

Dielectric properties, optimum formulation and microwave baking conditions of chickpea cakes

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Abstract The aim of this study was to correlate dielectric properties with quality parameters, and to optimize cake formulation and baking conditions by response surface methodology. Weight loss, color, specific volume, hardness and porosity were evaluated. The samples with different DATEM (0.4, 0.8 and 1.2%) and chickpea flour concentrations (30, 40 and 50%) were baked in microwave oven at different power (300, 350, 400 W) and baking times (2.50, 3.0, 3.50 min). It was found that microwave power showed significant effect on color, while baking time showed effect on weight loss, porosity, hardness, specific volume and dielectric properties. Emulsifier level affected porosity, specific volume and dielectric constant. Chickpea flour level affected porosity, color, hardness and dielectric properties of cakes. The optimum microwave power, baking time, DATEM level and chickpea flour level were found as 400 W, 2.84 min, 1.2% and 30%, respectively. The comparison between conventionally baked and the microwave baked cakes at optimum points showed that color difference, weight loss, specific volume and porosity values of microwave baked cakes were less than those of conventionally baked cakes, on the other hand, hardness values were higher. Moreover, a negative correlation between dielectric constant and porosity, and weight loss values were detected for microwave baked samples. A negative correlation between dielectric loss factor and porosity was observed. These correlations indicated that quality characteristics of a microwave baked cake sample can be assessed from dielectric properties. These

correlations provides understanding on the behavior of food material during microwave processing.

Keywords Microwave baking · Chickpea flour · Dielectric properties · Optimization · RSM

Introduction

Pulses, like bean and chickpea are significant crops in all over the world due to their nutritional quality (Arab et al. 2010). Protein, complex carbohydrates, fibre, vitamins and minerals which are essential for the diet are included in legumes. They are low in fat and sodium, besides, they do not contain cholesterol. Pulses have been identified as low glycemic index foods that has attributed to their high amylose content (Tiwari and Singh 2012). Chickpea (*Cicer arietinum* L.) is considered as the 5th valuable legume in terms of worldwide economical standpoint (Ionescu et al. 2009). There are several studies in literature which are focused on the incorporation of chickpea flour to the basic recipe of various bakery products such as cakes (Gomez et al. 2008), cookies (Faheid and Hegazi 1991) pasta (Goni and Valentin-Gamazo 2003; Wood 2009), bread (Abdel-Aal et al. 1987; Hatzikamari et al. 2007; Coda et al. 2010), extruded snack products (Shirania and Ganesharane 2009; Meng et al. 2010), bakery fillings (Klamczynska et al. 2001) and crackers (Kohajdova et al. 2011). In this research, in order to produce functional cake, chickpea flour was added to the formulation with different concentrations.

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,

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evaporation of water, crust formation and browning reactions (Sakiyan et al. 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). The advantages of microwave processing lead the researchers to investigate some alternative solutions to overcome these quality problems. Suggesting new formulations and baking conditions can be a promising method to solve above drawbacks. Integration of emulsifiers to the regular recipe is a common method in bakery production. Until the cake structure is set, emulsifiers have the ability to provide the necessary aeration and gas bubble stability during the process (Turabi et al. 2008). Their function of reducing interfacial tension between oil and water droplets makes the sequencing of oil droplets easier (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. As it was mentioned, optimizing the formulation, which is one of the primary factors effective on quality of cake samples and optimizing the baking conditions can be a solution for these troubles. 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. 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; Sakiyan 2015).

Dielectric properties (dielectric constant and dielectric loss factor) of a material have a vital effect on the interaction between electromagnetic energy and the material itself, for this reason, it is important to have knowledge about the dielectric properties of the material to control the process. Dielectric constant signifies the ability to store electric energy and the dielectric loss factor signifies the ability to convert electric energy into heat. There are limited studies in literature about dielectric properties of the food materials. Sakiyan et al. (2007) investigated the variation of dielectric properties of different cake formulations during baking in microwave and infrared-microwave combination oven. Similarly, the effects of different gums on dielectric properties and quality of rice cakes baked in infrared-microwave combination oven were

studied by Turabi et al. (2010). Dielectric properties of microwave-baked cakes and its constituents over a frequency range of 0.915–2.450 GHz were also examined by Al-Muhtaseb et al. (2010).

This study was conducted to optimize cake formulation and baking conditions in terms of quality parameters and dielectric properties of baked cakes. The other objectives were to find a correlation between dielectric properties and quality parameters of the cakes, to formulate functional cake by adding chickpea flour and to study the effect of emulsifying agent DATEM on quality of cakes during microwave heating.

Materials and methods

Materials

Chickpea flour having 9.37% moisture, 21.77% protein and 3.02% ash was obtained from a local market. Wheat flour containing 11.83 % moisture, 9.52% protein, 20.1% wet gluten, 6.8% dry gluten and 0.6% ash was supplied by Ülker Biscuit Factory (Ankara, Turkey). Salt, nonfat dry milk, cake shortening, sugar, baking powder and egg white powder were bought from a local market. Emulsifier was obtained from Pakmaya (Ankara, Turkey).

Preparation of cake batter

A white layer cake batter recipe containing 100 g sugar/100 g cake flour, 12 g nonfat 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. Depending on the cake formulation different chickpea/wheat flour ratios (30:70, 40:60 and 50:50) were added. Fat was inserted to the formulation with an amount of 25 g fat/100 g cake flour. DATEM concentration of the cake samples varied as 0.40/100 g cake flour, 0.80/100 g cake flour and 1.20/100 g cake flour. The control cakes had no emulsifier and they are chickpea flour free. First, all dry ingredients were mixed. Fat was melted, cooled down to the room temperature and added to the previously mixed sugar and egg white, and mixed with a mixer for 1 min at 75 rpm (Arçelik, K 1433, Turkey). All other dry ingredients and water were added and mixed for 1 min at 75 rpm, 1 min at 125 rpm, and 2 more min at 75 rpm. 100 g of cake batter was weighed in a glass baking pan (8 cm in diameter).

Conventional baking

Conventional baking was performed in a conventional oven (Arçelik, Turkey) at 175 °C for 25 min. The oven

was preheated for 3 min before placing the cake samples in it. Three samples were baked at a time. Conventionally baked cakes were used as control.

Microwave baking

A microwave oven (Bosch, Germany) was used. The power of the microwave oven had been determined as 805 W by using IMPI 2-liter test (Buffler 1993). Cake samples were baked at 300, 350 and 400 W microwave power for 2.5, 3.0 and 3.5 min. One sample (100 g) was baked at a time.

Experimental design

Response surface methodology was employed as an optimization tool to determine the effects of chickpea/wheat flour ratio, emulsifier content and baking conditions on the quality parameters and dielectric properties of cakes. There were four independent variables each having three levels, which were microwave power (X_1 300, 350 and 400 W), baking time (X_2 2.50, 3 and 3.50 min), emulsifier content (X_3 0.40, 0.80 and 1.20% of flour weight) and chickpea/wheat flour ratio (X_4 30:70%, 40:60%, and 50:50%) (Table 1). The levels of these variables were determined by preliminary experiments. To study the main effects and interactions Box-Behnken design was used. For convenience, the actual values were converted into coded values. The coded and uncoded (actual) levels of the independent variables used in the experiments are given in Table 1. In this design, the experiments were randomised to minimise the effects of extraneous variables.

Determination of batter density

Batter density was determined by using a graduated cylinder (Gomez et al. 2008).

Determination of dielectric properties

The dielectric properties of ingredients, different formulated batters and cake samples were measured by using a network analyzer (Agilent Technologies ES061B ENA Series Network Analyzer, ABD) with an open-ended coaxial line connected to a dielectric probe. The network analyzer was calibrated with air, metallic short and distilled water at 25 °C. Dielectric properties of ingredients, cake batter and cake samples were measured at room temperature. All measurements were done in triplicate

(Al-Muhtaseb et al. 2010). The penetration depth was calculated by using the following equation;

$$D_p = \frac{c}{\sqrt{2\pi f \left[2\epsilon' \left\{ 1 + \sqrt{\left(\frac{\epsilon''}{\epsilon'} \right)^2 - 1} \right\} \right]^{1/2}}} \quad (1)$$

where c is the velocity of light given as 3×10^8 m/s.

Cake analysis

The percentage weight loss of the cakes were calculated by measuring the weights of the cake samples before (W_0) and after the baking process (W_1) (Eq. 2). The data was the average of 3 replicates (Turabi et al. 2008).

$$(\%) \text{Weight Loss} = \frac{W_0 - W_1}{W_0} \times 100 \quad (2)$$

The upper surface color of the cakes were measured by using Minolta Color Reader (CR-300, Japan) and expressed as the Hunter 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. Color difference (ΔE) was calculated from Eq. 3;

$$\Delta E = \left[(L_0 - L)^2 + (a_0 - a)^2 + (b_0 - b)^2 \right]^{1/2} \quad (3)$$

Barium sulphate was selected as reference point and its L, a, and b values were represented as L_0 , a_0 , and b_0 (Ozkahraman et al. 2016).

Baked cake samples were cut into two halves vertically. The image of the cut sample was taken by using a digital camera (Nikon Coolpix S2600, Japan). The images were analyzed by using the software Image J (Image Processing and Analysis in Java) that uses the contrast between the two phases (pores and solid part) in the image. The color image was first converted to gray scale. Using bars of known lengths, pixel values were converted into distance units. The largest possible rectangular cross-section of the cake halves was cropped. After adjusting the threshold, the porosity was determined by using the software (Demirkesen et al. 2011).

Specific volume of cake samples were measured by using rape seed displacement method (AACC 1990).

Hardness (N) of cake samples were measured using a texture analyzer (TAPlus, Lloyd Instruments LR 30K, UK) (AACC 1990). Samples having dimensions of 30, 30 and 20 mm were cut from the central regions of the cakes and were compressed to 25% of their original thickness at a speed of 55 mm/min. A cylindrical probe with a diameter of 1.27 mm and a load cell of 50 N were used.

Table 1 Experimental design for RSM and experimental data for cakes

X ₁ (W)		X ₂ (min)		X ₃ (%)		X ₄ (%)	
Coded	Uncoded	Coded	Uncoded	Coded	Uncoded	Coded	Uncoded
0	350	0	3.0	-1	0.4	1	50
-1	300	-1	2.5	0	0.8	0	40
0	350	-1	2.5	-1	0.4	0	40
0	350	1	3.5	-1	0.4	0	40
0	350	0	3.0	0	0.8	0	40
1	400	0	3.0	0	0.8	1	50
0	350	-1	2.5	0	0.8	-1	30
1	400	0	2.5	1	1.2	0	40
0	350	1	3.5	1	1.2	0	40
1	400	1	3.5	0	0.8	0	40
-1	300	1	3.5	0	0.8	0	40
0	350	0	3.0	0	0.8	0	40
1	400	0	3.0	-1	0.4	0	40
0	350	1	3.5	0	0.8	-1	30
0	350	-1	2.5	0	0.8	1	50
0	350	-1	2.5	1	1.2	0	40
1	400	-1	2.5	0	0.8	0	40
0	350	0	3.0	0	0.8	0	40
0	350	0	3.0	-1	0.4	-1	30
0	350	0	3.0	1	1.2	-1	30
-1	300	0	3.0	1	1.2	0	40
-1	300	0	3.0	0	0.8	1	50
1	400	0	3.0	0	0.8	-1	30
0	350	0	3.0	0	0.8	0	40
-1	300	0	3.0	-1	0.4	0	40
0	350	1	3.5	0	0.8	1	50
-1	300	0	3.0	0	0.8	-1	30
0	350	0	3.0	1	1.2	1	50

X₁ Microwave power, X₂ baking time, X₃ DATEM content, X₄ chickpea flour content

Multiple regression analysis was performed to fit second order models to dependent variables by using Minitab Release 16 (Minitab Inc., State College PA, USA). The models were used to plot contour lines and optimum conditions were determined by performing multiple optimization by using response optimizer in Minitab release 16 software. Since, high specific volume and soft texture and brown crust color are required quality characteristics for cakes, maximum color difference, minimum hardness, maximum specific volume and maximum porosity values were selected for optimization. The significant difference between independent variables ($p \leq 0.05$) was determined by Analysis of Variance. The correlation between dielectric properties and quality parameters were also detected by using Minitab release 16 software. The data were the average of three replicates.

Results and discussion

Analysis of raw materials and batter samples

The dielectric properties of ingredients and dielectric properties and densities of different formulated cake batters are reported in Tables 3 and 4. Shortening and water had the highest dielectric properties with a dielectric constant of 4.45 and 70.48, respectively and dielectric loss factor of 0.63 and 9.2, respectively. On the other hand DATEM had the lowest dielectric properties with a dielectric constant of 1.43 and dielectric loss factor of 0.017.

Cake ingredients showed significant effects on the dielectric properties and densities of different formulated cake batter samples (Table 4). Although the effect of chickpea flour concentration on dielectric constant was

Table 2 Regression equations for baked cakes

Quality parameter	Equation	r ²	Lack of fit
Weight loss	$Y_1 = 9.0036^* + 0.0583X_1 + 3.3823^*X_2 + 0.0632X_3 + 0.1777X_4 - 0.7089X_1^2 + 1.8944^*X_2^2 - 0.7946X_3^2 + 1.3718^*X_4^2 + 0.0494X_1X_2 - 0.6981X_1X_3 + 0.0857X_1X_4 - 0.0995X_2X_3 - 2.8252^*X_2X_4 + 0.0269X_3X_4$	91.03	7.97**
Total color change	$Y_2 = 58.7210^* - 0.8761^*X_1 - 0.1981X_2 + 0.5482X_3 - 1.5821^*X_4 - 0.3913X_1^2 - 1.0461X_2^2 + 1.4338^*X_3^2 + 2.4371^*X_4^2 + 0.2765X_1X_2 + 0.2557X_1X_3 - 0.5526X_1X_4 + 2.2745^*X_2X_3 - 0.5794X_2X_4 - 2.7823^*X_3X_4$	85.25	0.86**
Specific volume	$Y_3 = 1.9001^* - 0.0061X_1 + 0.1219^*X_2 - 0.1796^*X_3 - 0.0345X_4 + 0.0092X_1^2 - 0.0225X_2^2 - 0.0892^*X_3^2 - 0.1087^*X_4^2 + 0.0243X_1X_2 + 0.0677X_1X_3 - 0.0605X_1X_4 - 0.0438X_2X_3 - 0.0010X_2X_4 - 0.2095^*X_3X_4$	89.19	3.48**
Hardness	$Y_4 = 0.5093^* + 0.0367X_1 + 0.2572^*X_2 + 0.0196X_3 + 0.0741^*X_4 + 0.0181X_1 + 0.2776^*X_2^2 - 0.1062X_3^2 + 0.0128X_4^2 - 0.1197^*X_1X_2 - 0.0477X_1X_3 + 0.0278X_1X_4 - 0.0578X_2X_3 - 0.0135X_2X_4 - 0.0074X_3X_4$	92.74	0.93**
Porosity	$Y_5 = 26.2175^* + 0.5325X_1 + 1.3925^*X_2 + 1.2879^*X_3 - 1.9520^*X_4 - 0.3429X_1^2 + 1.3709^*X_2^2 - 0.5671X_3^2 - 1.7270^*X_4^2 - 1.0385X_1X_2 + 0.5264X_1X_3 + 0.2094X_1X_4 + 1.2386X_2X_3 + 0.9700X_2X_4 + 0.2439X_3X_4$	89.14	0.65**
Dielectric constant	$Y_6 = 10.3965^* + 0.6747X_1 - 1.2189^*X_2 + 0.8627^*X_3 + 1.1913^*X_4 + 0.7176X_1^2 - 1.5489^*X_2^2 + 0.2410X_3^2 + 0.5648X_4^2 + 1.4369^*X_1X_2 + 2.1053^*X_1X_3 + 1.2967^*X_1X_4 - 0.0249X_2X_3 - 0.2968X_2X_4 - 1.2399^*X_3X_4$	87.31	6.45**
Dielectric loss factor	$Y_7 = 2.9105^* + 0.2952X_1 - 0.4004^*X_2 + 0.2580X_3 + 0.5951^*X_4 + 0.4322X_1^2 - 0.2401X_2^2 + 0.6360^*X_3^2 + 0.5317^*X_4^2 + 1.100^*X_1X_2 + 0.8901^*X_1X_3 + 0.7330^*X_1X_4 - 0.5485X_2X_3 - 0.0805X_2X_4 - 0.4868X_3X_4$	87.21	1.00**

X_1 Microwave power, X_2 baking time, X_3 DATEM content, X_4 chickpea flour content

* Significant at $p \leq 0.05$

** Not significant at $p \leq 0.05$

found to be insignificant, an increase in DATEM concentration resulted in a decrease in the dielectric properties. This may be explained by the higher amount of air entrapped in the structure. The effect of cake formulation was not significant on penetration depth of the batter samples. Since there was no statistical difference between formulations in terms of penetration depth, the homogeneity of the microwave baking did not differ for each sample. Both chickpea flour concentration and DATEM concentration showed significant effect on density values of the batter samples. As the chickpea flour concentration increased, the density of the batter increased. It was reported by Gomez et al. (2008) that the presence of chickpea flour decreased air incorporation in the batter which resulted in samples with higher density. On the other hand, due air entrapment affect of emulsifier, as the DATEM concentration increased, a decrement in density values of the sampled was observed.

Analysis of microwave baked different formulated cake samples

The second order model-equation given as Eq. 4 was used to fit the independent and dependent variables and examined for goodness of fit.

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_1^2 + b_6X_2^2 + b_7X_3^2 + b_8X_4^2 + b_9X_1X_2 + b_{10}X_1X_3 + b_{11}X_1X_4 + b_{12}X_2X_3 + b_{13}X_3X_4 \quad (4)$$

In this equation, X_i 's are the independent variables (X_1 is microwave power, X_2 , baking time; X_3 , emulsifier level; and X_4 , chickpea flour level), b_i 's are the model constants, and Y 's are dependent variables (specific volume, total color difference, hardness, weight loss, porosity, dielectric constant and dielectric loss factor). The second order equations, the model constants and coefficient of determination values of each dependent variable were given in Table 2.

It was reported that R^2 should be at least 80% for a good fit model (Gan et al. 2007). The results showed that the models for all the response variables were adequate because they had satisfactory R^2 (as >85%). 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 is insignificant for all response variables.

According to the multiple regression analysis, baking time was found to be the only significant factor which showed significant effect on the weight loss of cake (Table 2; Fig. 1). When baking time increased, weight loss of the cakes increased too. When the other factors were constant, increasing baking time from 2.50 to 3.50 min, increased weight loss from 5.50 to 13%. Similar results have also been reported by other researchers (Demirekler 2004; Turabi et al. 2008; Sakiyan 2015). This trend can be related to longer contact time of sample with microwaves. As a result of longer contact time more water vapor evaporated. Moreover, high moisture loss in microwave

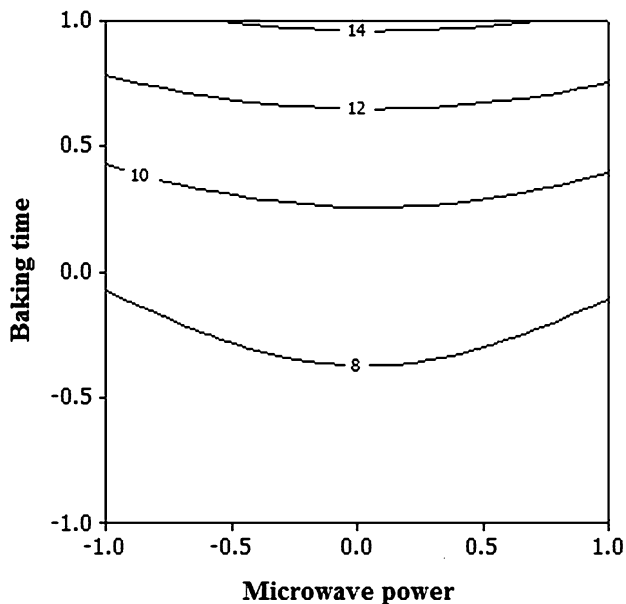


Fig. 1 Effect of microwave power and baking time on weight loss ($X_3 = 0$, $X_4 = 0$)

baked products can be explained by high pressure and moisture gradients in microwave baked products as compared to conventional baking (Datta 1990; Cauvain 1998).

Color values showed that both microwave power and chickpea flour content had a significant negative effect on color differences of the samples (Table 2). It is thought that decreasing L values is the main cause of this negative correlation. An increase in chickpea flour level darkened the color of samples. Gomez et al. (2008) had also reported a similar relation. Additionally, when these values were compared with the ones for control cakes, it can easily be detected that they were far more smaller than color difference values of conventionally baked samples. It is a known fact that, lack of maillard reactions on the surface of cakes is one of the drawbacks of microwave mechanism. This disadvantage resulted in less surface color formation. Sumnu et al. (2005) had reported similar results. They found that control cakes had ΔE value of 67.8 and ΔE values of microwave baked cakes were about 37% lower than the control cakes even at the end of baking. And they explained this result by short baking times and low temperatures common in microwave processing and lack of browning reactions.

Emulsifier (DATEM) concentration and baking time were found to be significantly effective on the specific volume of the cakes (Table 2). When the cakes were baked for 2.50 min, the specific volume of the sample was calculated as 1.5780 m³/kg. If the baking time was increased to 3.50 min by keeping the other factors constant, the specific volume was recalculated as 2.1163 m³/kg. The

positive correlation between baking time and specific volume can be explained by the necessity of the air bubbles in the batter to form the porous structure of the cake. As the baking time increases, the air bubbles in the structure expands and forms the expected porous structure. Sakiyan (2015) reported that an increase in baking time increased the specific volume of microwave baked cakes. DATEM showed negative effect on specific volume. The increase in DATEM concentration from 0.4 to 1.2%, decreased specific volume from 1.5780 m³/kg to 1.4287/kg. This inverse relation between emulsifier content and specific volume indicated that DATEM was not a good selection for microwave baked chickpea flour cakes. Although it was found that chickpea flour level did not show significant effect on specific volume of the cake samples, it had a significant positive affect on hardness. This contradiction may be explained by the fiber and moisture content of the samples. Although the specific volume decrease was not significant with an increment in chickpea flour level, the hardness increase was found to be significant due to higher amount of fiber content and lower moisture content of the samples. Similarly, in contradiction to the non-significant affect of chickpea flour level on specific volume, it was found to be negatively related to porosity. It is known that specific volume and porosity were correlated, but in the case of microwave baking previously reported nonhomogeneous pore size distribution (Şakiyan et al. 2008) can be the main reason for this contradiction. Singh et al. (2016) reported that specific volume of muffins decreased with black carrot fiber incorporation. They attributed this decrease to the presence of fibres in black carrot dietary fibre which might have collapsed the carbon dioxide gas bubbles during baking and caused reduction in the volume.

The other quality parameter which was examined in the study was hardness of samples. The model derived for hardness data showed that baking time and the chickpea flour concentration are the two parameters which had significant effect on hardness (Table 2). An increase in baking time significantly increased the hardness values which might be related with moisture loss (Fig. 2). While chickpea flour content increased, hardness of cakes also increased. Gomez et al. (2008) reported similar results. The reason of this effect may be related to absence of gluten in chickpea flour. Due to lack of gluten, chickpea flour decreased protein matrix complex during baking. This caused to decrease pore structure. As a result of these facts, the cakes with higher chickpea flour concentration was found to be firmer. In addition, firm texture in the presence of chickpea flour can be explained by fiber content, too. Wang et al. (2010) reported the fiber content of chickpeas as 15.4–24.6%. It was known that, higher amount of fiber content resulted in higher hardness values of the samples (Gomez et al. 2010; Yamsaengsung et al. 2010).

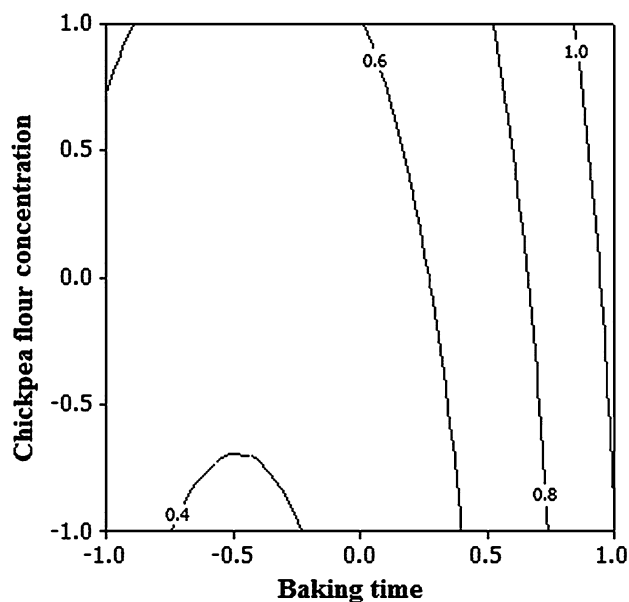


Fig. 2 Effect of chickpea flour concentration and baking time on hardness ($X_1 = 0$, $X_3 = 0$)

The results of our experimental set up showed that baking time, DATEM level and chickpea flour level significantly affected porosity values (Table 2). While baking time and DATEM level were positively related to porosity while, chickpea flour was negatively related. The correlation between baking time and porosity can be explained by the necessity of the air bubbles in the batter to form the porous structure of the cake. As the baking time increased, the air bubbles in the structure expanded and caused an increase in the porosity. Additionally, positive effect of emulsifier on the porosity may be due to the positive effect of emulsifier on the incorporation of the air to the cake batter thus producing a cake that expanded readily. Moreover, emulsifier addition was known to improve the gas retention and to increase resistance of the cake to collapse (Turabi et al. 2008; Mohamed and Hamid 1998). The negative effect of chickpea flour level on porosity values can be explained by the batter density values. As it was discussed earlier, there was a significant effect of formulation on batter densities (Table 4). An increase in chickpea flour level increased the density of the batter which resulted in less air incorporation in the batter. Gomez et al. (2008) also reported that there was a positive relation between chickpea flour concentration and density causing less porous cakes. Moreover, Ozkahraman et al. (2016) found that addition of legume flour decreased the number of pores at the legume based cakes baked in microwave-infrared combination oven.

The effect of baking time and chickpea flour level showed significant effect on dielectric properties (Table 2). The increase in baking time decreased

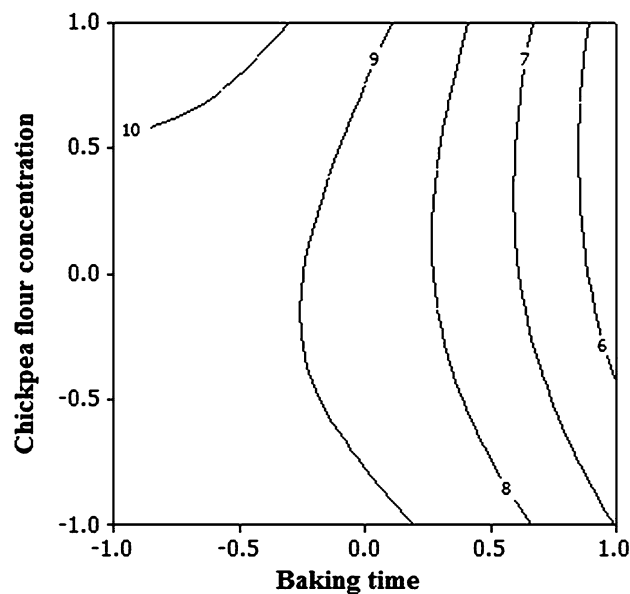


Fig. 3 Effect of chickpea flour concentration and baking time on dielectric constant ($X_1 = 0$, $X_3 = 0$)

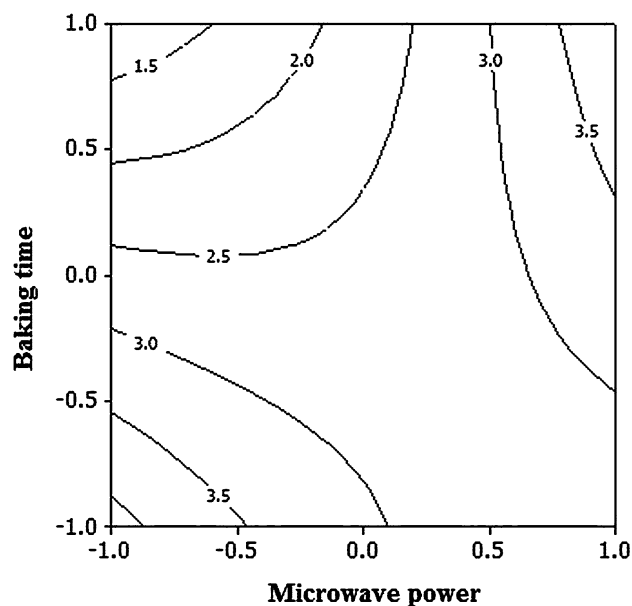


Fig. 4 Effect of microwave power and baking time on dielectric loss factor ($X_3 = 0$, $X_4 = 0$)

dielectric constant and loss factor of all formulations (Figs. 3, 4). This can be explained by the variation of the porosity of samples during baking (Table 2). As baking time increased porosity of the samples increased. Thus, the presence of more air decreased the dielectric properties. Another reason for the decrement in dielectric constant and loss factor was the increase of weight loss or in other words the reduction of moisture content of the samples as the baking time increased (Fig. 1). The

moisture content of the sample is quite important for microwave heating because of its dipolar mechanism. When there is much free water in the system, electric field will see more polarized dipole moments per unit volume of the sample (Sakiyan et al. 2007). The effect of chickpea flour concentration on both dielectric constant and loss factor were positive. This may be due to the fact that chickpea flour as a raw material had high dielectric properties (Table 3). Moreover, this may also be explained by the batter density values and consequently, porosity values. An increase in chickpea flour level increased the density of the batter which resulted in less air incorporation in the batter, thus led to increase in dielectric properties. As it was discussed so far, there found to be a negative correlation between dielectric constant and porosity and weight loss with correlation coefficients of -0.405 ($p = 0.033$) and -0.732

($p = 0.000$), respectively. Moreover, a negative correlation between dielectric loss factor and porosity was observed ($r = -0.464$, $p = 0.013$). These correlations indicated relationship of quality characteristics of a microwave baked cake with dielectric properties. In addition, these correlations may help in understanding the behavior of food material during microwave processing.

Optimization of the formulation and baking conditions

The response optimization tool in Minitab Release 16 software was utilized to find the optimum microwave power, baking time, emulsifier content and chickpea flour content. The optimum points were determined by considering minimum weight loss within a range of 5.6239–13.8813%, maximum color difference within a

Table 3 Dielectric properties of cake batter ingredients at 2450 MHz and 25 °C

Ingredient	Dielectric constant	Dielectric loss factor	Penetration depth (cm)
DATEM	1.4259 ± 0.0720	0.0168 ± 0.0020	1.9794 ± 0.2100
Baking powder	1.7144 ± 0.3070	0.0355 ± 0.0100	1.0746 ± 0.2000
Chickpea flour	2.2590 ± 0.1000	0.1129 ± 0.0100	0.3695 ± 0.0270
Sugar	1.5942 ± 0.1200	0.0024 ± 0.0007	9.4064 ± 0.0120
Water	70.4842 ± 2.2400	9.2665 ± 0.1800	0.0250 ± 0.0008
Milk powder	1.6816 ± 0.2100	0.0365 ± 0.0120	1.0620 ± 0.2520
Salt	1.9540 ± 0.0040	0.0410 ± 0.0030	0.9395 ± 0.0098
Wheat flour	2.0722 ± 0.1900	0.1396 ± 0.032	0.2996 ± 0.0670
Egg white powder	1.6656 ± 0.2200	0.0257 ± 0.0045	1.4057 ± 0.1460
Shortening	4.4570 ± 0.0290	0.6330 ± 0.0055	0.0920 ± 0.0030

Table 4 Density values and dielectric properties different cake batter formulations

Chickpea flour (%)	Dattem (%)	Dielectric constant	Dielectric loss factor	Penetration depth (cm)	Density (g/cm ³)
0	0	(14.2429 ± 0.5073) ^{ac}	(6.6332 ± 0.2844) ^{ac}	(0.0161 ± 0.0004) ^a	(1.2693 ± 0.0033) ^{cd}
0	0.4	(12.6446 ± 0.6004) ^{ab}	(5.7263 ± 0.3390) ^{ab}	(0.0175 ± 0.0006) ^a	(1.2484 ± 0.0077) ^{ce}
0	0.8	(11.3861 ± 0.4945) ^{abc}	(5.7732 ± 0.2569) ^{abc}	(0.0166 ± 0.0003) ^a	(1.2150 ± 0.0100) ^{cf}
0	1.2	(11.9610 ± 0.8856) ^{abc}	(6.0192 ± 0.5022) ^{abc}	(0.0163 ± 0.0007) ^a	(1.1816 ± 0.0124) ^{cg}
30	0	(11.6638 ± 1.4379) ^{ac}	(5.8105 ± 0.7896) ^{ac}	(0.0168 ± 0.0012) ^a	(1.2917 ± 0.0145) ^{cd}
30	0.4	(14.8770 ± 0.0684) ^{ab}	(7.1497 ± 0.0946) ^{ab}	(0.0015 ± 0.0002) ^a	(1.2202 ± 0.0008) ^{ce}
30	0.8	(14.1606 ± 0.7891) ^{abc}	(6.6907 ± 0.4697) ^{abc}	(0.0016 ± 0.0006) ^a	(1.1984 ± 0.0060) ^{cf}
30	1.2	(13.4360 ± 0.5715) ^{abc}	(6.2795 ± 0.3262) ^{abc}	(0.0165 ± 0.0005) ^a	(1.1916 ± 0.0050) ^{cg}
40	0	(10.2163 ± 1.4379) ^{ac}	(4.9949 ± 0.5783) ^{ac}	(0.0182 ± 0.0011) ^a	(1.3062 ± 0.0061) ^{bd}
40	0.4	(14.4464 ± 0.5224) ^{ab}	(6.8612 ± 0.3150) ^{ab}	(0.0156 ± 0.0004) ^a	(1.2677 ± 0.0021) ^{be}
40	0.8	(14.0564 ± 0.5720) ^{abc}	(6.6451 ± 0.3060) ^{abc}	(0.0159 ± 0.0004) ^a	(1.2342 ± 0.0019) ^{bf}
40	1.2	(11.9136 ± 2.1099) ^{abc}	(5.4962 ± 1.0503) ^{abc}	(0.0181 ± 0.0022) ^a	(1.2154 ± 0.0016) ^{bg}
50	0	(11.6012 ± 0.7928) ^{ac}	(5.7467 ± 0.3086) ^{ac}	(0.0168 ± 0.0003) ^a	(1.3338 ± 0.0046) ^{ad}
50	0.4	(15.6476 ± 2.9922) ^{ab}	(7.2607 ± 1.2846) ^{ab}	(0.0155 ± 0.0012) ^a	(1.3028 ± 0.0030) ^{ae}
50	0.8	(14.3998 ± 0.2156) ^{abc}	(6.8130 ± 0.0795) ^{abc}	(0.0157 ± 0.0001) ^a	(1.2798 ± 0.0038) ^{af}
50	1.2	(13.7292 ± 0.5287) ^{abc}	(6.5156 ± 0.3056) ^{abc}	(0.0161 ± 0.0004) ^a	(1.2401 ± 0.0075) ^{ag}

Columns with different letters (a, b i.e.) are significantly different ($p \leq 0.05$)

range of 55.7076–63.554, minimum hardness within a range of 0.2451–1.1954 N, maximum specific volume within a range of 1.3485–2.1484 ml/g and maximum porosity within a range of 19.3085–31.8130%. The optimum points were obtained as 1 for X_1 , -0.3131 for X_2 , 1 for X_3 and -1 for X_4 . The corresponding uncoded values of the optimum point were calculated as 400 W for microwave power, 2.84 min baking time, 1.2% for DATEM concentration and 30% for chickpea flour concentration. The predicted responses at the optimum points can be listed as 0.35 N for hardness, 6.19% for weight loss, 63.49 for color difference, 1.86 ml/g for specific volume and 27.36% for porosity. Additionally, hardness, weight loss, color difference, specific volume and porosity data of control cakes were determined as 0.12 N, 10.24%, 77.13, 1.94 ml/g and 48.67% respectively. It was found that color difference, weight loss, specific volume and porosity values of microwave baked cakes were less than those of control cakes, on the other hand, hardness values were higher. Although, microwave baking enables the production of cakes in a very short time, it needs further development to overcome these quality problems.

Conclusion

The study was performed to obtain a correlation between dielectric properties and quality parameters and to optimize the formulation of chickpea flour cakes and conditions of microwave baking. The results showed that there was a negative correlation between dielectric constant and porosity and dielectric constant and weight loss. In addition, a negative correlation between dielectric loss factor and porosity was detected. It can be reported that RSM is really a helpful tool to detect the optimal levels of microwave power, baking time, chickpea flour concentration and DATEM concentration without the necessity of testing all possible combinations. The optimum points were obtained as 400 W for microwave power, 2.84 min baking time, 1.2% for DATEM concentration and 30% for chickpea flour concentration. Although, microwave baking enables the production of cakes in a very short time, it needs further development to overcome quality problems. For this purpose, dielectric properties can easily be used.

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