hydrophobic and hydrophilic components. Several vegetable proteins from soy, sunflower, pea, tomato seed, wheat, white lupin and faba bean have been successfully tested to stabilize oil-in-water (o/w) emulsions (Abu Ghoush, Samhouri, Al-Holy, & Herald, 2008; Raymundoa et al., 2002; Riscardo et al., 2003).

From another point of view, one of the consumer demands is reducing fat level in mayonnaise and salad dressing. Fats play many functional roles in food emulsion. They contribute to the flavor, appearance, texture and shelf life of food emulsion in high specific ways (Worrasinchai, Suphantharika, Pinjai, & Jamnong, 2006). Therefore, it is difficult to imitate traditional product quality when preparing low fat foods (Mun et al., 2009). There is the possibility of choosing particular fat substitutes in specific quantities in order to make a product with a texture close to that of traditional mayonnaise (Liu et al., 2007). Some fat mimetics such as modified starch, inulin, pectin and microcrystalline cellulose, carrageenan, some thickeners (Liu et al., 2007; Mun et al., 2009) and proteins (Raymundoa et al., 2002) were generally used to stabilize the emulsion and increase the viscosity of light mayonnaise.
Soybean is composed of 40% protein, 15% mono- & oligosaccharides, 15% dietary fiber, 20% oil and 10% others. Soy is a high quality and healthy source of proteins. It can help lower cholesterol levels and prevent the development of cancerous cells (Tsang, 2011). In addition to these benefits, soy protein was used as an effective emulsifier and also as low-cost replacer filler (Garcia, Srirattanata, No, Corredor, & Prinyawiwatkul, 2009; Puppo et al., 2008). Soy protein may be used as an ingredient in low cholesterol salad products with properties similar to salad dressings or mayonnaise (Puppo, Sorgentini, & Añón, 2003).

To achieve mayonnaise with appropriate emulsion properties and high stability, several investigations have been conducted mostly by using proteins with various emulsifiers and gums such as xanthan and guar gums (Bortnowska & Tokarczyk, 2009; Lorenzo, Zaritzky, & Califano, 2008). The gum–protein interaction may play an important role in the mayonnaise compared to the single contribution of the individual polymer (Abu Ghoush et al., 2008).

In most studies on low-fat or low-cholesterol mayonnaise, several vegetable proteins with some thickeners such as gums were applied. However, there has been slight concentration on soy products especially soy flour and soy milk as a fat replacer or even as a good emulsifier. For example, Marquez, Palazolo, and Wagner (2005) proposed a formulation of cream-like emulsion which is prepared with soy milk and xanthan gum. In another work, Garcia, Sanchez, Jose, Villavicencio, and Nunez (2002) studied influence of powdered soy milk concentration as an emulsifier to obtain dressing-type mayonnaise.

In fact, there is no published data in the literature on application of soy milk with gums and emulsifiers to completely replace egg yolk and reduce cholesterol and fat in mayonnaise. Therefore, considering the importance of producing functional product with low cholesterol and fat and also lowering production expenses, we tried to take advantage of the gum–soy milk interaction with mono- & diglycerides to formulate a mayonnaise with similar characteristics to full fat mayonnaise prepared with egg yolk. In more detail, in the proposed approach, the soy milk is a protein source which can be used instead of the egg yolk. Furthermore, in addition to the soy milk that has emulsifying properties, mono- & diglycerides used as aid emulsifier. We also obtained the best formulation of the mayonnaise using Mixture Design approach which can be used by the food processors to produce high quality products.

2. Materials and methods

2.1. Raw materials characterization

Full fat soy flour contained about 40% protein, 22% fat, 4% fiber and 5.50% ash, was a gift from Toos Soya Inc. Xanthan gum and guar gum were purchased from Sigma Aldrich company and mono- & diglycerides (with the commercial name of Multec Mono 9402 sfp) obtained from Golnan Puratos Inc. Other ingredients as composition of the model mayonnaise such as sunflower oil, vinegar, Sugar, salt and mustard powder were all purchased from a local supermarket.

2.2. Soy milk preparation

To prepare soy milk, full fat soy flour was added to hot water at 80 °C (1:3 ratios) and then it was blended by a mixer (Moulinex, DFC3, France) for about 10 min. After completely mixing materials and obtaining a homogeneous composition with appropriate consistency, the final mixture (which called soy milk) was refrigerated, because emulsion stability of the mayonnaise would decrease by using hot soy milk (DePaolis, 1979).

2.3. Emulsion preparation

800 g of each mayonnaise sample was prepared in this study. The recipe contained the following ingredients in percentage (w/w): soy milk 10, sunflower oil 60, vinegar 7.5 (5% (w/v) acetic acid), salt 0.7, mustard powder 0.4, sugar 4, stabilizers and emulsifier totally 0–0.36 and water 17.04. The mayonnaise samples were prepared by fully replacing the egg yolk with the soy milk prepared before.

The mayonnaise samples were prepared using a standard mixer (Moulinex, DFC3, France). The mayonnaise is made in a three-step procedure. In the first step, briefly, the soy milk and water were mixed together, followed by the addition of the sugar, salt, mustard, and stabilizers (xanthan and guar gums) with mono- & diglycerides emulsifier (Table 1). Then a small fraction of the total oil was utilized. The ingredients were admixed for about 5–10 min while in conventional methods, 1 min is more usual. In the second step, the vinegar is gradually blended in. In the third step, the remaining major amount of oil is slowly added and admixed in a blender.

Through the above formulation, a mayonnaise product with stable emulsion and little (if any) syneresis is produced. The mayonnaise samples were transferred to 1 L glass bottles with caps and stored in refrigerator until analysis.

2.4. Stability test

15 g (F0) of each sample transferred to test tubes (internal diameter 15 mm, height 125 mm) which were tightly sealed with plastic caps and then centrifuged for 30 min at 5000 rpm (Hettich, Roto silent/K, Germany). The weight of the precipitated fraction (F1) was measured, and the emulsion stability was characterized as (%): \(\frac{F_1}{F_0} \times 100\) (Mun et al., 2009).

Furthermore, to measure the heat stability of mayonnaise samples, they stored at 80 °C for 30 min. After that, emulsions were placed in centrifuge tubes and processed for 30 min at 5000 rpm. Then, the heat stability was characterized using the above equation.

2.5. Texture profile analysis

Mayonnaise texture measurements were carried out by the Texture Analyzer (QTS-25, England) with a 5 kg load cell. Back extrusion cell with 42 mm width compression square plate was used. The stainless steel cubic container (45 mm internal width and 55 mm depth) was carefully full by the samples. One cycle was applied, at a constant crosshead velocity of 60 mm/min, to a sample depth of 40 mm, and then returned. From the resulting force–time curve, the values of texture attributes including firmness, adhesive

Table 1

<table>
<thead>
<tr>
<th>Formulation</th>
<th>Ingredient proportion*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X1 (MDG)</td>
</tr>
<tr>
<td>1</td>
<td>1.000</td>
</tr>
<tr>
<td>2</td>
<td>0.000</td>
</tr>
<tr>
<td>3</td>
<td>0.000</td>
</tr>
<tr>
<td>4</td>
<td>0.500</td>
</tr>
<tr>
<td>5</td>
<td>0.500</td>
</tr>
<tr>
<td>6</td>
<td>0.000</td>
</tr>
<tr>
<td>7</td>
<td>0.333</td>
</tr>
<tr>
<td>8</td>
<td>0.667</td>
</tr>
<tr>
<td>9</td>
<td>0.167</td>
</tr>
<tr>
<td>10</td>
<td>0.167</td>
</tr>
</tbody>
</table>

* MDG – mono- & diglycerides emulsifier, GG – guar gum, XG – xanthan gum.
force, and adhesiveness were obtained. Firmness is the maximum force as the test cell penetrated into the sample. Adhesiveness was the negative force area representing the work necessary to pull the compressing plunger away from the sample (Worrasinchai et al., 2006). The maximum negative force is taken as an indication of the adhesive force (Liu et al., 2007).

2.6. Rheological behavior

Rheological properties of mayonnaise samples were determined using a Couette Bohlin rheometer (Malvern, Visco) equipped with a temperature-control unit (Julabo Labotechnik, F12, Germany). The rheometer had a bob-cup configuration with a cup C14 and rotational bob. Measurements were carried out in the shear rate range of 14–100 s⁻¹ at constant temperature (25°C ± 0.2). 4 g of each sample was placed between bob and cup and the measurement was started immediately. The apparent viscosity was determined as a function of shear rate. Obtained data were fitted to Power law model using slidewrite software (version 2.1.0.23) and consistency coefficient and flow behavior index values were calculated according to the following model.

\[ \eta_a = K \gamma^n \]

where \( \eta_a \) is the apparent viscosity (Pa s), \( K \) is the consistency coefficient (Pa s^n), \( \gamma \) is the shear rate (s⁻¹) and \( n \) is flow behavior index (dimensionless).

2.7. Microscopic examination

The glassy flat was coated with mayonnaise sample and placed on the stage of microscope (Microscope Olympus DP12, B41TE, Japan). Then, the focus knob was adjusted to get a clearly view field. Pictures of the mayonnaise microstructure were obtained at the magnification of 40× by a digital camera connected with the microscope (Liu et al., 2007).

2.8. Sensory evaluation

Sensory evaluation was conducted on the mayonnaise samples after one-day storage at room temperature. Sensory characteristics including appearance, color, odor, texture, taste, and overall acceptance were evaluated by 10 panelists of male and female graduate students of food science and technology department at Ferdowsi University of Mashhad (22–25 years old), on 5-point hedonic scale, 1 = the least/lowest; 5 = the most/highest. Before the sensory analyses, panelists were trained about the sensory attributes. Water was provided between samples to cleanse the palate.

2.9. Experimental design

The Design-Expert (8.0.5) software was used to determine the optimum proportions of the mayonnaise formulation. A three component, simplex-centroid mixture design was chosen for the experiments because all the components had the same range, between 0 and 1 (0–0.36%), and there were no constrains on the design space (Abdullah & Chin, 2010). The mixture components consisted of xanthan gum (X1 or A), guar gum (X2 or B) and mono- & diglycerides emulsifier (X3 or C). Component proportions were expressed as fractions of the mixture with a sum (X1 + X2 + X3) of one. These three components (i.e. xanthan gum, guar gum, and mono- & diglycerides emulsifier) levels and experimental design in terms of pseudo-components as 10 combinations are presented in Table 1. These ten points consists of three single-ingredient treatments, three two-ingredient mixtures and four three-ingredient mixtures (Fig. 1).

2.10. Statistical and data analysis

The linear, quadratic, and cubic models (Eqs. (1)–(3)) were used to represent the fitted response values. The statistical significance of each equation was determined by variance analysis (ANOVA) at 5%.

\[ Y = b_1 X_1 + b_2 X_2 + b_3 X_3 \]

(1)

\[ Y = b_1 X_1 + b_2 X_2 + b_3 X_3 + b_1 b_2 X_1 X_2 + b_1 b_3 X_1 X_3 + b_2 b_3 X_2 X_3 \]

(2)

\[ Y = b_1 X_1 + b_2 X_2 + b_3 X_3 + b_1 b_2 X_1 X_2 + b_1 b_3 X_1 X_3 + b_2 b_3 X_2 X_3 + b_1 b_2 b_3 X_1 X_2 X_3 \]

(3)

where \( Y \) is the predictive dependent variable (stability, heat stability, K; n, viscosity, firmness, adhesive force, adhesiveness, and overall acceptance), \( b \) the equation coefficients (determined according to Cornell, 2002); and \( X \) the proportions of pseudo-components.

3. Results and discussion

3.1. Fitting for the best model

Table 2 presents the results of mixture design studies. Both the independent and dependent variables were fitted to linear, quadratic, special cubic, full cubic, and special quadratic models and residuals plots were generated to check the goodness of model fit. The best model has low standard deviation, low predicted sum of squares, and high predicted R-squared (Cornell, 2002). Following these guides, the linear model was found the best fitted for rheological properties (K, n and \( \eta_a \)), adhesive force and adhesiveness. In addition, the quadratic model was adequately fitted to the responses of heat stability and firmness while the special cubic model was found the best fitted for stability and overall acceptance responses (Table 3).

3.2. Stability test

Emulsion stability usually involves preventing droplet coalescence, flocculation, and creaming. Creaming is not usually problem in mayonnaise samples that have high fat contents (~ 80%) because the droplets are so closely packed together so that they cannot

Fig. 1. An overview of the simplex-shaped mixture region for a three-component mixture.
move. However, in products with low-fat content, creaming is usually prevented by adding a thickening agent such as gum or a protein to the aqueous phase to slow down the droplet movement (Mun et al., 2009). Our low-fat mayonnaise samples showed a high stability, because of the increased viscosity of the aqueous phase, mainly due to adding the xanthan and guar gums to the soy milk that consequently slowed down oil droplets movement. Table 2 represents the results related to stability and heat stability. Among these results, the highest stability values (higher than 97%) were obtained for formulations 3, 10 and 6 with 1.000, 0.667 and 0.5 of xanthan gum, respectively. Besides, the lowest stability value (65.67%) was obtained for the sample contained 1.000 MDG and 0.5 of xanthan gum, respectively. This result is mainly due to adding the xanthan and guar gums to the soy milk and might be used in manufacturing low-fat mayonnaise as a stabilizing agent. The most effective component interaction (MDG interaction (MDG

Table 2
Experimental results for stability, heat stability, K, n, viscosity, firmness, adhesive force, adhesiveness and overall acceptance for each formulation.

<table>
<thead>
<tr>
<th>Std</th>
<th>1 Stability (%)</th>
<th>2 Heat stability (%)</th>
<th>3 K (Pa s(^n))</th>
<th>4 n</th>
<th>5 Viscosity (Pa s) (at shear rate 50 s(^{-1}))</th>
<th>6 Overall acceptance (%)</th>
<th>7 Firmness (g)</th>
<th>8 Adhesive force (g)</th>
<th>9 Adhesiveness (gs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>65.67</td>
<td>45.56</td>
<td>10.54</td>
<td>0.42</td>
<td>1.03</td>
<td>2.50</td>
<td>219.00</td>
<td>338.00</td>
<td>513.11</td>
</tr>
<tr>
<td>2</td>
<td>93.02</td>
<td>85.11</td>
<td>56.37</td>
<td>0.31</td>
<td>3.17</td>
<td>3.33</td>
<td>423.00</td>
<td>801.00</td>
<td>1203.79</td>
</tr>
<tr>
<td>3</td>
<td>97.78</td>
<td>95.89</td>
<td>72.22</td>
<td>0.24</td>
<td>3.87</td>
<td>3.67</td>
<td>670.00</td>
<td>1037.00</td>
<td>1548.22</td>
</tr>
<tr>
<td>4</td>
<td>74.47</td>
<td>72.34</td>
<td>29.39</td>
<td>0.36</td>
<td>1.98</td>
<td>3.40</td>
<td>332.00</td>
<td>547.00</td>
<td>731.89</td>
</tr>
<tr>
<td>5</td>
<td>88.89</td>
<td>85.71</td>
<td>38.42</td>
<td>0.33</td>
<td>2.20</td>
<td>3.67</td>
<td>340.00</td>
<td>565.00</td>
<td>800.33</td>
</tr>
<tr>
<td>6</td>
<td>97.62</td>
<td>93.33</td>
<td>65.40</td>
<td>0.27</td>
<td>3.59</td>
<td>3.33</td>
<td>636.00</td>
<td>1007.00</td>
<td>1213.54</td>
</tr>
<tr>
<td>7</td>
<td>95.74</td>
<td>81.25</td>
<td>45.10</td>
<td>0.32</td>
<td>2.50</td>
<td>3.67</td>
<td>484.00</td>
<td>725.00</td>
<td>991.88</td>
</tr>
<tr>
<td>8</td>
<td>82.22</td>
<td>69.39</td>
<td>23.41</td>
<td>0.37</td>
<td>1.54</td>
<td>3.33</td>
<td>307.00</td>
<td>519.00</td>
<td>843.67</td>
</tr>
<tr>
<td>9</td>
<td>91.49</td>
<td>83.33</td>
<td>50.39</td>
<td>0.32</td>
<td>2.90</td>
<td>3.50</td>
<td>492.00</td>
<td>804.00</td>
<td>984.04</td>
</tr>
<tr>
<td>10</td>
<td>97.78</td>
<td>95.56</td>
<td>59.42</td>
<td>0.28</td>
<td>3.29</td>
<td>3.67</td>
<td>600.00</td>
<td>959.00</td>
<td>1234.57</td>
</tr>
</tbody>
</table>

Regression coefficients and correlation for the adjusted model to experimental data in mixtures design.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficients</th>
<th>(R^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stability</td>
<td>66.12 92.73 97.45</td>
<td>–19.19 28.93* 17.63</td>
</tr>
<tr>
<td>Heat stability</td>
<td>45.88 84.95 96.87</td>
<td>20.16 54.36** 4.77</td>
</tr>
<tr>
<td>K</td>
<td>7.18 55.72 72.30</td>
<td>– – –</td>
</tr>
<tr>
<td>n</td>
<td>0.42 0.31 0.24</td>
<td>– – –</td>
</tr>
<tr>
<td>Viscosity</td>
<td>0.82 3.16 3.83</td>
<td>– – –</td>
</tr>
<tr>
<td>Firmness</td>
<td>211.22 420.22 673.50</td>
<td>121.19 –328.26* 457.74*</td>
</tr>
<tr>
<td>Adhesive force</td>
<td>291.20 842.20 1057.20</td>
<td>– – –</td>
</tr>
<tr>
<td>Adhesiveness</td>
<td>464.54 1109.52 1445.46</td>
<td>– – –</td>
</tr>
<tr>
<td>Overall acceptance</td>
<td>2.50 3.33 3.66</td>
<td>1.94** 2.32** –0.68**</td>
</tr>
</tbody>
</table>

\(\beta_1\): MDG, \(\beta_2\): GG, \(\beta_3\): XG.

\(\beta_1\): Significant at 0.05 level.

\(\beta_2\): Significant at 0.001 level.
The two-component interaction (MDG–XG and GG–XG) had a more notable influence on firmness as shown by the higher coefficient value (Table 3). According to Fig. 3a, the XG–GG edge represented the highest values of firmness response. The highest adhesive force values occurred in samples with only XG, and then, in samples containing 0.5 XG and 0.5 GG. As represented in Table 2, the lowest values were recorded in those with only MDG (formulation 1). The linear regression model was highly...
significant ($P < 0.01$). In the contour plot, the highest adhesive force values were in the XG vertex and edge of XG–GG (Fig. 3b).

Adhesiveness was significantly higher for samples containing only XG (formulation 3) and lower in those with only MDG (Table 2). The predicted regression coefficients for adhesiveness showed that the linear model is appropriate for this parameter (Table 3). Higher adhesiveness values were observed in the vertex of the XG and to some extent in XG–GG edge. Increased MDG concentration also reduced sample adhesiveness (Fig. 3c).

High xanthan gum levels gave low-fat mayonnaise products with more firmness, adhesiveness, and adhesive force values compared to products with no added xanthan gum. This result probably is caused by increasing the viscosity of the emulsion contained high levels of xanthan gum. The viscosity of the samples can partially, but not all, reflect the texture analysis parameters (Liu et al., 2007). Addition of gum may increase the elasticity of the emulsion by itself as a result of the formation of a strong gel-like structure in the continuous phase, imparting a more firm and adhesive structure and also yielding smaller oil droplet diameters because of a reduced coalescence process during emulsification (Raymundo et al., 2002).

Similar results were reported in the literature in which the composition of low-fat oil-in-water emulsions (stabilized by white lupin protein) was optimized. Firmness and adhesiveness increased with protein, xanthan gum, and oil concentration (Raymundo et al., 2002).

### 3.4. Rheological properties of mayonnaise samples

Fig. 4 shows the flow rheograms of mayonnaise samples formulated by using various amount of xanthan gum, guar gum, and mono- & diglycerides. For all mayonnaise samples, shear stress and shear rate data showed that the relationship of them was nonlinear. Thus, non-Newtonian flow characteristic was observed and the flow behavior index ($n$) was found to be less than unity. As seen in Fig. 4, samples showed different shear stress values as a function of shear rate. Differences in apparent viscosities of samples at 50 s$^{-1}$, the shear rate in mouth, were found to be significant ($P < 0.05$) (Karaman, Yilmaz, & Kayacier, 2011).

The power law model was used to explain the relationship between shear rate and apparent viscosity and all samples were well fitted to the model with high determination coefficients (0.978–0.999). Flow behavior index values of samples were determined in the range of 0.24–0.42 (Table 2). Flow behavior values showed that rheological characteristics of all samples were shear thinning and the apparent viscosity of all samples decreased with increasing shear rate. In a concentrated emulsion, flocculation leads to the formation of a three-dimensional network of aggregated droplets. Increasing the shear rate causes progressive deformation and disruption of the aggregated particles, which in turn decreases emulsion resistance to flow and reduces its apparent viscosity (Mun et al., 2009).

Consistency coefficients ($K$) of the samples were calculated to range between 10.54 and 72.22 Pa s$^{n}$ (Table 2) and differences between the mayonnaise samples were found to be significant ($P < 0.05$) with respect to the mentioned power law parameters.

Similar results were reported in the literature in which Raymundo et al. (2002) optimized the composition of emulsions using different contents of the white lupin protein, xanthan gum and oil. As a result, all emulsions showed a shear-thinning behavior and viscosity of the oil in water emulsion samples significantly increased with xanthan gum.

In addition, all investigated mayonnaise samples with 4xGTase-modified rice starch and xanthan gum showed a shear-thinning response (Mun et al., 2009).

This result is similar to that previously reported by Lorenzo et al. (2008) who observed shear-thinning behavior of low-in-fat emulsions stabilized with xanthan/guar mixtures.

Table 3 indicates the predicted models, significance of the regression coefficients and the $R^2$ values obtained for 10 mixtures. These values were important in showing the significance of equations or models developed from the design. As seen in that table, $R^2$ values of the predicted models for rheological parameters were higher than 0.98, indicating that they were relatively adequate for the prediction purpose.

Fig. 5 shows ternary contour plots indicating the effects of processing components on the viscosity and power law parameters of mayonnaise samples. Fig. 5a indicates that the viscosity contour values increased toward the xanthan gum (XG) vertex where maximum viscosity contour could be seen; however, the lowest viscosity values were at mono- & diglycerides (MDG) vertex. From this point of view, it could be said that the use of xanthan gum in mayonnaise as a stabilizer increased the viscosity of the final product, while use of the others decreased.

For the mixture 3 in which only the xanthan gum is presented and the mixtures 6 in which xanthan and guar gums were presented, the $K$ values were the highest and $n$ values were the lowest. However, the lowest $K$ and the highest $n$ values were observed in the mixture 1, containing 1.000 mono- & diglycerides, and the mixture 8, containing 0.167 XG, 0.167 GG and 0.667 MDG (Table 2). These results indicated that xanthan gum was the component having the highest increasing effect on the consistency of the mixture samples, followed by guar gum. The contour plots indicated the highest $K$, but the lowest $n$ values occur at GG–XG and XG–MDG edges and XG vertex. The lower values of $K$ and higher values of $n$ were observed at MDG vertex. Briefly, $K$ values were increased by increasing XG proportion (Fig. 5b and c).

It was obvious from these results that XG had a greater effect on the viscosity and flow parameters (i.e. $K$ and $n$) of mayonnaise samples compared with the other components including GG and mono- & diglycerides.

In other literature such as Mun et al. (2009) in which a reduced-fat mayonnaise was proposed by using modified starch and xanthan gum, it was shown that when xanthan gum was added to the reduced-fat mayonnaises with 4xGTase-treated starch as a fat replacer, consistency index ($K$) was markedly increased and the flow behavior index ($n$) decreased. Besides, the structure of the reduced-fat mayonnaise plus gum sample was very similar to that of the full fat mayonnaise.
Additionally, Lorenzo et al. (2008) observed that the viscosity of low-in-fat o/w emulsions stabilized with xanthan/guar mixtures was improved by hydrocolloids content.

3.5. Microscopic examination

Optical microscopy was used to provide information about the mayonnaise samples microstructures. Mayonnaise consists of oil droplets dispersed in an aqueous medium. Nevertheless, mayonnaise properties could vary widely with different formulations because of their various compositions and microstructures. Factors such as the emulsifying and stabilizing agent types and their concentration, the size of the droplets, oil concentration and the viscosity of the water phase are important parameters in determining mayonnaise microstructure (Mun et al., 2009). As shown in Fig. 6, the mean particle diameter of some mayonnaise samples (formulations 5, 6, 7 and 8) was above 30 μm. However, about other samples the mean particle diameter was below 30 μm and microstructure of these formulations was practically uniform except for formulation 9 and 10 which had some fraction of the particles with greater diameter.

The viscosity of polydisperse (droplets of different size) emulsions such as formulation 8 was significantly lower than that observed in equivalent monodisperse (uniform droplets) emulsions such as formulation 3 at the same volume fraction (Fig. 6). Moreover, reduction of the fat content also dramatically decreased viscosity of concentrated close packing emulsions. So that the viscosity of all samples discussed in this work probably is lower than full fat commercial ones. According to Fig. 6, we can describe why the firmness and adhesiveness of some formulations such as 3 was higher than other samples.

This result indicated that low-fat mayonnaises may have a wide variety of microstructures depending on the production conditions and compositions.

3.6. Sensory evaluation

The Highest overall acceptance scores (3.67) were given to the mixtures 3, 5, 7 and 10 in which the xanthan gum was present at higher concentration and the guar gum was either absent or present at lower concentration. And also the lowest overall acceptance score was achieved when mayonnaise samples contained only MDG (Table 2). Overall acceptance was high-significantly \((P < 0.01)\) affected by two-component interactions. In addition, three-component interactions had also significant \((P < 0.05)\) effects on this sensory parameter (Table 3).

Contour plot shows that overall acceptance score was higher at the closest points to the xanthan gum vertex and XG-MDG edge,
indicating that the mayonnaise samples were more preferred by the panelists when the MDG was mixed with XG in the mayonnaise. However, the lowest overall acceptance observed in MDG vertex (Fig. 7). Consequently, the addition of xanthan gum as a stabilizer increased the overall acceptance of samples.

Sensory evaluation scores of the mayonnaise samples are shown in Table 4. For all sensory properties, scores were more than 2.5 (i.e. the desired border) except for the sensory scores of texture and taste of formulation 1 with only MDG. In mayonnaise samples contained three components of XG, GG, and MDG (i.e. formulations 7, 8 and 9) almost all sensory scores were the best. Since it is reasonable that the sensory attributes with scores higher than 2.5 are considered acceptable, nearly all our mayonnaise samples were desirable. Thus, the low-fat mayonnaises with completely egg substitution were judged to be sensorially acceptable.

3.7. Mixture proportion optimization

An optimal mayonnaise formulation was obtained by solving the previous equations (Table 3) to yield the average values of each independent variable measured for these mayonnaises as a response. Using this approach, a set of combinations of xanthan gum, guar gum and mono- & diglycerides was found but the best solution is presented in Table 5. All of these combinations, in terms of emulsion composition, had properties close to the ranges of variation of the commercial mayonnaises. Therefore, if the main

Table 4
Mean values for sensory scores of the mayonnaise samples.

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Appearance</th>
<th>Color</th>
<th>Odor</th>
<th>Texture</th>
<th>Taste</th>
</tr>
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<td>3.33</td>
<td>2.33</td>
<td>2.17</td>
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<td>2.67</td>
<td>3.83</td>
</tr>
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<td>3.00</td>
<td>3.50</td>
<td>3.17</td>
<td>3.33</td>
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</tr>
</tbody>
</table>

Table 5
Optimum mixture proportions.

<table>
<thead>
<tr>
<th>Components</th>
<th>Proportions (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mono- &amp; diglycerides</td>
<td>6.7</td>
</tr>
<tr>
<td>Guar gum</td>
<td>36.7</td>
</tr>
<tr>
<td>Xanthan gum</td>
<td>56.7</td>
</tr>
</tbody>
</table>
goal is to produce low cholesterol-low fat emulsions with soy milk, formulation with 6.7% mono- & diglycerides, 36.7% guar gum, and 56.7% xanthan gum should be used. This optimum solution is shown by a clear flag on the overlay plot (Fig. 8). As illustrated in Fig. 8, the zone indicated by the Label D, at the bottom of the plot, represents all appropriate solutions given by the software. According to these results, high contents of gums are needed to obtain low-fat mayonnaise contained soy milk.

4. Conclusion

From the results of the present work, it can be concluded that mixture design approach is a fitting method to optimization of low cholesterol-low fat mayonnaise formulation. According to experimental results and contour plots, an increase of xanthan gum followed by guar gum improved the stability, heat stability, consistency coefficient, viscosity, firmness, adhesiveness, adhesive force and overall acceptance; and declined the flow behavior index. However, the sample with xanthan gum did not receive high sensory scores. Therefore, it should be used as a mixture with guar gum to improve sensory properties when optimum combination levels of gums are taken into account. Additionally, it was observed that in low-fat mayonnaises contained only mono- & diglycerides or samples with high levels of this emulsiﬁer; all measured parameters including stability, rheological characteristics, textural properties, and overall acceptance were declined.

By using desirable levels of xanthan gum, guar gum, and mono- & diglycerides, producing low cholesterol-low fat mayonnaise with properties closely similar to those of commercial ones is possible.

References


Puppo, M. C., Sorgentini, D. A., & Afonso, M. C. (2003). Rheological properties of emulsions containing modiﬁed soy protein isolates. JAOCs, 80(6).


