Investigation of dielectric properties, total phenolic content and optimum formulation of microwave baked gluten-free cakes

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Abstract This study discusses the production of microwave baked gluten-free cakes formulated by mixing buckwheat flour and rice flour at different concentrations. Three different ratios of buckwheat flour to rice flour (20:80%, 30:70%, 40:60%) and two different gum types (xanthan and guar gum) with a white layer cake recipe were employed. The batters were baked in microwave oven at different microwave powers (540 W, 450 W, 360 W) for different baking times (3 min, 3.5 min, 4 min). The effect of microwave power, baking time and buckwheat flour concentration on weight loss, color, specific volume, porosity, total phenolic content and dielectric properties were investigated. The optimum microwave power, baking time and buckwheat flour concentration were found as 432.77 W, 3 min, 40% for guar gum added cakes and 360 W, 3.70 min and 29.23% for xanthan gum added ones. It was found that weight loss and color values of the cakes that were baked at the optimal conditions were less than those of control cakes. On the other hand, total phenolic content, specific volume, porosity, dielectric constant and dielectric loss factor values were higher for guar gum added cakes compared to control samples. In addition, it was observed that the cakes prepared with guar gum had similar pore size distribution with control cakes. As a conclusion of the study, it can be declared that surface color and specific volume problems of microwave baking

could be solved by addition of guar gum to the formulation which also enables the production of functional, phenolic rich microwave baked cakes.

Keywords Microwave baking · Buckwheat flour · Gums · Dielectric properties

Introduction

Celiac disease, which is also known as gluten sensible intestine illness, is one of the most widespread food intolerances. The number of patients having celiac disease is estimated as one out of 85–500 in Europe, which changes depending on the country (Turabi et al. 2008). In Turkey, it is predicted that the frequency of patients is one of every 150 people. Celiac patients must have a lifelong gluten-free diet. In the light of all these facts, it is clear that development of gluten free products has a growing importance.

Buckwheat (*Fagopyrum esculentum Moench*), which is a functional food with its high amount of phenolic compounds (four flavonol glycosides including rutin, quercetin, kaemferol-3-rutinoside and a trace amount of a flavanol triglycoside), is a traditional crop in Asia and Europe (Tian et al. 2002). Buckwheat is a highly nutritious pseudo-cereal. It contains protein (which includes essential amino acids), vitamins, starch, dietary fiber, essential minerals, and trace elements (Altindag et al. 2015). Nowadays, scientists' interest to buckwheat has increased due to its preventive properties in chronic human diseases. Moreover, it can be considered as a potential ingredient for gluten-free diet. In literature, its usage in gluten free biscuits (Baljeet et al. 2010), crackers (Sedej et al. 2011), bread formulations (Constantini et al. 2014) and cakes (Przygodzka et al. 2015) were reported.

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Rice flour is natural, hypoallergenic and colorless and it has a bland taste; these properties make it a suitable ingredient for gluten free products. Besides, rice flour has also a very low level of protein, sodium, fat, fiber and high amount of easily digested carbohydrates and small amount of prolamin (2.5–3.5%) (Demirkesen et al. 2010). Gluten free buckwheat-rice formulations are widely used in literature in bread formulations (Turkut et al. 2016) and cookies (Altindag et al. 2015).

Microwave baking has some advantages over conventional methods such as; short processing times, less floor space, and improved product quality. However, it causes some quality problems too. Dense or gummy texture, crumb hardness, low volume, lack of surface color, high moisture loss and rapid stalling have been reported in the final baked product (Sumnu 2001). These problems can be overcome by adding emulsifiers, enzymes and gums to the formulation. For example, the effects of gums (xanthan and guar) at different concentrations on fresh and frozen microwave-reheated breads were studied by Mandala (2005).

Optimizing the formulation, which is one of the primary factors effective on quality of cake samples, can be a solution for the drawbacks of microwave technology. The relation between response variables and experimental variables can be examined by using RSM. It has been used in different studies which focused on microwave baking, combination baking and formulation optimization (Turabi et al. 2008; Sakiyan 2015).

Dielectric properties are important for microwave baked products due to their influence on quality parameters of food material treated by microwave. There are limited studies in literature about dielectric properties of baked products. Keskin et al. (2007) examined the effects of different gums on dielectric properties of doughs and breads baked in infrared-microwave combination oven. The quality parameters of breads formulated with different gums were also compared. Another study in the literature is the investigation of the variation of dielectric properties of different cake formulations during baking in microwave and infrared-microwave combination oven (Sakiyan et al. 2007). Similarly, Alifaki and Sakiyan (2017) found a correlation between dielectric properties and quality parameters of microwave baked chickpea cakes.

The use 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 buckwheat-rice cakes. This study was conducted to determine optimum cake formulation and baking conditions in terms of weight loss, porosity, specific volume, color, phenolic content and dielectric properties of baked cakes. Moreover, production of gluten-free cake with addition of buckwheat flour to rice flour was another goal of the research. Finally,

it was aimed to eliminate quality problems of microwave cakes with the help of two different gum types (guar gum and xanthan gum).

Materials and methods

Materials

Buckwheat flour, rice flour, salt, nonfat dry milk, cake shortening, sugar, baking powder, gums and egg white powder were bought from Smart Kimya Company, Turkey.

Methods

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 150 g water/100 g cake flour was used in the experiments. Depending on the cake formulation different buckwheat/rice flour ratios (20:80, 30:70 and 40:60) were used as cake flour. Fat and gums were added to the formulation with an amount of 25 g/100 g cake flour and 0.5 g/100 g cake flour, respectively. The gum concentration was determined by preliminary experiments. Control cakes had no gums and they were buckwheat flour free. First, all dry ingredients were mixed. Fat was melted in microwave oven at 900 W for 30 s, 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 to the previous mixture 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 (Termikel 13007-GGB, Turkey) at 175 °C for 30 min. The oven was preheated for 2 min. Three samples were baked at a time. Conventionally baked cakes were used as control group.

Microwave baking

A microwave oven (Arnica, ChefMaster Lux, Turkey) was used. The power of the microwave oven had been determined as 735 W by using IMPI 2-liter test (Büffler 1993). Cake samples were baked at 360 W, 450 W and 540 W

microwave power for 3, 3.5 and 4 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 buckwheat rice flour ratio and baking conditions on the quality parameters, phenolic contents and dielectric properties of cakes. There were three independent variables each having three levels, which were microwave power (X_1 ; 360 W, 450 W and 540 W), baking time (X_2 ; 3 min, 3.50 min and 4 min), and buckwheat rice flour ratio (X_3 ; 20%:80%, 30%:70%, and 40%:60%). The levels of these variables were determined by preliminary experiments. To study the main effects and interactions, Box-Behnken design having 15 experimental runs was employed (Table 2). For convenience, the actual values were converted into coded values. The experimental runs were repeated for each gum types.

Weight loss

The weight loss percentage of the cakes was calculated by using Eq. 1.

$$\text{Weight Loss (\%)} = \frac{W_0 - W_1}{W_0} \times 100 \quad (1)$$

where W_0 is the weight of dough samples in g, W_1 is the weight of the cake samples after the baking process in g. The data was the average of 3 replicates (Alifaki and Sakiyan 2017).

Color difference

The upper surface color of the cakes was measured by using Minolta Color Reader (CR-300, Japan) and expressed as the CIE L^* , a^* , and b^* color scale. Five measurements were taken from the surface of the cakes at room temperature, and the mean value was recorded. Color difference (ΔE) was calculated from Eq. 2;

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

Barium sulphate was selected as the reference standard and its L^* , a^* , and b^* values were represented as L_0^* , a_0^* , and b_0^* (Alifaki and Sakiyan Demirkol 2016).

Porosity

Baked cake samples were cut vertically in half. 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. 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 (Alifaki and Sakiyan 2017).

Specific volume

Specific volume of cake samples was measured by using rape seed displacement method (Alifaki and Sakiyan 2017).

Dielectric properties

The dielectric properties of cake samples were measured by using a network analyzer (Agilent Technologies ES061B ENA Series Network Analyzer, ABD). The network analyzer was calibrated with air, short block and distilled water at 25 °C. Dielectric properties of ingredients and cake samples were measured at room temperature. All measurements were done in triplicate (Al-Muhtaseb et al. 2010).

Preparation of extracts from buckwheat- rice cakes

The cakes were freeze-dried and ground into powder with a laboratory scale blender. The powdered samples were sieved through a 60-mesh screen and then stored at -18 °C until being analyzed. Buckwheat rice cake powders (1 g) were extracted with 10 ml of 65% (v/v) ethanol. After ultrasonic vibration for 1 min, the solution was mixed and centrifugated for 5 min at $5000 \times g$ at 4 °C. The supernatants were collected into a flask and extracts were stored at -18 °C till the analysis of total phenolic content (TPC) (Przygodzka et al. 2015).

Total phenolic content

TPC was determined with Folin–Ciocalteu reagent using the method which was adapted from Przygodzka et al. (2015). Briefly, 0.1 ml of the extract was mixed with 0.5 ml Foline Ciocalteu reagent (previously diluted with distilled water (1:10, v/v)) and 4 ml sodium carbonate (Na_2CO_3) solution (previously diluted with distilled water (7.5:100, v/v)). The mixture was incubated at room temperature for 2 h. The absorbance value of the mixture was measured at 725 nm using a spectrophotometer (LAMBDA 950, Perkin Elmer, USA). TPC was standardized against gallic acid and expressed in terms of mg gallic acid equivalents (GAE)/g dw cake.

Sensory analysis

Twenty-one (21) untrained panellists including students and staff from Ankara University evaluated three (3) different cake samples (~ 10 g) (the xanthan and guar gum added cake samples that are baked at optimal conditions and the control group) for overall acceptability, appearance, color, flavor, odor, taste and texture using a nine-point hedonic scale (1 = disliked extremely, 9 = liked extremely). Samples were served at room temperature (25 °C) (Rothschild et al. 2015).

Statistical analysis

Multiple regression analysis was used 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 applying 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. The data were reported as the average of three replicates.

Results and discussion

Quality characteristics

The second order model-equation (Eq. 3) was used to fit the independent and dependent variables and examined for goodness of fit.

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_1^2 + b_5X_2^2 + b_6X_3^2 + b_7X_1X_2 + b_8X_1X_3 + b_9X_2X_3 \quad (3)$$

In this equation, X_i 's are the independent variables (X_1 is microwave power, X_2 is baking time, X_3 is buckwheat flour content), b_i 's are the model constants, and Y 's are dependent variables (specific volume, total color change, weight loss, porosity, total phenolic content, 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 1a, b for two different gum types used. Multiple regression analysis of experimental data was used for the determination of regression equations and coefficients. The equations had high regression coefficients ($r^2 > 0.83$) and the lack of fit values of the regression models were insignificant ($p > 0.05$). These findings indicated that the quadratic models fit the data well.

The first quality characteristic to be discussed is weight loss. According to statistical analysis, microwave power and baking time were found to be effective on weight loss. For

both types of gum, weight loss values were fitted to a second-order model and a high coefficients of determination were observed ($r^2 = 0.995$ – 0.986) (Table 1a, b). Weight loss of cakes which is an index of moisture loss increased with increasing microwave power and baking time (Table 2). This can be explained by relatively higher amount of interior heating during microwave baking which results in significant internal pressure; the internal pressure increases the liquid flow through the food boundary (Datta 1990). Similarly, it can be stated that at constant baking time, higher microwave power means more microwaves are coupling to the cake samples resulting in more heating. This trend can also be related to longer contact time of sample with microwaves. As a result of longer contact time more water vapor is evaporated. Similar results were reported by other researchers (Turabi et al. 2008; Demirekler et al. 2004). It was observed that both guar and xanthan gum added samples expressed similar weight loss results. This may be due to the fact that both gum types have similar water holding capacities at corresponding concentrations (Keskin et al. 2007).

Color, which has an important effect on the general conception of the consumers, was the other dependent variable of the study. The results showed that the only significantly effective independent variable was buckwheat flour content which had a negative effect on total color change for both gum types (Tables 1a, b, 2). The dark color of buckwheat flour may be responsible for this fact. In literature it is given that L^* values of buckwheat flour is much more lower than rice flour and this is explained by the higher polyphenolic content of buckwheat (Altindag et al. 2015). Fujita et al. (2004) stated that flour color is often influenced by its polyphenolic content. Constantini et al. (2014) reported that there was a considerable difference between wheat and buckwheat bread samples regarding the lightness (L). Moreover, they found that buckwheat enhanced a and b values of wheat breads due to its beige color. Singh et al. (2016) observed similar results reporting lower L^* values for muffins prepared with black carrot fibre addition to the rice flour and Shevkani et al. (2015) determined L^* value of the muffins prepared from rice flour alone was 70.3, while those prepared with red cowpea protein isolate was 57.5. Therefore, the differences in color of the muffins may be attributed to the variation in the color of the black carrot fiber and red cowpea protein isolate. Beneficially, the browner color obtained by buckwheat addition might be a solution to microwave baked products' color problem. It is a known fact that, lack of maillard reactions on the surface of bakery products is one of the drawbacks of microwave mechanism.

A significant positive effect of microwave power and baking time was detected on specific volume for both types of cake samples (Tables 1a, b, 2). When the cakes were baked for 3 min, the specific volume of the sample was

Table 1 Regression equations for (a) guar gum added cakes, (b) xanthan gum added cakes

Dependent variable	Equation	r ²	Lack of fit
(a)			
Weight loss	$Y_1 = 13.3685^* + 5.3667^*X_1 + 2.9891^*X_2 - 0.0461 X_3 + 0.7765^*X_1^2 - 0.1982X_2^2 + 0.3429X_3^2 + 0.4160X_1X_2 + 0.0810X_1X_3 - 0.4810^*X_2X_3$	99.5	0.920 ^{ns}
Total color change	$Y_2 = 68.5549^* + 0.3504X_1 + 0.1858X_2 - 3.2631^*X_3 - 1.1679^*X_1^2 + 0.7874^*X_2^2 - 0.5285^*X_3^2 + 0.1469X_1X_2 + 0.5720^*X_1X_3 - 0.5094^*X_2X_3$	97.8	0.069 ^{ns}
Specific volume	$Y_3 = 1.5538^* + 0.0431^*X_1 + 0.0398^*X_2 + 0.0266^*X_3 + 0.0169X_1^2 + 0.0659^*X_2^2 + 0.01505^*X_3^2 - 0.0259X_1X_2 + 0.0459^*X_1X_3 + 0.0143X_2X_3$	94.4	0.077 ^{ns}
Porosity	$Y_4 = 32.2432^* + 1.7872^*X_1 + 1.5174^*X_2 + 1.6833^*X_3 - 1.5560^*X_1^2 - 2.8033^*X_2^2 + 2.5701^*X_3^2 - 0.2186X_1X_2 - 1.7853^*X_1X_3 + 0.6370^*X_2X_3$	98.6	0.060 ^{ns}
Total phenolic content	$Y_5 = 0.8415^* - 0.0717^*X_1 - 0.0425^*X_2 + 0.0518^*X_3 - 0.0687^*X_1^2 - 0.0597^*X_2^2 - 0.0052X_3^2 + 0.0182X_1X_2 - 0.0083X_1X_3 - 0.0689^*X_2X_3$	82.9	0.236 ^{ns}
Dielectric constant	$Y_6 = 11.6244^* - 1.4374^*X_1 - 1.0543^*X_2 + 0.8419^*X_3 + 0.4374X_1^2 - 0.1799X_2^2 - 0.4086X_3^2 - 0.2024X_1X_2 + 0.3450X_1X_3 - 0.1327X_2X_3$	87.1	0.099 ^{ns}
Dielectric loss factor	$Y_7 = 3.78733^* - 0.74678^*X_1 - 0.72463^*X_2 + 0.48658^*X_3 + 0.57289^*X_1^2 + 0.58267^*X_2^2 + 0.39047X_3^2 + 0.03476X_1X_2 + 0.44638X_1X_3 - 0.07338X_2X_3$	83.7	0.299 ^{ns}
(b)			
Weight loss	$Y_1 = 13.9118^* + 5.3182^*X_1 + 3.0587^*X_2 - 0.1202X_3 + 0.2322X_1^2 + 0.5959X_2^2 - 0.3896X_3^2 + 1.0407^*X_1X_2 + 0.1088X_1X_3 + 0.0643X_2X_3$	98.6	0.104 ^{ns}
Total color change	$Y_2 = 65.0101^* - 0.1093X_1 - 0.0373X_2 - 1.7287^*X_3 + 0.1372X_1^2 - 0.1143X_2^2 - 0.5447^*X_3^2 - 0.0640X_1X_2 - 0.2518X_1X_3 - 0.0090X_2X_3$	97.7	0.877 ^{ns}
Specific volume	$Y_3 = 1.54306^* + 0.03826^*X_1 + 0.04399^*X_2 - 0.01020^*X_3 + 0.01050X_1^2 + 0.00541X_2^2 - 0.00727X_3^2 - 0.01143^*X_1X_2 + 0.00931X_1X_3 + 0.00848X_2X_3$	97.00	0.113 ^{ns}
Porosity	$Y_4 = 42.9622^* + 2.4448^*X_1 + 3.2119^*X_2 - 0.3307X_3 + 0.6186 X_1^2 - 1.0468X_2^2 + 0.3940X_3^2 + 1.0083X_1X_2 - 0.0435X_1X_3 + 0.1806X_2X_3$	92.4	0.145 ^{ns}
Total phenolic content	$Y_5 = 0.6893^* - 0.0622^*X_1 - 0.03191^*X_2 + 0.1125^*X_3 + 0.0978^*X_1^2 + 0.0208X_2^2 + 0.0521^*X_3^2 + 0.0989^*X_1X_2 - 0.0328^*X_1X_3 - 0.0050X_2X_3$	96.9	0.192 ^{ns}
Dielectric constant	$Y_6 = 11.4057^* - 1.0676^*X_1 - 0.2710^*X_2 + 0.0186 X_3 + 1.4051^*X_1^2 - 1.0750^*X_2^2 - 0.7331^*X_3^2 + 0.2302X_1X_2 + 0.2088X_1X_3 + 0.3727^*X_2X_3$	98.1	0.439 ^{ns}
Dielectric loss factor	$Y_7 = 4.5465^* - 0.5563^*X_1 - 0.1483X_2 + 0.1354 X_3 + 0.9132X_1^2 - 0.9528^*X_2^2 - 0.1066X_3^2 - 0.3335^*X_1X_2 - 0.1112X_1X_3 + 0.4729^*X_2X_3$	95.4	0.064 ^{ns}

*Significant at $p \leq 0.05$, ns not significant at $p \leq 0.05$ (X1, microwave power; X2, baking time; X3, buckwheat flour content)

Table 2 Experimental design for RSM and experimental data for cakes

X_1 (W)		X_2 (min)		X_3 (%)		Weight loss (%)		Total color change		Specific volume (ml/g)	
Coded	Uncoded	Coded	Uncoded	Coded	Uncoded	Xanthan gum	Guar gum	Xanthan gum	Guar gum	Xanthan gum	Guar gum
−1	360	−1	3	0	30	7.01 ± 0.05	6.16 ± 0.61	65.64 ± 0.50	68.26 ± 0.28	1.474 ± 0.002	1.526 ± 0.007
0	450	0	3.5	0	30	13.97 ± 0.09	13.90 ± 0.18	64.66 ± 0.32	69.17 ± 0.84	1.547 ± 0.001	1.550 ± 0.007
1	540	−1	3	0	30	15.87 ± 0.40	15.96 ± 0.11	64.75 ± 0.21	69.21 ± 1.02	1.562 ± 0.14	1.690 ± 0.024
1	540	0	3.5	−1	20	19.23 ± 0.51	19.84 ± 0.94	67.69 ± 1.15	69.62 ± 0.46	1.591 ± 0.007	1.687 ± 0.011
1	540	0	3.5	1	40	18.60 ± 0.05	19.97 ± 0.94	62.48 ± 0.15	64.15 ± 6.09	1.589 ± 0.005	1.816 ± 0.024
0	450	1	4	−1	20	16.68 ± 0.46	17.16 ± 0.29	66.32 ± 0.64	71.32 ± 0.83	1.590 ± 0.004	1.772 ± 0.021
−1	360	0	3.5	−1	20	9.13 ± 0.33	9.17 ± 0.47	66.92 ± 0.78	68.79 ± 1.08	1.522 ± 0.004	1.718 ± 0.015
0	450	−1	3	−1	20	11.18 ± 0.17	10.02 ± 0.17	66.74 ± 0.29	72.12 ± 1.05	1.513 ± 0.009	1.700 ± 0.018
0	450	0	3.5	0	30	14.11 ± 0.04	13.24 ± 0.30	64.66 ± 1.22	68.37 ± 0.87	1.542 ± 0.004	1.564 ± 0.001
1	540	1	4	0	30	24.55 ± 0.23	22.57 ± 0.20	64.32 ± 0.39	68.45 ± 0.89	1.622 ± 0.010	1.696 ± 0.003
0	450	−1	3	1	40	11.42 ± 0.16	10.83 ± 0.13	63.38 ± 0.68	66.44 ± 0.35	1.476 ± 0.006	1.740 ± 0.005
−1	360	0	3.5	1	40	8.06 ± 0.24	8.97 ± 0.47	63.57 ± 0.32	60.73 ± 1.21	1.483 ± 0.004	1.664 ± 0.013
0	450	1	4	1	40	17.19 ± 0.49	16.05 ± 0.11	63.07 ± 0.52	65.44 ± 0.42	1.586 ± 0.013	1.870 ± 0.017
−1	360	1	4	0	30	11.52 ± 0.08	11.11 ± 0.11	64.83 ± 0.27	67.23 ± 0.77	1.579 ± 0.002	1.636 ± 0.014
0	450	0	3.5	0	30	13.66 ± 0.23	12.96 ± 0.67	64.89 ± 0.32	68.29 ± 0.40	1.540 ± 0.001	1.548 ± 0.003

 X_1 , microwave power; X_2 , baking time; X_3 , buckwheat flour content

Table 3 Total phenolic contents and dielectric properties of cake batter formulations

Buckwheat flour content (%)	Gum type	Dielectric constant	Dielectric loss factor	Total phenolic content (mg gallic eq./g dw batter)
0	No gum	5.13 ± 0.04^d	2.26 ± 0.03^d	0.42 ± 0.03^c
20	Guar	11.94 ± 0.64^c	5.86 ± 0.55^c	0.62 ± 0.03^b
30	Guar	14.43 ± 0.07^b	8.09 ± 0.04^b	0.73 ± 0.01^b
40	Guar	18.14 ± 0.06^a	9.83 ± 0.03^a	1.05 ± 0.06^a
20	Xanthan	20.61 ± 0.38^g	11.55 ± 0.05^g	0.60 ± 0.01^b
30	Xanthan	22.70 ± 0.38^f	12.75 ± 0.12^f	0.71 ± 0.02^b
40	Xanthan	24.34 ± 0.25^e	14.47 ± 0.19^e	1.05 ± 0.02^a

1.69 ml/g. If the baking time was increased to 4 min while keeping the other factors constant, the specific volume was found as 1.82 ml/g. Similarly, the increase in microwave power from 360 to 540 W has increased the specific volume from 1.53 to 1.71 ml/g. The rise in specific volume due to an increase in microwave power and baking time was also reported by other researchers too (Demirekler et al. 2004). The buckwheat flour content had a significant negative effect on specific volume values for the xanthan gum added samples (Table 1b). In literature, there are various studies which reported the negative correlation between buckwheat flour concentration and specific volume of final product (Atalay et al. 2013; Drobot et al. 2014). The reason may be expounded by dilution of protein content of flour blend which is responsible for the matrix of the product structure. On the contrary, for guar gum added samples, specific volume increased with an increment in buckwheat flour content (Table 1a). This difference between guar and xanthan gum can be explained by their individual effects on specific volume of bakery products (Keskin et al. 2007). The other reason may be the synergistic effect of buckwheat flour and guar gum in gluten free formulations. Mezaize et al. (2009) reported that guar gum addition to buckwheat breads improved specific volume of final product, while xanthan gum addition did not significantly affect specific volume values. Similarly, mixing xanthan gum with gluten-free bread formulation based on rice flour was found to have negative effect on specific volume due to the increase in rigidity of dough systems (Lazaridou et al. 2007).

Porosity, as the final quality parameter, was also modelled. A second order model was fitted and a high coefficient of determination ($r^2 = 0.924$ and 0.986) was observed for both gum types. It was found to be positively affected by microwave power and baking time for both types of gums (Table 1a, b, Supplementary file). This trend was a result of formation of air bubbles during baking of the batter. Similar results were reported by different researchers (Sakiyan et al. 2007; Alifaki and Sakiyan Demirkol 2016).

Total phenolic content

The possibility of upgrading gluten-free products such as bread, pasta and confectionary products by using pseudo-cereals are important for baking industry. In this study to obtain a functional food product, buckwheat flour, of which total phenolic content is reported within a range of 0.823–10.47 mg/g (Zhang et al. 2010), was added to the formulation in different concentrations. Total phenolic contents of guar gum and xanthan gum added batters were given in Table 3, respectively. The increase in buckwheat flour content resulted in an increase in total phenolic content of the formulation due to high amounts of phenolics in buckwheat itself. Results (Table 1a, b) showed that microwave power and baking time had a negative effect on total phenolic content of samples for both formulations (Supplementary file). It is a well known fact that thermal processing has an important effect on total phenolic content of processed products. The detrimental effect of thermal processing on flavonoid content of buckwheat was also reported (Dietrych-Szostak and Oleszek 1999). In our study, total phenolic content of guar and xanthan gum added batters, which contained 40% buckwheat flour, were found as 1.046 and 1.053 mg GAE/g dw batter, respectively. These values were reduced to 0.690 and 0.846 mg GAE/g dw cake after baking. However, it should be noted that although microwave baking caused a reduction in total phenolic content, the decrease was more drastic for the samples baked in conventional oven (Table 4).

The other significantly effective independent variable on total phenolic content of cake samples was buckwheat flour concentration (Table 1a, b). For both gum types, its positive effect was significant. The total phenolic content of guar gum added sample, (with 20% buckwheat flour content) which was baked at 540 W for 3.5 min, was found as 0.62 mg GAE/g dw cake. This value was increased to 0.758 mg GAE/g dw cake, when the buckwheat flour content was raised to 40% while keeping the other factors constant. Similarly, for xanthan gum cakes, at constant microwave power and baking time, when buckwheat flour

Table 4 Results for optimum points and control cake

Dependent variable	Control	Optimum guar gum added	Optimum xanthan gum added
Weight loss	11.70 ± 0.37%	8.30 ± 0.52%	6.31 ± 0.54%
Total color change	71.11 ± 0.43	62.38 ± 0.27	70.07 ± 1.01
Total phenolic content	0.13 ± 0.01 mg GAE/g dw cake	0.90 ± 0.01 mg GAE/g dw cake	0.77 ± 0.01 mg GAE/g dw cake
Specific volume	1.29 ± 0.01 ml/g	1.72 ± 0.01 ml/g	1.52 ± 0.01 ml/g
Porosity	24.35 ± 3.51%	41.85 ± 0.43%	34.24 ± 0.32%
Dielectric constant	11.53 ± 0.28	12.74 ± 0.48	12.46 ± 0.32
Dielectric loss factor	4.40 ± 0.21	4.92 ± 0.31	3.98 ± 0.17

content was raised from 20 to 40%, the total phenolic content was increased from 0.69 to 0.86 mg GAE/g dw cake. This was an expected result. Since buckwheat have high phenolic content, an increase in buckwheat flour concentration causes a rise in total phenolic content of the sample.

Chlopicka et al. (2012) found similar results for buckwheat breads. They reported that buckwheat flour had the highest phenolic content (7.25 ± 0.23 mg/g dw) among other crop flours and the best results were obtained when buckwheat flour was added to the formulation with a concentration of 30% (2.65 ± 0.10 mg/g dw).

Dielectric properties

The results of dielectric properties revealed that water, shortening, gums and flours were the ingredients with high dielectric properties at 2450 MHz (25 °C). This makes them critical for microwave baking. During baking, the batter undergoes a number of physical, chemical and structural changes, all of which may affect the dielectric properties. Microwave power, baking time and buckwheat flour concentration were found to be significantly effective on dielectric properties of samples that contained guar gum. However, microwave power was the sole significant parameter for the samples including xanthan gum (Table 1a, b). The increase in microwave power and baking time decreased the dielectric properties (Supplementary file). This may be due to higher degree of moisture loss at extreme baking conditions. Al-Muhtaseb et al. (2010) reported that moisture content was the dominant parameter in affecting the dielectric properties. With regard to this information, the weight loss and dielectric properties were found to be correlated in this study. A negative correlation was determined between dielectric constant and weight loss values for both guar gum ($r = -0.834$, $p = 0.000$) and xanthan gum added cakes ($r = -0.595$, $p = 0.019$). Moreover, a negative correlation was found between dielectric loss factor and weight loss values for both formulations. The r and p values were -0.702 , 0.004 and -0.521 , 0.046 for the samples containing guar gum and

xanthan gum, respectively. These correlations can be explained by the following statement; the more free water in the system, the more easily it is polarized (dipole moment per unit volume) (Sakiyan et al. 2007). The variation of dielectric properties with respect to baking time and microwave power can also be clarified by the porosity of samples; the presence of more air decreased the dielectric properties (Table 1a, b). Dielectric properties of guar gum added cakes were found to be affected by buckwheat flour concentration too. This may be due to the effect of buckwheat flour content on dielectric properties of batter (Table 3). A significant increase in both dielectric constant and dielectric loss factor was detected as buckwheat flour content was increased.

Optimization of the formulation and baking conditions

The response optimization tool in Minitab Release 16 software was used to determine the optimum microwave power, baking time and buckwheat flour content. The optimum points were found by considering minimum weight loss and maximum color difference, specific volume, porosity, phenolic content, dielectric constant and dielectric loss factor. The optimum points were obtained as -1 for X_1 , 0.402 for X_2 , -0.077 for X_3 for xanthan gum added formulation and -0.191 for X_1 , -1 for X_2 , 1 for X_3 for guar gum added ones. The corresponding uncoded values of the optimum points were calculated as 360 W microwave power, 3.70 min baking time, 29.22% buckwheat flour concentration for the cakes containing xanthan gum and 432.77 W, 3 min, 40% for the cakes that includes guar gum. The predicted responses, obtained at optimum process conditions, of xanthan gum including cakes can be listed as 12.46 dielectric constant, 3.98 dielectric loss factor, 6.31% weight loss, 70.07 color difference, 1.52 ml/g specific volume, 34.24% porosity and 0.77 mg GAE/g dw cake total phenolic content. The same values were 12.74, 4.92, 8.30%, 62.38, 1.72 ml/g, 41.85%, 0.90 mg GAE/g dw cake for guar gum containing cakes, respectively. The experimental results obtained at the optimal

Fig. 1 The pictures of the cakes baked in microwave oven (at optimal conditions) and conventional oven (control group) (**a** guar gum containing cake, **b** xanthan gum containing cake, **c** control)

conditions and the results of control cake were given in Table 4. When the experimental and predicted results were examined for both gum types, it was observed that they were comparable, which gives us information about the accuracy of the models obtained in the study. In addition, the cakes baked at the optimal conditions showed promising results compared to the control. Especially, guar gum containing formulation baked at optimal conditions can be suggested for microwave baking since it has lower weight loss, higher total phenolic content, specific volume, porosity and comparable total color change values.

Sensory analysis

The pictures of the cakes baked in microwave oven (at optimal conditions) and conventional oven (control group) were shown in Fig. 1. In addition, the results of the sensory analysis were given in Fig. 2. There were no significant

differences between the microwave baked cakes and the control group in terms of texture, flavor, taste and overall acceptability (Fig. 2). Moreover, the xanthan gum and guar gum added formulations had significantly higher color and appearance scores which were 6.81, 6.86 and 6.71, 7.14, respectively. Buckwheat flour has a brown color, which can be a solution for the lack of browning problem of microwave baked cakes, thus a high score is desirable for appearance and color parameters. However, the odor of control cake had the highest score (6.24). Flavor, taste, odor and overall acceptability of cakes could be improved by adding some spices. For example, Przygodzka et al. (2015) found that using selected spices especially vanilla and cinnamon at 2%, in recipes of rye-buckwheat ginger cakes, significantly increased the overall acceptability and successfully masked the specific, pungent aroma and taste of roasted buckwheat groat flour (30% addition). For texture parameter, the scores of xanthan gum added

Fig. 2 Sensory analysis results for the cakes baked in microwave oven (at optimal conditions) and conventional oven (control group)

formulation and guar gum added formulation had 6.43 and 6.14, respectively. According to Torbica et al. (2010) combination of rice and buckwheat flour (husked and unhusked) resulted in high sensorial acceptability, and satisfying textural properties. Addition of unhusked buckwheat flour at 20% was accepted for further rice-buckwheat breads development (Torbica et al. 2010).

Conclusion

This study was conducted to produce gluten-free cake with addition of buckwheat flour to rice flour. Weight loss, porosity, specific volume, color, phenolic content and dielectric properties of baked cakes were considered to optimize the cake formulation and baking conditions. It

was also aimed to find a correlation between dielectric properties and quality parameters of the samples and to eliminate quality problems of microwave baked cakes with the help of two different gum types (guar gum and xanthan gum). The optimum microwave power, baking time and buckwheat flour concentration were found as 432.77 W, 3 min, 40% for guar gum added cakes and 360 W, 3.70 min and 29.23% for xanthan gum added ones. A negative correlation between dielectric properties and weight loss were detected for both formulations. In addition, synergistic effect of guar gum and buckwheat flour combination was detected and their capability to give better characteristics to the microwave baked gluten free cakes was reported. Guar gum helped to eliminate surface color and specific volume problems of microwave baking. Moreover, functional and phenolic rich microwave baked

cakes can be produced with this formulation in a very short time.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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