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Optimization of Baking of Rice Cakes in Infrared–Microwave Combination Oven by Response Surface Methodology

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Abstract In this study, response surface methodology was used to design gluten-free cakes made from rice flour to be baked in infrared-microwave combination oven. Two types of cake formulations containing different types of gums were used in the experiments, which were xanthan gum and xanthan–guar gum blend. The independent variables were emulsifier content (0, 3, and 6% of flour weight), upper halogen lamp power (50, 60, and 70%), and baking time (7, 7.5, and 8 min). Specific volume, surface color change, firmness and weight loss of the cakes were determined for optimization. Cakes formulated with xanthan gum had better quality characteristics than cakes containing xanthan–guar gum blend. Cakes formulated with xanthan gum and 5.28% emulsifier and baked using 60% halogen lamp power for 7 min had the most acceptable quality.

Keywords Infrared · Microwave · Optimization · Response surface methodology · Rice cake

Introduction

Celiac disease, which is due to the sensitivity to prolamin part of gluten, affects the small intestine. Patients who have this disease must follow a lifelong gluten-free diet. Gluten is the main structure-forming protein and is responsible for the elastic properties of the dough. In this respect, gluten replacement in designing gluten-free products is a challenging issue for food scientists and technologists.

Rice with its low level of gluten, low levels of sodium, protein, fat, fiber and a high amount of easily digested carbohydrates, is one of the most convenient cereal in designing such food gluten-free products. However, some food additives such as starches, gums, hydrocolloids, and dairy products are required to be used for obtaining the good quality characteristics such as high volume, desired texture, color, and crumb structure.

The ability to control the rheological characteristics of aqueous systems makes gums important ingredients in food systems. Moreover, gums affect the stabilization of the emulsions, help to suspend particles, control crystallization, and inhibit syneresis (Lucca and Tepper 1994). Xanthan and guar gum are among the group of gums frequently included in food formulations to improve the mouth feel and change the rheological properties. When used together, a synergistic interaction occurs between xanthan and guar gum, and in the study of Casas et al. (2000), the mixtures of xanthan and guar gum provided higher viscosity than when each gum was used individually.

Until the cake structure is set, emulsifiers have the ability of providing the necessary aeration and gas bubble stability during the process. Their function of reducing interfacial tension between oil and water droplets facilitates the disruption of oil droplets (Sahi and Alava 2003). In the study of Seyhun et al. (2003), using different emulsifier and gum types helped to retard staling of microwave-baked cakes effectively.

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Although microwave has the advantages of reducing the time and the energy during processing, it has disadvantages such as high moisture loss, unacceptable texture, and rapid staling. Moreover, browning reaction that is desirable for baked products does not occur because the surface temperature of dough or batter is not high enough to promote browning and crust formation. Microwaves can be combined by halogen lamp heating, as halogen lamp heating provides near-infrared radiation, and this radiation can be focused at the surface of the product. Therefore, required surface temperature for browning reactions can be obtained. Infrared–microwave combination oven has recently been used in cake and bread baking (Demirekler et al. 2004; Keskin et al. 2004; Sevimli et al. 2005).

Response surface methodology (RSM), which is a collection of statistical and mathematical techniques, is a useful tool for development, improvement, and optimization of processes. It is used to examine the relationship between one or more response variables and a set of quantitative experimental variables or factors. Many researchers have used this method in optimization of the bakery products. In the study of Sanchez et al. (2002), the proportions of cornstarch, cassava starch, and rice flour were optimized for production of gluten-free bread to maximize specific volume, crumb-grain score and bread score. In another study, RSM was used to optimize gluten-free bread fortified with soy flour and dry milk (Sanchez et al. 2004). Toufeili et al. (1994) studied the effects of methylcellulose, egg albumen, and gum arabic on the sensory properties of gluten-free pocket-type flat bread by using RSM.

Although there are many studies in which RSM was used as an optimization tool for bakery products, there is no study about the optimization of the baking of a gluten-free rice cake in the literature. Therefore, the objective of this study was to optimize the infrared–microwave combination baking condition and formulation of gluten-free rice cakes by RSM. In addition, the effects of different gums on the quality of cakes were compared.

Materials and Methods

Materials

Rice flour (Knorr-Çapamarka, Istanbul, Turkey), sugar, shortening (Becel, Turkey), salt, and baking powder (Bağdat Baharat, Ankara, Turkey) were bought from local market. Egg white powder was obtained from Igreca (Seiches-sur-le-Loir, France). Emulsifier Purawave™, which is composed of lecithin, soy protein, mono/diglycerides, and vegetable gums, was obtained from Puratos (Brussels, Belgium). Xanthan gum was obtained from Sigma-Aldrich (Germany), and guar gum was obtained from Aldrich Chemical Company Inc. (USA).

Preparation of the Cake

A cake batter recipe containing 100% rice flour, 100% sugar, 25% shortening, 9% egg white powder, 3% salt, 5% baking powder, and 90% water (all percentages are given on a flour weight basis) was used in the experiments. Xanthan and guar gum blend (in equal amounts) and xanthan gum were added to the recipe as 1% on flour weight basis. Emulsifier was added in three different concentrations (0, 3, and 6%).

During preparation of the cake, firstly, dry ingredients (rice flour, baking powder, salt and gum blend) were mixed thoroughly. After mixing sugar and egg white powder in another cup, melted shortening was added to sugar–egg white powder blend. When emulsifier was used, it was added to the melted shortening. By using a mixer (Kitchen Aid, 5K45SS, USA), shortening, sugar, and egg white powder were mixed for 1 min at 85 rpm. Dry ingredient mix and water were added simultaneously and mixed first for 2 min at 85 rpm, then for 1 min at 140 rpm, and finally, for 2 mins at 85 rpm.

Infrared–Microwave Combination Oven Baking

Infrared–microwave combination oven (Advantium oven, General Electric Company, Louisville, KY, USA), which combines microwave heating and infrared heating, includes three halogen lamps each having 1,500 W power. Two of the lamps are located at the top of the oven and at the bottom of the turntable. According to the IMPI test, microwave power of the oven was found to be 706 W (Buffler 1993). Preliminary studies showed that cakes baked in this oven lost a significant amount of moisture. Therefore, four beakers each containing 400 ml water were placed in the corners in the oven. One hundred grams of cake sample placed in a beaker of 500 ml was baked one at a time. The microwave power was set to 40%, and lower halogen lamp power was set to 70%. Three powers were used for upper halogen lamp (50, 60, and 70%).

Conventional Baking

For comparison, rice cake batter having the optimum formulation according to the results of infrared–microwave combination baking was baked in conventional oven (9411FT, Arcelik, Bolu, Turkey) at 175°C for 30 min. Two cake samples (100 g each) were baked at a time.

Table 1 Experimental design for RSM and experimental data for cakes containing xanthan gum and xanthan–guar gum blend

Factors					
X_1(%)		X_2(%)		X_3(min)	
Coded	Uncoded	Coded	Uncoded	Coded	Uncoded
−1	0	−1	50	0	7.5
1	6	−1	50	0	7.5
−1	0	1	70	0	7.5
1	6	1	70	0	7.5
−1	0	0	60	−1	7.0
1	6	0	60	−1	7.0
−1	0	0	60	1	8.0
1	6	0	60	1	8.0
0	3	−1	50	−1	7.0
0	3	1	70	−1	7.0
0	3	−1	50	1	8.0
0	3	1	70	1	8.0
0	3	0	60	0	7.5
0	3	0	60	0	7.5
0	3	0	60	0	7.5

where X_1 is emulsifier content, X_2 is upper halogen lamp level, and X_3 is baking time

Experimental Design

RSM was used as an optimization tool to relate the quality parameters to emulsifier content and baking conditions (Myers and Montgomery 2002). In this study, Box-Behnken design was used. There were three independent variables each having three levels, which were emulsifier content (X_1; 0, 3, and 6%), upper halogen lamp power (X_2; 50, 60, and 70 %), and baking time (X_3; 7.0, 7.5, and 8.0 min). The levels of these variables were determined by preliminary experiments. For convenience, the actual values were converted into coded values. The uncoded and coded independent variables and the experimental design is given in Table 1. In this design, the experiments were randomized to minimize the effects of extraneous variables.

Cake Analysis

Specific volume of the baked cakes was measured by using Rape Seed Displacement Method (Sahin and Sumnu 2006).

The percentage weight loss of the cakes was calculated by measuring the weights of the cake samples before and after the baking process.

The upper surface color of the cakes were measured by using Minolta Color Reader (CR-10, Japan) and expressed as the CIE L^*, a^*, and b^* color scale. Five measurements were made at different positions from the surface of the cakes at room temperature, and the mean value was recorded. Total color change (ΔE) was calculated from Eq. 1;

$$\Delta E = \left[(L^* - L_0)^2 + (a^* - a_0)^2 + (b^* - b_0)\right]^{1/2} \quad (1)$$

Cake batter was selected as reference point and its L^*, a^*, and b^* values were represented as L_0, a_0, and b_0.

Table 2 Regression equations for baked cakes containing xanthan–guar gum blend and xanthan gum

Quality parameter		Equation	r^2	Lack of fit (F)
Specific volume	Xanthan–guar gum blend	Y_1=1.491*** +0.104*** X_1−0.012^{ns} X_2−0.023^{ns} X_3−0.049* X_1^2−0.011^{ns} X_2^2−0.009^{ns} X_3^2+0.013^{ns} X_1X_2+0.016^{ns} X_1I_3−0.041^{ns} X_2X_3	96.7	1.92^{ns}
	Xanthan gum	Y_1=1.490*** −0.009^{ns} X_1−0.012^{ns} X_2−0.026** X_3+0.152*** X_1^2+0.004^{ns} X_2^2+0.008^{ns} X_3^2−0.013^{ns} X_1X_2+0.026* X_1X_3−0.017^{ns} X_2X_3	98.7	0.62^{ns}
Total color change	Xanthan–guar gum blend	Y_2=28.267*** +4.525*** X_1+5.275*** X_2+2.425*** X_3 −2.596*** X_1^2+ 0.154^{ns} X_2^2+0.004^{ns} X_3^2−1.925* X_1X_2−0.425^{ns} X_1X_3−0.025^{ns} X_2X_3	98.5	0.28^{ns}
	Xanthan gum	Y_2=30.733*** +6.750*** X_1+6.525*** X_2+4.075*** X_3−4.117*** X_1^2+ 0.433^{ns} X_2^2+0.133^{ns} X_3^2−0.500^{ns} X_1X_2−0.750^{ns} X_1X_3+1.550^{ns} X_2X_3	99.0	17.78^{ns}
Firmness	Xanthan–guar gum blend	Y_3=3.216*** −0.426*** X_1+0.045^{ns} X_2+0.228^{ns} X_3+0.255^{ns} X_1^2−0.297^{ns} X_2^2+0.456* X_3^2−0.427^{ns} X_1X_2+0.221^{ns} X_1X_3+0.036^{ns} X_2X_3	92.3	0.47^{ns}
	Xanthan gum	Y_3=3.065*** +0.276*** X_1+0.198*** X_2+0.087^{ns} X_3−0.486*** X_1^2− 0.163^{ns} X_2^2+0.161^{ns} X_3^2+0.190* X_1X_2+0.029^{ns} X_1X_3−0.113^{ns} X_2X_3	96.6	14.59^{ns}
Weight loss	Xanthan–guar gum blend	Y_4=13.857*** +0.536^{ns} X_1+0.855^{ns} X_2+1.334* X_3−0.213^{ns} X_1^2−0.367^{ns} X_2^2+0.238^{ns} X_3^2+0.018^{ns} X_1X_2+0.180^{ns} X_1X_3−0.212^{ns} X_2X_3	96.7	1.18^{ns}
	Xanthan gum	Y_4=12.922*** +0.214^{ns} X_1+0.541** X_2+1.592*** X_3−0.121^{ns} X_1^2−0.221^{ns} X_2^2+0.359^{ns} X_3^2+0.345^{ns} X_1X_2−0.099^{ns} X_1X_3−0.003^{ns} X_2X_3	98.5	0.92^{ns}

ns Not significant, X_1 emulsifier content, X_2 halogen lamp power, X_3 baking time (coded values)
*Significant at $p \leq 0.05$
**Significant at $p \leq 0.01$
***Significant at $p \leq 0.001$

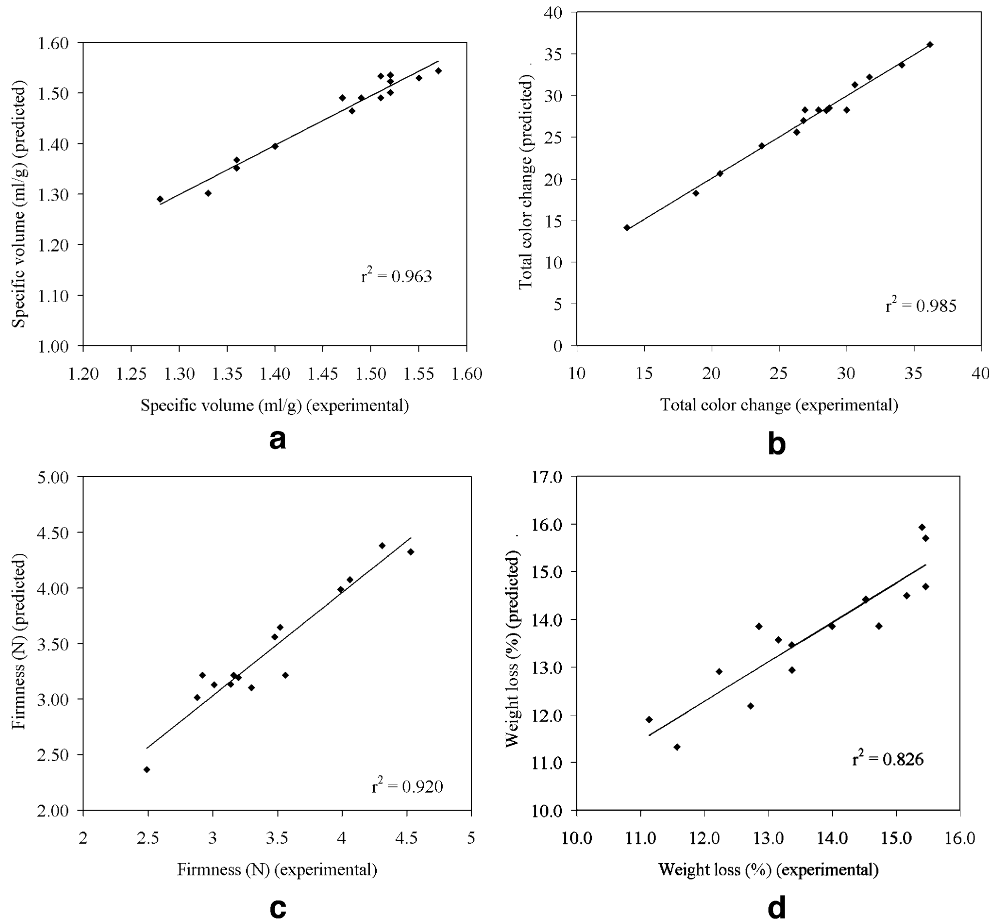

Fig. 1 Comparison of predicted and experimental values of dependent variables for cakes formulated with xanthan–guar gum blend. **a** Specific volume; **b** Total color change; **c** Firmness; **d** Weight loss

The firmness of the cakes was measured by using a texture analyzer (TAPlus, Lloyd Instruments, United Kingdom) after 30 min of baking. Cake samples were cut from the center in cubic shape having dimensions of 25 mm× 25 mm×25 mm, and they were compressed to 25% of their original thicknesses at a cross-head speed of 55 mm/min. A load cell of 50 N was used.

Statistical Analysis

Multiple regression analysis was performed to fit second-order models to dependent variables by using Minitab Release 14 (Minitab Inc., State College PA, USA). The models were used to plot contour surfaces and optimum conditions were determined by performing multiple optimization by using

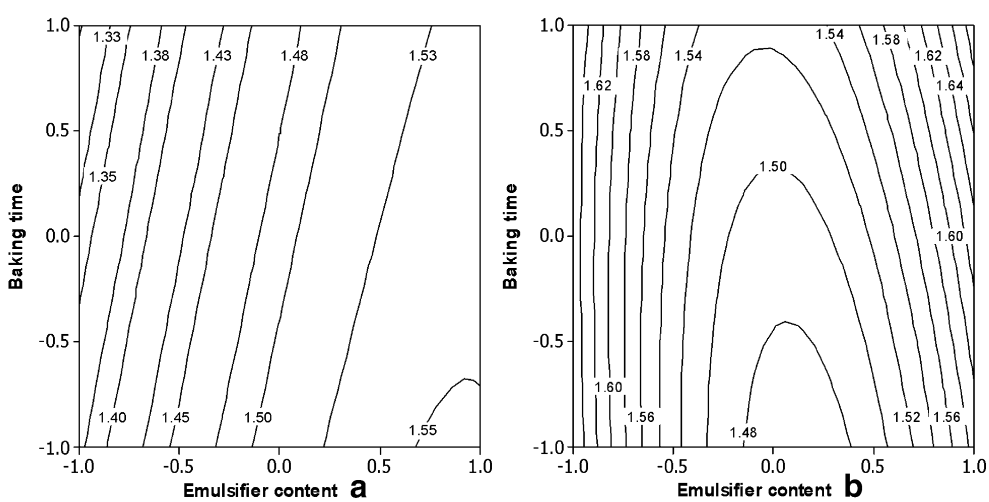

Fig. 2 Effects of emulsifier content (X_1) and baking time (X_3) on specific volume (ml/g) of cakes (X_2=0). **a** Xanthan guar gum blend; **b** Xanthan gum

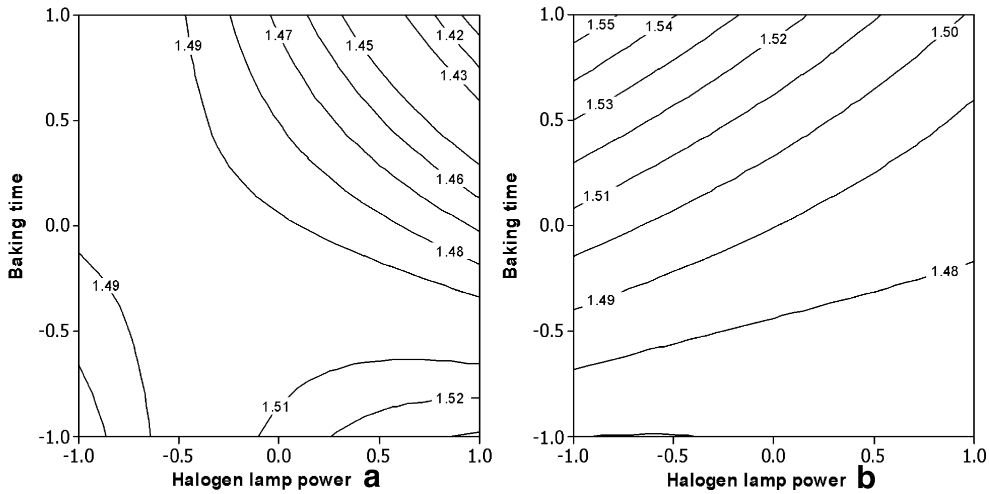

Fig. 3 Effects of halogen lamp power (X_2) and baking time (X_3) on specific volume (ml/g) of cakes (X_1=0). **a** Xanthan guar gum blend; **b** Xanthan gum

response optimizer in Minitab release 14 software. One-way analysis of variance (ANOVA) was applied to compare the effect of different gum types on all the dependent variables.

Results and Discussion

The independent and dependent variables were fitted to the second-order model equation (Eq. 2) and examined for goodness of fit.

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_1^2 + b_5X_2^2 + b_6X_3^2 + b_7X_1X_2 + b_8X_1X_3 + b_9X_2X_3 \quad (2)$$

In this equation, X_is are the independent variables (X_1 is emulsifier content, X_2 is upper halogen lamp level, and X_3 is baking time), b_is are the model constants, and Ys are dependent variables (specific volume, total color change, firmness, and weight loss).

In Table 2, the model constants and coefficient of determination values of each dependent variables were shown. The equations for each response could be derived from the predicted values of each response variable. Coefficient of determination (r^2) is the proportion of variation in the response attributed to the model rather than to the random error. It is suggested that r^2 should be at least 80% for good fit model (Gan et al. 2006). The results showed that the models for all the response variables were adequate because they had satisfactory r^2 of more than 90%, and there was also an insignificant lack of fit for all the response variables (Table 2). The lack of fit test is a measure of the failure of a model to represent data in the experimental domain at which points were not included in the regression (Varnalis et al. 2004).

Dependent variables at different experimental conditions were also predicted using the model. Predicted values were compared with the experimental values of cakes containing xanthan–guar gum blend (Fig. 1a–d). As can be seen in these figures, the coefficient of determination showing the relationship between predicted and experimental data were high. This indicates that the experimental data fits the model well.

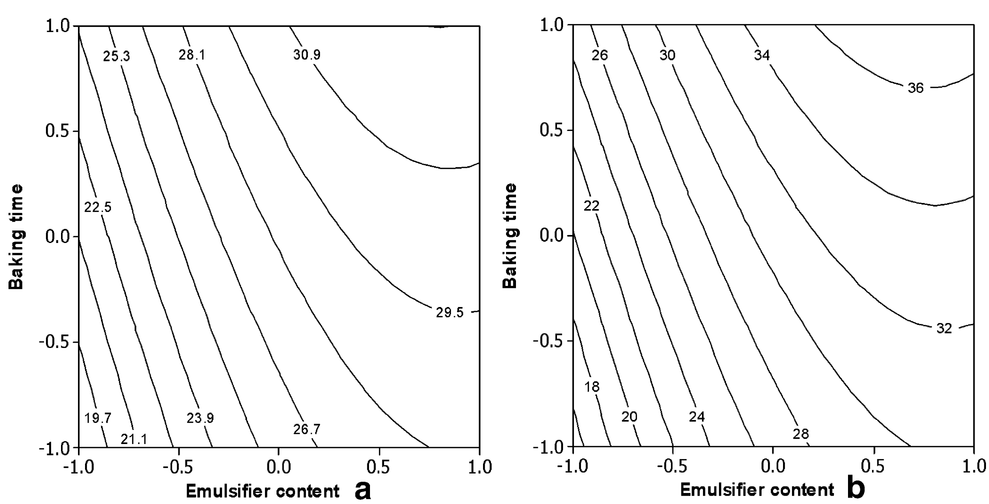

Fig. 4 Effects of emulsifier content (X_1) and baking time (X_3) on total color change of cakes (X_2=0). **a** Xanthan guar gum blend; **b** Xanthan gum

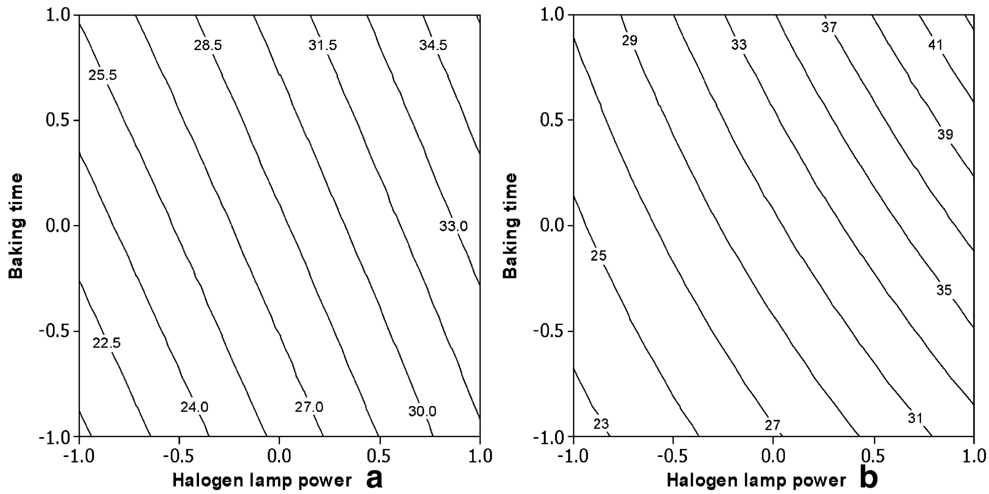

Fig. 5 Effects of halogen lamp power (X_2) and baking time (X_3) on total color change of cakes (X_1=0). **a** Xanthan guar gum blend; **b** Xanthan gum

According to the multiple regression analysis, emulsifier content was found to be the only significant main factor ($p \leq 0.001$) in affecting the specific volume of the cakes containing xanthan–guar gum blend. As shown in Fig. 2a, when emulsifier content increased, specific volume of the cakes increased. According to this figure, for cakes baked for 7 min, the increase in emulsifier content from 0 to 6%, increased the specific volume of the cakes by 12.3%. Emulsifier addition is known to improve the gas retention and to increase resistance of the cake to collapse. Therefore, the increase in the emulsifier content improved the specific volume of the cakes containing xanthan–guar gum blend. In the study of Mohamed and Hamid (1998), volume expansion was found to be correlated positively with emulsifier content for the rice cakes. The increase in baking time decreased the volume of cake, which may be explained by shrinkage of cakes within the studied range of time. It can be seen that for the 0% level of emulsifier content, when the baking time was increased from 7 to 8 min, the specific volume of cakes decreased from 1.38 to 1.33 g/cm^3 (Fig. 2a).

For cakes containing xanthan gum only, there was an optimum emulsifier concentration to obtain high voluminous cakes which was about 6% of emulsifier content for 7 min baking time. (Fig. 2b). This figure also shows that the effect of baking time on volume was a function of emulsifier content. Emulsifiers have the function of improving gas retention in the cake and cake structure. To prevent the collapse of cakes in the oven, baking time is also important. Emulsifier content is dependent on baking time on affecting the volume of cakes. This explains the significant interaction between the baking time and emulsifier content (Table 2).

According to one-way ANOVA, a significant difference was found between the gum types. When Fig. 2a and b were examined, it can be observed that xanthan gum containing cakes had higher specific volume values than the cakes containing xanthan–guar gum blend. Cakes containing xanthan guar gum blend had specific volumes of 1.33–1.55 g/cm^3 and cakes containing only xanthan gum had specific volumes of 1.48–1.64 g/cm^3. It was known that

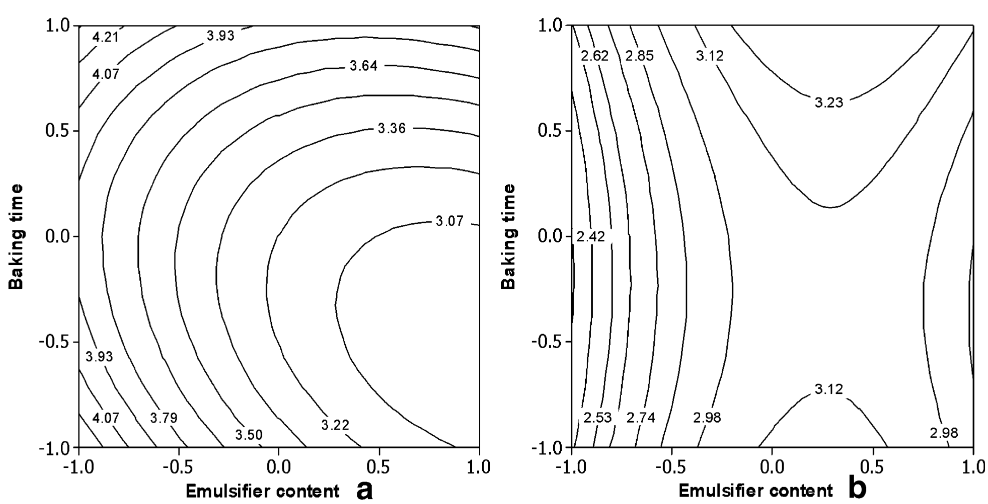

Fig. 6 Effects of emulsifier content (X_1) and baking time (X_3) on firmness of cakes (X_2= 0). **a** Xanthan guar gum blend; **b** Xanthan gum

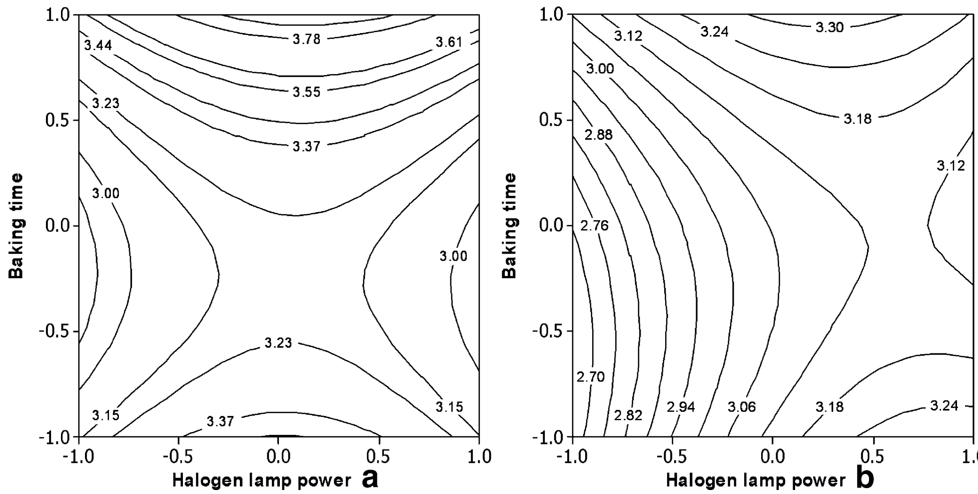

Fig. 7 Effects of halogen lamp power (X_2) and baking time (X_3) on firmness of cakes (X_1=0). **a** Xanthan guar gum blend; **b** Xanthan gum

xanthan had higher viscosities when it was used with guar gum because of the synergistic effect of the gums (Casas et al. 2000). The viscosity is an important physical property of cake batter that affects the final cake volume. There is an optimum viscosity of cake batter to obtain cakes with high volume. If the viscosity of the batter is too low, batter cannot hold the air bubbles inside and cake collapses in the oven. Although a highly viscous batter can hold the air bubbles inside, the expansion of this batter is restricted because of its high viscosity (Sahi and Alava 2003). Thus, cakes with lower volume are obtained. In our study, cakes containing xanthan gum had higher specific volume than the cakes containing xanthan–guar gum blend, as cake batter containing only xanthan gum had lower viscosity than the one containing xanthan–guar gum blend.

The increase in halogen lamp power decreased the volume of xanthan–guar gum blend containing cakes for longer baking times (Fig. 3a). For xanthan-containing cakes, the increase in halogen lamp power decreased the volume for all baking times (Fig. 3b). The reason for the decrease in volume of cakes as halogen lamp power increases is that the thicker crust formed on the cakes compressed the structure more and resulted in lower volumes (Sevimli et al. 2005).

All the independent variables were found to have a significant effect on the total color change of cakes containing both xanthan–guar gum blend and xanthan gum ($p \leq 0.001$) (Table 2). In Fig. 4a and b, the effects of emulsifier content and baking time on ΔE can be seen. Increase in both emulsifier content and baking time increased the total color change that is desirable for cake baking process. Maillard reactions take place between amino acids and reducing sugars in the presence of heat. In these reactions, the reactive carbonyl group of the sugar interacts with the nucleophilic amino group of the amino acid. As the emulsifier used in the study contains soybean protein, higher color change values were obtained as emulsifier concentration increased. When Fig. 5a and b were examined, one can easily see that the increase in both baking time and halogen lamp power caused an increase in total color change. In another study, in which a wheat flour cake was baked in infrared–

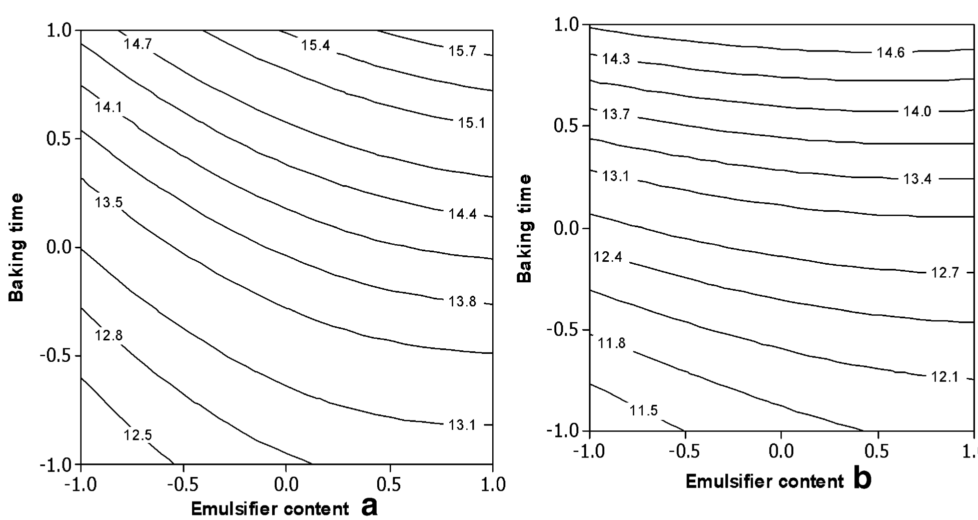

Fig. 8 Effects of emulsifier content (X_1) and baking time (X_3) on weight loss of cakes (X_2=0). **a** Xanthan guar gum blend; **b** Xanthan gum

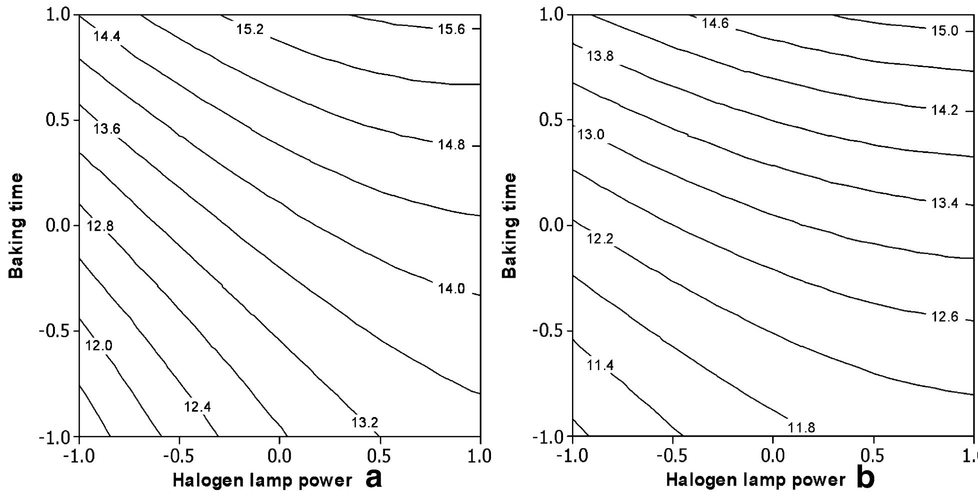

Fig. 9 Effects of halogen lamp power (X_2) and baking time (X_3) on weight loss of cakes (X_1=0). **a** Xanthan guar gum blend; **b** Xanthan gum

microwave combination oven, similar results were obtained (Sevimli et al. 2005). Higher halogen power means higher temperature, which enhances Maillard Browning reactions. Since halogen lamps allow the surface of the cakes to reach high temperatures, which is essential for Mailliard reactions, color change on the surface increased as halogen lamp power increased. No significant difference was found between the gum types with respect to total color change.

Only emulsifier content was found to significantly affect the firmness of cakes containing xanthan–guar gum blend ($p \leq 0.001$) (Table 2). As can be seen in Fig. 5a, as emulsifier content increased, the firmness of the cakes decreased, and softer cakes were obtained. For cakes baked for 7 min and containing xanthan–guar gum blend, the increase in the emulsifier content from 0 to 6% decreased the firmness of the cakes from 4.07 to 3.07 N. It can be observed that the baking time was not significant as emulsifier content to affect firmness of cakes.

For the cakes containing xanthan gum only, emulsifier content and halogen lamp power were found to be significant in affecting the firmness values ($p \leq 0.01$) (Table 2). The effect of baking time on firmness was observed to be a function of emulsifier content (Fig. 6b). This trend is similar to the results obtained for specific volume. For all baking times, the variation of firmness of cakes remained constant after an emulsifier concentration of about 4.8% (coded value of 0.6).

The effect of halogen lamp power on the firmness can be observed in Fig. 7a and b. It can be observed that halogen lamp was not significant to affect the firmness for cakes containing xanthan–guar gum blend. (Fig. 7a and Table 2). According to Fig. 7b, for most of the baking times, as the halogen lamp power increased, the firmness of the cakes increased. Higher halogen level meant higher moisture loss resulting in a firmer cake. As moisture loss is a function of baking time, as the baking time increased, the moisture loss and therefore firmness, of cakes increased. ANOVA results showed that there was significant difference between the gum types with respect to firmness. Cakes containing only xanthan gum were softer than those containing xanthan–guar gum blend.

Emulsifier content did not affect the weight loss of the cakes significantly (Fig. 8). In Fig. 9, it can be seen that as upper halogen lamp power and baking time increased, weight loss of the cakes containing xanthan–guar gum

Table 3 Optimum formulations and baking conditions in infrared–microwave combination oven for rice cakes containing xanthan gum and xanthan–guar gum blend

Parameters	Xanthan–guar gum blend		Xanthan gum	
	Coded	Uncoded	Coded	Uncoded
Emulsifier content (%)	0.56	4.68	0.88	5.28
Halogen lamp power (%)	1.00	70	0.08	60
Baking time (min)	−1.00	7	−0.99	7

Table 4 Quality characteristics of the cakes baked in conventional oven and at optimum conditions of infrared–microwave combination oven

Parameters	Infrared–Microwave combination baking		Conventional baking	
	Xanthan–guar blend	Xanthan gum	Xanthan–guar blend	Xanthan gum
Specific volume (ml/g)	1.57	1.75	1.30	1.38
Total color change (ΔE)	32.18	30.56	26.43	25.34
Firmness (N)	2.58	2.32	2.35	2.13
Weight loss (%)	13.69	11.94	10.65	7.70

blend and xanthan gum increased as in the study of Sevimli et al (2005). For xanthan–guar gum blend containing cakes, which were baked using halogen lamp of 50%, the increase in baking time increased from 7 to 8 min, increased weight loss from 11.6 to 14.4%. At the same conditions, weight loss increase of cakes containing only xanthan was from 11 to 14.2%. As baking time and halogen lamp power increased, higher moisture loss occurred, and therefore, weight loss increased. According to the ANOVA results, no difference was found between the gum types on affecting the weight loss.

The optimum baking conditions for rice cakes containing xanthan gum and xanthan–guar gum blend baked in infrared–microwave combination oven were found by multiple optimization by using the response optimizer in Minitab release 14 software. In determination of these optimum points, maximum specific volume, maximum color change, minimum firmness, and minimum weight loss were considered. In Table 3, optimum points can be seen as coded and uncoded values. When the optimum points were examined, 70% halogen lamp power was found to be optimum for cakes containing xanthan–guar gum blend, while 60% halogen lamp power was optimum for xanthan gum containing cakes (Table 3). As the viscosity of the xanthan gum containing batter was lower than that of xanthan–guar gum blend (Casas et al. 2000), gas produced inside the batter might not be held in the cake structure when the rate of heating was higher.

Values for the quality characteristics, which are specific volume, total color change, firmness, and weight loss, were calculated at these optimum conditions and shown in Table 4. Cakes formulated by xanthan or xanthan–guar blend and by optimum concentration of emulsifier, Purawave, were also baked in conventional oven for comparison. Cakes baked by using infrared–microwave combination oven had similar color and firmness values to those of conventional oven (Table 4). Infrared–microwave combination baking resulted in cakes with higher volume but lower moisture content. As infrared–microwave combination baking decreased conventional baking time by 77%, it may be recommended to be used in production of rice cakes. Using only xanthan gum in cakes gave better results with respect to specific volume and firmness (Table 4). On the other hand, in terms of total color change and weight loss of cakes, there were no significant differences between the gum types.

Conclusions

Response surface methodology was successfully applied to optimize the formulation and baking conditions of rice cakes in infrared–microwave combination oven. In general, the increase in emulsifier content increased the surface color and decreased the firmness of cakes. The increase in halogen power decreased specific volume, increased firmness, weight loss, and surface color. As baking time increased, surface color of cakes became darker, and they lost more moisture.

When only xanthan gum was added to the cakes, better results in terms of specific volume and firmness were obtained compared to xanthan–guar gum blend containing cakes. It is possible to produce high quality rice cakes for celiac patients using xanthan gum and emulsifier. Infrared–microwave combination baking may be an alternative of conventional baking to produce rice cakes.

In the experiments, both microwave and halogen lamp modes of the oven were operated at the same time. In a future study, the modes of microwave and halogen lamp can be operated at different times so that the effect of mode sequence on the quality of cakes can be observed.

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