EFFECT OF BAKING CONDITIONS ON THE PHYSICAL PROPERTIES OF HERBAL BREAD USING RSM

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ABSTRACT
The use of composite coriander-wheat flour for commercial bread making purposes and consumption of coriander leaf fortified bread are relatively new. Response surface methodology was used to study the effects of baking conditions on various baking parameters and thus the optimum conditions selected for further studies. Time and temperature are the two important baking conditions on which the quality and acceptability of the breads depend. In this study, baking temperature and time were the predictor variables and loaf specific volume, crumb moisture and crumb hardness were the dependent variables (responses). Baking temperature and time ranged from 200 to 240 °C and 10 to 30 min respectively. Loaf weight, volume, and the color of the crumb and crust of the bread samples varied significantly with the baking time and temperature. Quadratic model fitted with the experimental data of specific volume, crumb moisture and hardness obtained. The baking conditions of the herbal bread have been optimized with the help of RSM.

Key Words: Coriander Leaf, Response Surface Methodology, Brownness Index, Crumb Moisture, Specific Loaf Volume, Crumb Hardness

INTRODUCTION
Bread has become one of the most widely consumed non-indigenous food item in India. Fresh bread is characterized by a soft and elastic crumb, a brownish crust, a pleasant aroma and a moist mouth feel (Giannou et al., 2003). Baking is an important step of bread preparation. During this process, the raw dough piece gets transformed into a light, porous, flavorful and readily digestible product under the influence of heat (Therdthai, 2002). The quality of the final product mainly depends on the rate and amount of heat applied the type of baking chamber and the baking time. Some of the physical, chemical and biochemical changes during bread baking include volume expansion, evaporation of water, crust formation, inactivation of yeast and enzymatic activities, protein coagulation and starch gelatinization (Pyler, 1988).

The control of the baking parameters like temperature and time combination during baking is an engineering problem that is critical to the successful implementation of commercial flour baking technology (Shittu et al., 2007). Till now, few studies have been conducted on the effect of baking time-temperature on the quality of bread from 100% wheat flour (Bloksma, 1990; Singh & Bhattacharya, 2005; Therdthai et al., 2002; Zhang & Datta, 2006; Jusoh et al., 2007), very few on the composite wheat flour (Shittu et al., 2007) and virtually none has been reported on composite coriander-wheat bread.

Response surface methodology (RSM) is a collection of statistical and mathematical techniques used for development, improvement and optimization of processes or formulations (Malcolmson et al., 1993; Bas & Boyaci, 2007; Turabi, 2008). It is used to examine the relative significance between a set of quantitative experimental factors and the response variables. In food research studies, response surface methodology (RSM) is very frequently used to optimize the efficiency of the ingredients such as fibres, improvers (Collar et al., 1999; Collar et al., 2007; Clarke et al., 2003; Sabanis et al., 2009), composite flours (Shittu et al., 2007), optimization in food processes like product development, functional food preparation etc (Seog et al., 2008; Gupta et al., 2007; Flander et al., 2007) as well as in optimizing processing conditions (Ghodke et al., 2009; Mondal & Datta, 2010).
The aim of the present study was to observe the effect of various baking time-temperature combinations on bread loaf size, crust color, crumb moisture and hardness of the bread samples made from composite wheat flour consisting of 5% coriander leaf powder, and further to optimize the baking conditions using RSM technique.

**MATERIALS AND METHODS**

**Raw Materials**

Fresh coriander leaves were procured from the local market of Jadavpur, Kolkata. White refined flour, granulated sugar, salt, refined oil as shortening agent were purchased from the local grocery stores of Jadavpur, Kolkata, India. Compressed Baker’s yeast (Saf Yeast Company Pvt. Ltd., Mumbai, India) was used as the leavening agent in bread preparation.

**Preparation of The Raw Material**

The coriander leaves were washed in tap water to remove the adhering dirt. They were then de-rooted, blanched in lukewarm water (approx. 50ºC) for about 1 min. They were next dried in a Tray Dryer (Reliance Enterprise, Kolkata, India) at 60°C for approximately three and half an hour. Finally, the dried leaves were ground in a Grinder (GX, Bajaj Electricals Ltd, India), sifted to less than 150µm (BSS 100) and then stored in air-tight polythene packets to obtain the coriander leaf powder.

**Bread Preparation**

The ingredients and their proportions required for the preparation of bread samples were wheat 3.0%, sugar 5.0%, salt 2.0%, compressed wet yeast 2.5%, refined oil 5.0%, glycerol monostearate 1.5% and water 60.0%. The flour blend was prepared by mixing 100g wheat flour with 3.0% w/w of coriander leaf powder. The dry mix was prepared by mixing flour, sugar, salt and the chemicals. Baker’s compressed yeast was dissolved in water (10 ml) and kept at the 37ºC for the activation of the yeast cells. Small amount of flour (approx. 1g) and same amount of sugar were added to the warm water for activation of the yeast cells. Mixing is an important step for achieving homogenous as well as soft dough. Here, mixing was carried out manually according to the straight dough method. The dry ingredients, shortening and the activated yeast were added in a bowl and water added and then kneaded until the dough was elastic and the required consistency was reached. After this, the dough was rounded and kept in a bowl for the first proofing at the room temperature (30°C) for about 40 min. The bowl was covered with a wet cloth to maintain a relative humidity of 80-90%. After the first proofing, the dough was punched and worked lightly so that the excess gas could escape and the gas cells are redistributed. The dough was then shaped to fit lightly in greased bread molds. The dough was again kept for the final proofing for about 1 hour at 40±1°C. Finally, after second proofing, the breads in molds were baked in rotary oven (CM HS108, Chanmag Bakery Machine Co. Ltd., Taiwan) at different experimental temperatures and time. After baking, the prepared bread samples were cooled for about 1 hour at room temperature and then analyses carried out.

**Analysis for Bread**

**Loaf weight, volume and specific volume**

Bread samples were weighed after cooling and the volumes of the loaves were measured by the seed displacement method (Dhingra and Jood, 2004; Smith and Johansson, 2004). From these, the specific volume of the loaf was calculated as:

\[
\text{Specific volume (ml/g)} = \frac{\text{Loaf volume}}{\text{Loaf weight}}
\]  

**Crumb Moisture**

Bread crumb moisture was determined by taking 2g of the bread crumb, grinding it to small pieces and then drying for 2 hours at 130±2°C (AACC, 2000; McCarthy et al., 2005). After drying, the samples were cooled in a desiccator. Moisture content was determined as follows:
% moisture content = \frac{\text{Initial weight of the sample} - \text{Final weight of the sample}}{\text{Initial weight of the sample}} \times 100 \tag{2}

\text{Color}

The crust color of the bread samples were measured using the Hunter Lab color measurement system, ColorFlex 45/0, D65, 10° observer (Hunter Associates Laboratory Inc., Reston, VA, USA). A 3.5 cm thick layer was covered with the white standard plate (X=79.22; Y=84.10; Z=88.76) for measurement of diffused reflected light from the cell bottom using a 1.25 inch diaphragm aperture. Color of the bread samples were measured according to the CIELAB system of color measurement as \(L^*\)-whiteness/darkness (100-0), \(a^*\)-redness/greenness (+ to -) and \(b^*\)-yellowness/blueness (+ to -). The ‘brownness index’ (BI) was calculated as follows: (Maskan, 2001; Torregiani & Bertolo, 2001; Yan et al., 2008).

\[
\text{BI} = \frac{100(x-0.31)}{0.17(a+1.75L)} \tag{3}
\]

Where, \(x = \frac{(a+1.75L)}{(5.645L+a-3.012b)} \tag{4}\)

\text{Crumb Hardness}

The hardness of the bread crumb was measured using the Instron Universal Testing Machine, Table Model 4301 (Instron Ltd., High Wycombe, Bucks, UK) in the compression mode fitted with a 100N load cell. The bread samples were sliced and the middle slices having a width of 25mm were taken for measurement. A two-cycle crumb compression test was performed by compressing axially each sample with a 40mm diameter flat plate probe attached to the moving crosshead. The testing conditions were: compression ratio of 50% deformation from the initial height of the sample; 20mm/min crosshead speed and 20mm/min chart speed. The force-distance curve obtained was used to derive the various textural properties (Bandyopadhyay et al., 2005; Bourne, 1978).

\text{Experimental Design and Statistical Analysis}

The experimental design was done by RSM comprising of a central composite design with two-factors and five-levels (Table 1). The two independent variables (factors) used here were: baking time (\(X_1\)) and baking temperature (\(X_2\)) and the three dependent variables (responses) studied were loaf specific volume (\(Y_1\)), crumb moisture (\(Y_2\)) and crumb hardness (\(Y_3\)). 13 baking trials were performed with five centre points. The combination of the two factors (baking time and temperature), their actual and coded values are given in Table 1. For each response variable, model selection for linear, quadratic or cubic models were made on the basis of sequential model sum of squares (SMSS), lack-of-fit tests and the multiple correlation coefficients (R\(^2\)). The cubic model was aliased because there were not enough points for this type of model. From this information, the most accurate model was chosen which in all cases appears to be quadratic model. The second-order response functions for the experiments were fitted to the following quadratic regression equation:

\[
Y = b_0 + b_1X_1 + b_2X_2 + b_{11}X_1^2 + b_{22}X_2^2 + b_{12}X_1X_2 \tag{5}
\]

where \(X_1\) is the baking time; \(X_2\) is the baking temperature; \(b_0\) is the value of the fitted response at the centre point (0, 0) of the design; \(b_1\) and \(b_2\) are the linear regression terms; \(b_{11}\) and \(b_{22}\) are the quadratic terms and \(b_{12}\) is the interaction term.

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>Unit</th>
<th>Symbol</th>
<th>Coded levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baking time</td>
<td>min</td>
<td>(X_1)</td>
<td>-2 15 20 25 30</td>
</tr>
<tr>
<td>Baking temperature</td>
<td>°C</td>
<td>(X_2)</td>
<td>10 210 220 230 240</td>
</tr>
</tbody>
</table>

| Table 1: Independent variables and their levels in the central composite design
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Statistical analysis of variance (ANOVA) and multiple regression were performed using the software, Design Expert® Version 7.1.6 (Stat-Ease, Inc., Minneapolis, USA) to fit the equation. The results included the estimated model coefficients, the regression coefficients and the lack-of-fit test.

RESULTS AND DISCUSSION

Loaf Size

The effects of baking time and temperature on coriander fortified bread size are shown in Table 2. Loaf volume and weight ranged from 294.15 ml to 346.5 ml and 147g to 159g respectively. Higher loaf weight and volume are desirable to the bakers as consumers often get attracted to these factors over other factors. Specific volume, a ratio of loaf volume to loaf weight is a more precise measurement of loaf size. Loaf volume is mainly affected by the protein content of the flour (Ragaee & Abdel-Aal, 2006) as well as the proofing time and temperature (Zghal et al., 2002). On the other hand, loaf weight is mainly influenced by the amount of dough baked and the percent of moisture and carbon dioxide diffused out during baking (Shittu et al., 2007). In this study, increase in temperature and baking time has decreased the loaf weight (Table 2), while the reverse occurred in case of loaf volume. Since the formulation of the bread samples are same in all cases, the variation in loaf volumes is mainly because of the differences in the rate of gas evolution and starch gelatinization as baking time and temperature are varied.

Crust Color

Color in baked products is an inevitable quality, because the product color can be influenced by the ingredients, processing factors, quality and shelf-life of the produced bread as is evident from the previous works (Jusoh et al., 2007; Erkan et al., 2006; Gallagher et al., 2003a; Gallagher et al., 2003b). Therdthai et al., in 2002 reported that baking conditions affect the color of the crust technically. As the bread formulation remains same in all the samples, it can be assumed that the crumb color characteristics are not liable to differ significantly (Shittu et al., 2007).

In this study, the values of the color parameters L*, a* and b* of the bread crust are affected by the baking time-temperature combinations as is shown in Table 2. The values of L*, a* and b* ranged from 26.903 to 34.287, 2.737 to 7.503 and 8.713 to 14.433 respectively. Table 2 suggests that baking time and temperature were inversely proportional with the L* value of the crust. Breads baked at higher temperature had lower L* value. This is mainly due to the fact that the rate of brown pigment formation increases with time and temperature. This browning is mainly due to the Maillard reaction rather than

<table>
<thead>
<tr>
<th>Temp (°C)</th>
<th>Time (min)</th>
<th>Loaf size</th>
<th>Crust color</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Loaf wt. (g)</td>
<td>Loaf volume (ml)</td>
</tr>
<tr>
<td>230</td>
<td>25</td>
<td>150±0.677</td>
<td>234.9±1.081</td>
</tr>
<tr>
<td>220</td>
<td>20</td>
<td>154±0.74</td>
<td>338.8±1.31</td>
</tr>
<tr>
<td>230</td>
<td>15</td>
<td>157±0.959</td>
<td>322.84±1.617</td>
</tr>
<tr>
<td>220</td>
<td>10</td>
<td>159±0.902</td>
<td>294.15±1.166</td>
</tr>
<tr>
<td>200</td>
<td>20</td>
<td>156±0.416</td>
<td>312.465±0.882</td>
</tr>
<tr>
<td>220</td>
<td>20</td>
<td>155±1.465</td>
<td>346.5±1.191</td>
</tr>
<tr>
<td>220</td>
<td>20</td>
<td>154±1.008</td>
<td>338.13±1.293</td>
</tr>
<tr>
<td>240</td>
<td>20</td>
<td>147±1.52</td>
<td>341.48±0.904</td>
</tr>
<tr>
<td>210</td>
<td>25</td>
<td>151±0.444</td>
<td>324.65±1.49</td>
</tr>
<tr>
<td>220</td>
<td>30</td>
<td>147±1.059</td>
<td>342.51±1.076</td>
</tr>
<tr>
<td>210</td>
<td>15</td>
<td>158±1.361</td>
<td>303.044±1.294</td>
</tr>
<tr>
<td>220</td>
<td>20</td>
<td>155±0.514</td>
<td>341.0±0.63</td>
</tr>
<tr>
<td>220</td>
<td>20</td>
<td>153±0.576</td>
<td>345.65±0.80</td>
</tr>
</tbody>
</table>
Data represents means of three samples (n=3) ± s.d. Means with different superscripts within the same row are significantly different (p≤0.05) caramelization (Mondal & Datta, 2010). The brown color formation in the crust may be measured by the ‘brownness index’ (BI) of the loaf crust, which ranged from 38.824 to 92.353 for the bread samples. The other color components $a^*$ and $b^*$ reacted oppositely in contrast to $L^*$. $a^*$ values are directly proportional to baking time and temperature. Table 2 also shows that lower baking time and temperature produced breads of lower $a^*$ and $b^*$ values, or rather lower in redness and yellowness intensity.

Response Surface Models

Estimated regression coefficients for the dependent variables were obtained from responses by the multiple regression analysis (Table 3) and the mathematical models obtained from these are shown below:

Specific volume ($Y_1$) = $2.22 + 0.084X_1 + 0.11X_2 - 0.019X_1^2 - 0.037X_2^2 - 0.0009X_1X_2$ (6)
Crumb moisture ($Y_2$) = $39.86 - 1.17X_1 - 1.33X_2 - 3.73X_1^2 - 3.04X_2^2 - 3.75X_1X_2$ (7)
Crumb hardness ($Y_3$) = $9.93 + 1.08X_1 + 1.42X_2 + 2.18X_1^2 + 1.81X_2^2 + 2.75X_1X_2$ (8)

Analysis of variance (ANOVA) of the effect of baking time and temperature to produce the breads in the form of linear, quadratic and interaction terms on the response variables, the lack-of-fit test and the regression coefficients are depicted in the Tables 4. F-test values of 25.49, 44.75 and 108.12 for specific volume, crumb moisture and crumb hardness obtained from ANOVA of the quadratic regression models demonstrate that the models are significant. The P-value checked the significance of each of the coefficients to understand the interaction between the independent variables. The lower the P-values, the more significant are the model terms. Values of P less than 0.05 indicate that the model term is significant (Ghodke et al., 2009). The regression coefficient ($R^2$) checks the goodness of fit of the models. The closer the $R^2$ values to 1.0, the more fit are the models.

Table 3: Estimated coefficients of the fitted quadratic equation for different responses such as $Y_1$ (specific volume), $Y_2$ (crumb moisture) and $Y_3$ (hardness)

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>$Y_1$</th>
<th>$Y_2$</th>
<th>$Y_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b_0$</td>
<td>2.22</td>
<td>39.86</td>
<td>9.93</td>
</tr>
<tr>
<td>$b_1$</td>
<td>0.084</td>
<td>-1.17</td>
<td>1.08</td>
</tr>
<tr>
<td>$b_2$</td>
<td>0.11</td>
<td>-1.33</td>
<td>1.42</td>
</tr>
<tr>
<td>$b_1^2$</td>
<td>-0.019</td>
<td>-3.73</td>
<td>2.18</td>
</tr>
<tr>
<td>$b_2^2$</td>
<td>-0.037</td>
<td>-3.04</td>
<td>1.81</td>
</tr>
<tr>
<td>$b_1b_2$</td>
<td>-0.009</td>
<td>-3.75</td>
<td>2.75</td>
</tr>
</tbody>
</table>

Table 4: Analysis of variance of the responses by quadratic regression model

<table>
<thead>
<tr>
<th>Source</th>
<th>Degrees of Freedom</th>
<th>Specific volume</th>
<th>Crumb moisture</th>
<th>Crumb firmness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>0.0002*</td>
<td>&lt;0.0001*</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td>A</td>
<td>1</td>
<td>0.0004*</td>
<td>0.0317*</td>
<td>0.0006*</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>&lt;0.0001*</td>
<td>0.0184*</td>
<td>0.0001*</td>
</tr>
<tr>
<td>$A^2$</td>
<td>1</td>
<td>0.0938**</td>
<td>&lt;0.0001*</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td>$B^2$</td>
<td>1</td>
<td>0.0065*</td>
<td>&lt;0.0001*</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td>AB</td>
<td>1</td>
<td>0.7094**</td>
<td>0.0016*</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td>Lack of Fit</td>
<td>3</td>
<td>0.1269**</td>
<td>0.3664**</td>
<td>0.3444**</td>
</tr>
<tr>
<td>$R^2$</td>
<td></td>
<td>0.9479</td>
<td>0.9697</td>
<td>0.9872</td>
</tr>
</tbody>
</table>
The 3D response plots (Fig 1-3) are the graphical representation of the regression equations from where the values of the responses can be predicted with respect to the variable factors. The contour plots show multiple asymmetric saddling indicating a rather complex relationship between the dependent and the independent variables. The dependence of the baking levels, the response surfaces for specific volume, crumb moisture and hardness are shown in Figs 1 to 3.

**Specific Loaf Volume**

The specific volume of the bread samples ranged from 1.85 to 2.32 ml/g. Specific volume depended both upon baking time and temperature as it had positive linear effect (Table 3). The linear baking time and temperature terms and quadratic temperature term has significant P values (Table 4). The $R^2$ value of this model is 0.9479 which means that 94.795 of the variability in the response data fitted the model. Fig. 1 depicts the combined effect of baking time and temperature on loaf specific volume 3D surface. It shows that with increase in baking time and temperature the specific volume has increased almost linearly.

![Response Surface Plot for the Effect of Baking Time and Temperature on Loaf Specific Volume](image)

**Crumb Moisture**

Here, the linear, quadratic and interaction model terms are found to have significant P-values (Table 4). Thus crumb moisture depended upon baking time and temperature; the linear and quadratic effect of both the variables is negative. The $R^2$ value of 0.9697 suggests that the raw data had a good fit to the model. The crumb moisture content ranged from 23.0 to 42.0%. As evident from Fig. 2, with the increase in baking time and temperature, the crumb moisture content decreases. The combination of medium levels of both the factors resulted in higher crumb moisture content (Fig. 2). The moisture content of the bread crumbs may be governed by the extent of gelatinization of starch in dough during baking. The crumb moisture content has some implication on the mechanical (Zghal et al., 2002) and keeping qualities (Defloor et al., 1993).
Crumb Hardness

Hardness is an important factor in bakery products and is strongly related with the consumer’s perception of bread freshness (Ahborn et al., 2005). Table 4 shows that all the linear and quadratic model terms have significant P values. Crumb hardness depends both on baking time and temperature and the linear and quadratic effects being positive in this case (Table 3). The $R^2$ value is 0.9872 stating that 98.72% of the data fits with the model. The crumb hardness values ranged between 9N to 21N. Fig 3 defines the 3D plot of crumb hardness with respect to baking time and temperature. Hardness of the breads increased with increasing baking time and temperature (Fig 3). An optimum of crumb hardness has been reached at the middle points of baking time and temperature. On a whole, Fig 3 is just the inverse nature of Fig 2. Thus from the two figures it can be inferred that crumb moisture and hardness here are inversely proportional to each other.
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Optimization
The next step involved the detection of the best combination of factors that are able to produce the expected characteristics in the final product. The optimization of the baking conditions arises from compromises among the different responses (Sabanis et al., 2009). Each variable response may either be maximized or minimized. The widely accepted bread quality criteria are large volume, soft crumb and optimum crumb moisture content. Thus, to obtain such product, loaf specific volume should be maximized, crumb hardness minimized and moisture content to be controlled. As a result of optimization, the best baking conditions that were attained for the expected responses were a baking temperature of 220±2°C and baking time of 20±2 min.

CONCLUSIONS
This study showed that varying temperature-time combination during baking leads to significant changes in the physical characteristics of coriander fortified wheat breads. All the responses were significantly affected by the varying factors. Bread specific volume, crumb moisture and hardness fitted well with the quadratic model. The baking conditions obtained from optimization were 220±2°C and a baking time of 20±2 min. From this optimization, bread loafs having desired loaf weights, volume, crumb softness and crust color were obtained. Thus, the study is useful in interpreting the basic baking conditions of wheat breads fortified with herbal constituents.

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