Optimization of formulation of soy-cakes baked in infrared-microwave combination oven by response surface methodology

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Abstract The aim of present work is to optimize the formulation of a functional cake (soy-cake) to be baked in infrared-microwave combination oven. For this optimization process response surface methodology was utilized. It was also aimed to optimize the processing conditions of the combination baking. The independent variables were the baking time (8, 9, 10 min), the soy flour concentration (30, 40, 50 %) and the DATEM (diacetyltartaric acid esters of monoglycerides) concentration (0.4, 0.6 and 0.8 %). The quality parameters that were examined in the study were specific volume, weight loss, total color change and firmness of the cake samples. The results were analyzed by multiple regression; and the significant linear, quadratic, and interaction terms were used in the second order mathematical model. The optimum baking time, soy-flour concentration and DATEM concentration were found as 9.5 min, 30 and 0.72 %, respectively. The corresponding responses of the optimum points were almost comparable with those of conventionally baked soy-cakes. So it may be declared that it is possible to produce high quality soy cakes in a very short time by using infrared-microwave combination oven.

Keywords Soy-cake · Infrared · Microwave · Optimization · Response surface methodology

Introduction

Baking is a complex process that brings about a series of physical, chemical and biochemical changes in food such as gelatinization of starch, denaturation of protein, liberation of

carbon dioxide from leavening agents, volume expansion, evaporation of water, crust formation and browning reactions (Sakıyan 2007). The use of microwave energy in baking process is an interesting alternative for researchers due to time and space saving advantages of microwave heating (Martin and Tsen 1981; Megahey et al. 2005). But in case of microwave baking some quality problems like dense or gummy texture, crumb hardness, low volume, lack of surface color, high moisture loss have been reported in the final baked product (Sumnu 2001). The lack of completion of some physicochemical changes and interactions of major ingredients, which would normally occur over a lengthy baking period in a conventional system, during the short baking period of a microwave system, can be suggested as reasons for these quality problems (Hegenbert 1992). A plenty of microwave combination has been searched to overcome these problems such as hot air-microwave combination, steam-microwave combination and infrared-microwave combination (Datta and Rakesh 2013). Combination of microwaves with near infrared heating is a promising development in microwave baking. The infrared-microwave combination oven combines the browning and crisping advantages of near infrared heating with the time saving advantages of microwave heating.

Infrared-microwave combination baking has been used in bread baking and it has reduced the conventional baking time of breads by about 75 % (Keskin et al. 2004). Specific volume and color values of breads baked in infrared-microwave combination oven were comparable with that of conventionally baked breads but weight loss and firmness values of those breads were higher. Demirekler et al. (2004) optimized the baking conditions of bread in an infrared-microwave combination oven by reducing the conventional baking time of breads by 60 %. It was found that the breads baked at optimum condition had comparable quality with the conventionally baked ones. The processing conditions during infrared-

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microwave baking of cake were optimized by using Response Surface Methodology (Sevimli et al. 2005). The upper halogen lamp power, the microwave power, and the baking time were found to have significant effects on the weight loss, the specific volume, and the firmness of the cakes. A formulation study in cakes baked by infrared-microwave combination was performed by Turabi et al. (2010). The effects of different gums (xanthan, guar, locust bean, κ -carrageenan and xanthan-guar blend) on macro and micro structure of gluten-free cakes baked in conventional and combination ovens were determined. The researchers investigated the images obtained by scanner and scanning electron microscopy to evaluate structures of the samples. They reported that the cakes baked in combination oven had higher porosity values than those of cakes baked in conventional oven. Another research on combination oven was performed by Demirkesen et al. (2011). The main objective of their study was to design gluten free breads. Chestnut and rice flour and xanthan-guar gum blend was used in the formulation. Different formulations were baked in infrared-microwave combination oven. They found that breads containing 46.5 % chestnut flour and 0.62 % emulsifier and baked using 40 % of upper halogen lamp power (1500 W) and 30 % of microwave power (682 W) for 9 min had the optimum quality characteristics.

The other important characteristic of cake is formulation. In this research, in order to produce functional cakes, soy flour was added to the formulation with different concentrations. Soy beans have high amount of protein content. Soy protein has a functional property. It is highly nutritional and also it is healthy due to plasma cholesterol inducing and osteoporosis preventive effect (Dube et al. 2007). Bhattacharya and Jena (2007) investigated the sensory characteristics of microwave heated gels of fat free soy flours with different concentrations during different times (15–70 s). It was reported that the increasing microwave heating time caused an increase of firmness of samples. Similarly, Sung et al. (2006) searched the quality parameters of cake samples with different soy protein concentrations during baking in conventional oven. The results of study showed that higher protein concentration increased the pH values and firmness of cake samples and decreased the specific volume.

As it can be concluded from the previous studies in the literature, soy-cakes have some quality problems. Optimizing the formulation, which is one of the primary factors effective on quality of cake samples, can be a solution for this trouble. Response surface methodology (RSM) is an attractive tool for the optimization of formulation of baked products. It helps to detect the optimal levels of several variables without the necessity of testing all possible combinations. The relation between response variables and experimental variables can be examined by using RSM. It has been used in other studies about microwave baking, combination baking and formulation optimization (Sumnu et al. 2000; Sevimli et al. 2005; Turabi et al. 2008).

As it was mentioned, the usage of RSM for the optimization of formulation of cakes has been reported several times. However, there is no study in the literature on optimization of baking of soy-cakes. The objective of this study was to optimize the formulation and processing conditions of infrared-microwave combination baked soy-cakes.

Materials and methods

Materials

Commercially available cake flour containing 8 g dry gluten/100 g cake flour, 0.65 g ash/100 g cake flour and 13.5 g moisture/100 g cake flour was obtained from Ankara Un A.Ş., Turkey. Soy flour, sugar, non-fat dry milk, cake shortening, salt and baking powder were bought from a local market. Egg white powder was procured from Kitchen Crafts, Inc. (USA). Emulsifier DATEM was obtained from Ankara Halk Ekmek Fabrikası, Turkey.

Methods

Preparation of cake batter

A standard white layer cake batter recipe containing 100 g sugar/100 g cake flour, 25 g fat/100 g cake flour, 12 g non-fat dry milk/100 g cake flour, 9 g egg white powder/100 g cake flour, 3 g salt/100 g cake flour, 5 g baking powder/100 g cake flour and 90 g water/100 g cake flour was used in the experiments. For the preparation of cake batter 100 g wheat and soy flour mixture/100 g cake flour was used. The percentages of wheat and soy flour were adjusted as the following; 70 % wheat flour and 30 % soy flour, 60 % wheat flour and 40 % soy flour and 50 % wheat flour and 50 % wheat flour. Emulsifier, DATEM was added at a concentration of 0.4, 0.6 and 0.8 % on flour basis. All dry ingredients were mixed as a first step in preparation of the cake batter. Then, melted fat was added to the previously mixed sugar and egg white and mixed with a laboratory mixer/blender for 1 min at low speed (Toastermaster, 1776CAN, China). All other dry ingredients and water were added and mixed for 1 min at low speed, 1 min at medium speed, and 2 additional minutes at low speed.

Baking

Infrared-microwave combination baking was performed by using AdvantiumTM oven (General Electric Company, Louisville, KY, USA). It consists of two upper halogen lamps, one lower halogen lamp, a turntable and a microwave source. The cavity size of Advantium oven was 21 cm height, 48 cm length and 33 cm width (Sumnu et al. 2005). The microwave power of oven has been determined as 706 W by using IMPI

2-l test (Buffler 1993). For the infrared-microwave combination baking, the power levels of the upper (1500 W) and lower (1500 W) halogen lamps (IR source) were adjusted to 50 %, and the microwave power of 50 % were used. The levels of halogen lamp and microwave power were determined by preliminary experiments. Cakes were baked for 8, 9 and 10 min. In order to provide the required humidity during baking in the combination oven, two beakers containing 400 ml of water were placed at the back corners of the oven (Sevimli et al. 2005). It should be noticed that the water (800 ml) placed for humidity adjustment absorbed some of microwave power during baking. One cake (100 g) was placed at a time in the oven during baking process. The control cakes were baked in conventional oven at 175 °C for 24 min.

Experimental design

The optimum levels of soy flour, emulsifier content and baking time were determined by using RSM. A Box-Behnken design was preferred in this study. The effects of extraneous variables were minimized by randomizing the experiments. The independent variables were emulsifier content (X_1 ; 0.4, 0.6 and 0.8 %), soy-flour content (X_2 ; 30, 40 and 50 %) and baking time (X_3 ; 8, 9 and 10 min). The reason for selection of emulsifier DATEM content as independent variable was its significant positive effect on baking products. This positive effect was previously reported by several researchers (Seyhun et al.; 2003; Köhler and Grosch 1999). Soy flour content was chosen as the second independent variable to produce functional cakes. The health benefits of soy flour were frequently reported as it is given in “Introduction” section. The last independent variable for experimental design was baking time due its significant effect on quality of final product. The levels of these independent variables were determined by preliminary experiments and previous researches. Weight loss, specific volume, texture and total color change were chosen to be the dependent variables of this study since they are the most effective quality attributes in terms of consumer expectation. For convenience, the actual values were converted into coded variables. Table 1 gives the experimental design with uncoded and coded independent variables.

Determination of weight loss

Weight loss during baking was calculated using weight of the batter before it is placed into the oven (W_i) and weight of the baked cake immediately after it is removed from the oven (W_f) and the following equation (Sakiyan et al. 2007a):

$$\text{Weight loss}(\%) = \frac{W_i - W_f}{W_f} \times 100$$

Table 1 Experimental design for RSM

Factors					
X_1 (%)		X_2 (%)		X_3 (min)	
Coded	Uncoded	Coded	Uncoded	Coded	Uncoded
0	40	1	0.8	1	10
0	40	0	0.6	0	9
−1	30	0	0.6	−1	8
1	50	1	0.8	0	9
0	40	−1	0.4	1	10
0	40	0	0.6	0	9
−1	30	−1	0.4	0	9
0	40	0	0.6	0	9
1	50	0	0.6	1	10
1	50	0	0.6	−1	8
1	50	−1	0.4	0	9
−1	30	1	0.8	0	9
−1	30	0	0.6	1	10
0	40	−1	0.4	−1	8
0	40	1	0.8	−1	8

X_1 is soy flour concentration, X_2 is DATEM concentration, and X_3 is baking time

Color measurement

The surface color of cakes was determined by Minolta Color Reader (Minolta Inc., Model CR-10, Osaka, Japan) in terms of CIE Lab color parameters L^* (Lightness), a^* (redness/greenness), b^* (yellowness/blueness) following the method described by Xiao et al. (2009) with some modifications. The total color change (ΔE) was then calculated using the following equation (Bai et al. 2013);

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

Barium sulphate (white color) was used as the reference point, whose L^* , a^* , b^* value was denoted by L_0^* , a_0^* and b_0^* (Sumnu et al. 2005).

Texture measurement

Texture analyzer (Lloyd Ins., UK) was used for determination of the hardness of the cake samples. The cake samples (width of 20 mm, length of 30 mm and height of 15 mm) were compressed by 25 % of its initial height under the influence of a load cell of 50 N force. The cross head speed for texture measurement was 55 mm/min. The hardness value can be explained as the peak force of the first compression of the product (Sakiyan et al. 2007b).

Determination of specific volume

Cake specific volume was determined by the rape seed displacement method (AACC 1990). Equations (3), (4), and (5) were used to calculate the volume of cakes.

$$W_{\text{seeds}} = W_{\text{total}} - W_{\text{cake}} - W_{\text{container}} \quad (3)$$

$$V_{\text{seeds}} = W_{\text{seeds}} / \rho_{\text{seeds}} \quad (4)$$

$$V_{\text{cake}} = V_{\text{container}} - V_{\text{seeds}} \quad (5)$$

Specific volume of cakes were calculated by using the following equation,

$$SV_{\text{cake}} = V_{\text{cake}} / W_{\text{cake}} \quad (6)$$

where W (kg) is weight, V (m³) is volume, ρ (kg/m³) is density and SV (m³/kg) is the specific volume.

Statistical analysis

Minitab software version 16 (Minitab Inc., State College PA, USA) was used to fit second-order equations to all the dependent variables by multiple regression.

The second order model-equation given as Eq. 7 was used to fit the independent and dependent variables and examined for goodness of fit (Gao et al. 2008).

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_1^2 + b_5X_2^2 + b_6X_3^2 + b_7X_1X_2 + b_8X_1X_3 + b_9X_2X_3 \quad (7)$$

In this equation, X_i s are the independent variables (X_1 is soy flour concentration, X_2 is DATEM content, and X_3 is baking time), b_i s are the model constants, and Y s are dependent variables (specific volume, total color change, firmness,

and weight loss). The equations obtained from multiple regression were used to plot contour surfaces and optimum conditions were determined by performing multiple optimization by using response optimizer in Minitab Release 16 software. The significant difference between independent variables ($p \leq 0.05$) was determined by Analysis of variance. Duncan's multiple range test was utilized to compare variable means. The data were the average of three replicates.

Results and discussion

The model equations and coefficient of determination (r^2) for each dependent variable were given in Table 2. It was reported that in order to have a good fit model the minimum value for r^2 should be 80 % (Gan et al. 2007). The results showed that the models for all the response variables can be considered as good fit model due to their coefficient of determination which was more than 90 %. In order to measure the failure of a model to represent data in the experimental domain at which points were not included in the regression, the lack of fit test can be used (Varnalis et al. 2004). As it is given in Table 2 the lack of fit was insignificant for all the response variables.

Weight loss data is important because it is an index of moisture loss. It was shown in Table 2 that all baking time, DATEM concentration and soy flour concentration are significantly effective on weight loss of samples. As expected, the weight loss increased as the baking time increased because of higher moisture loss. When the other factors were constant, increasing baking time from 8 to 10 min, increased weight loss from 22.7 to 28.8 %. A similar result was obtained by Turabi et al. (2008). They reported that an increase in baking time resulted in an increase in weight loss values of rice-cakes. The second factor which was found significantly effective on weight loss values was soy flour concentration (Fig. 1). As it can be seen both from Table 2 and Fig. 1 there is a negative relation between soy flour concentration and weight loss. This negative correlation can be explained by higher water holding

Table 2 Regression equations for cakes with different formulations baked during different baking times in combination oven

Quality parameter	Equation	r^2	Lack of fit
Weight loss	$Y_1 = 27.2833^{***} - 0.6936^{**}X_1 - 0.4263^*X_2 + 2.6026^{***}X_3 - 0.9962^{**}X_1^2 - 1.0384^{**}X_2^2 - 1.2487^{**}X_3^2 - 0.1037^{ns}X_1X_2 + 0.3010^{ns}X_1X_3 - 0.0262^{ns}X_2X_3$	96.91	0.267 ^{ns}
Total color change	$Y_1 = 58.3728^{***} + 1.6641^{***}X_1 + 0.0716^{ns}X_2 + 3.9558^{***}X_3 - 0.5407^*X_1^2 + 0.1550^{ns}X_2^2 + 1.8106^{***}X_3^2 + 0.1075^{ns}X_1X_2 + 0.0533^{ns}X_1X_3 - 0.3022^{ns}X_2X_3$	99.11	0.594 ^{ns}
Specific volume	$Y_1 = 1.30497^{***} - 0.04634^{**}X_1 + 0.02243^*X_2 + 0.09863^{***}X_3 - 0.05883^{**}X_1^2 - 0.06608^{**}X_2^2 - 0.02389^{ns}X_3^2 - 0.00014^{ns}X_1X_2 + 0.01725^{ns}X_1X_3 + 0.00500^{ns}X_2X_3$	93.32	6.49 ^{ns}
Hardness	$Y_1 = 0.1528^{***} + 0.0090^{ns}X_1 - 0.0137^*X_2 + 0.0395^{***}X_3 + 0.0035^{ns}X_1^2 - 0.0099^{ns}X_2^2 + 0.0036^{ns}X_3^2 - 0.0109^{ns}X_1X_2 + 0.0097^{ns}X_1X_3 - 0.0029^{ns}X_2X_3$	85.51	15.65 ^{ns}

*The term is significant at $p \leq 0.05$

**The term is significant at $p \leq 0.01$

***The term is significant at $p \leq 0.001$

Fig. 1 Variation of weight loss of cakes with soy flour content and baking time

capacity of soy flour with respect to wheat flour. Water binding is a function of the protein and the fiber present in soy flour. Traynham et al. (2007) evaluated the water holding capacities of wheat-soy flour blends. They declared that wheat-soybean flour blends had greater water holding capacity than wheat flour and as the proportion of soybean flour increased the water holding capacity increased. DATEM concentration was the third factor. It was found that the correlation between weight loss and third factor is dominantly negative (Table 2 and Fig. 2). One of the common reasons of emulsifier usage in baking industry can be reported as capability of increasing water absorption of product (Stampfli et al. 1996). Its efficiency on moisture retention can be explained by high water binding capacity (Seyhun et al. 2003). Seyhun et al. (2003) reported that Purawave and DATEM were the most effective emulsifier types on moisture retention of microwave-baked cakes.

Before further discussion one should notice that change in total color is desirable in cake baking process. According to

Fig. 3 Variation of total color change of cakes with soy flour content and baking time

the multiple regression analysis, soy flour concentration and baking time are the significant factors which are effective on total color change of the soy-cake samples (Table 2, Figs. 3 and 4). When Fig. 4 is examined, it can be concluded that total color change was almost constant with changing DATEM concentration. For higher soy flour content, higher total color change values were obtained due to the presence of actual light brown color of the original soy flour. Soy flour contains about 6 % non-fermentable sugars. During baking these take part in the browning reaction of the crust, giving a more pleasing crust color (Stauffer 2008). Total color change values of cakes baked in infrared-microwave combination oven increased with baking time (Fig. 3). Infrared heating is known to provide low penetration depth and concentrate radiation at the surface, so the surface temperature can reach the required values for browning (Sakiyan 2007). In some other studies which are conducted on wheat flour and rice flour cakes baked in infrared-microwave combination oven, similar results were obtained (Sevimli et al. 2005; Turabi et al. 2008).

Fig. 2 Variation of weight loss of cakes with DATEM content and baking time

Fig. 4 Variation of total color change of cakes with DATEM content and baking time

Fig. 5 Variation of specific volume of cakes with soy flour content and baking time

Soy flour concentration, DATEM concentration and baking time were all found to be significantly effective on the specific volume of the cakes (Table 2). There is a negative correlation between soy flour concentration and specific volume (Fig. 5). The increase in soy flour concentration from 30 to 50 %, decreased specific volume from 1.2 m³/kg to 1.1 m³/kg. As shown in Fig. 6 when emulsifier content increased, specific volume of the cakes increased. This may be explained by the positive effect of emulsifier on the incorporation of the air to the cake batter thus producing a cake that expands readily. Moreover, emulsifier addition is known to improve the gas retention and to increase resistance of the cake to collapse. The similar results were obtained by several researchers (Turabi et al. 2008; Mohamed and Hamid 1998). According to the results of the study, an increase in baking time caused an increase in the specific volume of the cakes. When the cakes were baked for 8 min, the specific volume of the sample was calculated as 1.17 m³/kg. If the baking time was increased to 10 min by keeping the other factors constant, the specific

Fig. 6 Variation of specific volume of cakes with DATEM content and baking time

Fig. 7 Variation of hardness of cakes with soy flour content and baking time

volume was recalculated as 1.37 m³/kg. In another study, in which wheat-cakes were baked in microwave infrared combination oven, similar results were obtained (Sevimli et al. 2005).

The independent variables which are significantly effective on hardness of the cakes are DATEM concentration and baking time (Table 2). It was found that an increase in baking time ended up with an increase in hardness values of samples (Figs. 7 and 8). Actually, it was an expected result because as the baking time increased, the cakes were subjected to more microwave and IR radiation and so moisture loss increased (Figs. 1 and 2). The same results were reported by some other researchers too (Sevimli et al. 2005; Turabi et al. 2008; Demirkesen et al. 2011). The effect of soy flour concentration on hardness of samples was found to be insignificant (Table 2). On the other hand DATEM concentration was significantly effective (Fig. 8). The reason of negative correlation between hardness and emulsifier concentration may be related with specific volume of samples. As it was reported

Fig. 8 Variation of hardness of cakes with DATEM content and baking time

before DATEM concentration has a positive effect on specific volume of cakes. Since emulsifier addition is known to improve the gas retention and to increase resistance of the cake to collapse, production of puffer cakes is enabled. As the air entrapped in the structure increased, softer cakes were baked.

The response optimization tool in Minitab Release 16 software was utilized to find the optimum baking time, soy flour and emulsifier content. The optimum points were determined by considering minimum weight loss, maximum color change, minimum hardness and maximum specific volume. The software gave the optimum points of -1 for X_1 , 0.616 for X_2 and 0.737 for X_3 . The corresponding uncoded values of the optimum point were calculated as 30 % for soy flour concentration, 0.72 % for DATEM concentration and 9.5 min for baking time. The predicted responses at the optimum points can be listed as 0.1646 N for hardness, 26 % for weight loss, 59.9 for color change and 1.33 ml/g for specific volume. Additionally, hardness, weight loss, color change and specific volume data of control cakes were determined as 0.25 N, 10.51 %, 55.7 and 1.55 ml/g respectively. Cakes baked in combination oven were found to be almost comparable in quality with conventionally baked cakes. The only difference is between weight loss values of the samples and the control cakes. Weight loss of control cakes were found to be far less than that of combination baked cakes. Since it enables the production of high quality cakes in a very short time, infrared-microwave combination oven may be recommended to be used for soy-cake baking.

Conclusion

The study, performed for the optimization of formulation of soy cakes and conditions of combination baking, showed that RSM is really a helpful tool to detect the optimal levels of baking time, soy flour concentration and DATEM concentration without the necessity of testing all possible combinations. It was found that soy-flour concentration, DATEM concentration and baking time were significantly effective on weight loss and specific volume of soy cakes. A negative relation has been detected between soy-flour concentration and weight loss and specific volume. Additionally, an increase in DATEM concentration decreased weight loss and increased specific volume data of the samples. Moreover, longer baking time resulted in higher weight loss and higher specific volume values. DATEM concentration and soy flour concentration were the independent variables which were not significantly effective on total color change and hardness, respectively. On the other hand, total color change and hardness values were found to be positively affected by baking time. The optimum points were found as 30 % for soy flour concentration, 0.72 % for DATEM concentration and 9.5 min for baking time and the corresponding predicted responses were 0.1646 N for

hardness, 26 % for weight loss, 59.9 for color change and 1.33 ml/g for specific volume. Since the results for combination oven were almost comparable with those of conventional oven it may be declared that it is possible to produce high quality soy cakes in a very short time by using infrared-microwave combination oven.

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