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A response surface methodology (RSM) for optimizing the gluten free bread formulation containing hydrocolloid, modified starch and rice flour

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Abstract Response surface methodology was used to investigate the effects of xanthan gum, extruded rice flour and corn starch on the quality characteristics on gluten free bread. A rotatablecentral-composite design consisting of three variables (xanthan gum, extruded rice flour and corn starch), in a five-level pattern with 20 runs (gluten-free formulations), was prepared over three blocks. This design was used to develop models for the specific volume, crumb hardness and sensory score of the gluten free bread. Responses were mostly affected by the specific combinations of independent variable. The developed mathematical models for themeasured responses could be successfully used for their prediction during baking. Shelf life study of the optimized formulation exhibited lower crumb firmness and moisture content values, thus remained softer through storage period of five days. Shelf life analysis of the optimized formulation over five days revealed that, as crumb firmness increased, crust firmness and crumb moisture decreased.The optimized formulation determined from the data contained xanthan gum =0.74, corn starch =25.1% and pre gel rice flour of 25.2% flour basis.

Keywords: Gluten-free, rice flour, specific volume, firmness, optimization, mathematic modelling.

Introduction

Gluten-free breads require polymeric substances that mimic the viscoelastic properties of gluten in bread dough.

Response surface methodology (RSM) is effective statistical method for relating the relationship between and dependent and independent parameters. RSM is particularly appropriate for product development work. The effectiveness of response surface methodology (RSM) in optimization of ingredient levels, formulations and processing conditions in food technology from raw tofinal products such as varieties of cereal product have been documented by different researchers. RSM consists of a group of mathematical and statistical procedures that can be used to study the relationshipsbetween one or more responses (dependent variables) and factors (independent variables) (Murphy et al., 2003). RSM uses an experimentaldesign such as central composite design to fit a modelusing least squares regression analysis. Adequacy of a proposed model is revealed by diagnostic checking provided by analysis of variance (ANOVA) and residual plots. RSM is also a useful tool to minimize the numbers of trials and provide multiple regression approach to achieve optimization.

At present, no studies on the optimization of the formulation of gluten free bread using pre-gelatinized rice flour combination of corn starch and xanthan gum have been published. Therefore, the objective of the study is to optimize the gluten free bread formulations using RSM.

Material and methods

The dry ingredients were placed in a seven-speed spiral mixer (Model KM 400) and mixed for 1-2 min at 90 rpm. The yeast was dissolved in lukewarm water (30-35°C), the resulted solution was added to the dry ingredients, and finally the oil was added. The mixture was blended at 90 rpm for 2 min and following at 180 rpm for 6 min. 240 g of the resultant dough were placed in aluminium baking pans (measuring 13×6×8 cm) and proofed at an incubation chamber (Bekso EB 1N) set at 35°C and 80% relative humidity for 40 min. Baking for each sample was conducted in a laboratory oven with air circulation at 210°C for 40 min. The loaves were removed from the pans and cooled at room temperature.

Table 1 Developed formulation for gluten free bread

Ingredient	**Amount (g/100g)**
Rice flour	100
Sunflower oil	4
Yeast	15
Citrifibre	2
Sugar ,	3
Salt	2
Water[b]	-
Xanthan Gum	Variable[*]
Pre gel rice flour	Variable[*]
Corn Starch	Variable[*]

*Amount varied according to the experimental design (Table 2), b –varied to maintain same dough consistency.

Preparation of pre-gelatinized rice flour

Rice flour (1 kg) was soaked inwater (10 L) for 30 min, and the suspension was heated in a steam-jacketed kettle at 95°C for 15 min. The slurry was cooledto room temperature, spread on stainless steel trays, and driedin an air-draft oven (Name of the oven) at 110°C for 15 hr. The dried flakes were ground sieved to pass through 300 µm perforations and stored at 4°C until used. The powder composition was: The powder composition was: protein (NX5.95), 6.35%; fat, 1.98%; moisture, 6.04%; ash, 0.47%; degree of gelatinization, 93.23%. It had a particle size distribution of 165 µm maximum; 50% of the particles were <140.43 µm.

Bread Quality assessment

Breads were weighed (g) and then their loaf volume (mL) was determined by rape-seed displacement. Specific volume (mL/g) was calculated by dividing volume by weight. The moisture content of bread crumb and crust was determined by drying 5–6 g of sample in a forced convection oven at 105°C for 24 h. The samples were cooled in desiccators and weighed by an analytical balance (sensitivity, 0.01 mg). Results were expressed on a wet weight basis.

Crumb firmness was evaluated by the Texture Analyser (TA-XTi2 Stable Microsystems, Surrey, UK). The bread samples were sliced in the middle using a double blade knife (fabricated in house) to obtain uniform slices of 1 cm thickness. A two cycle's crumb compression test was performed using the SMS P/45 aluminium platen probe (probe diameter 36 mm, probe surface area 10 cm^2, test speed 3 mm/s, penetration distance 15 mm). The peak force of compression was reported as firmness (N) in accordance with the AACC method 74–09.

The shelf life of the optimized formulation was evaluated by determining crumb firmness over a five day period at the room temperature of 25°C and relative humidity of 60%. The average value of three measurements is presented. In the case of bread analysis, the replicates were from the same baking process but from different bread pieces.

Experimental Design

In designing this experiment by response surface methodology (RSM), a central composite design was employed (Table 1). Three quantitative controllable factors (independent variables) were used: level of xanthan gum (X1), level of extruded rice flour (X2) and level of corn starch (X3). Three dependent variables were selected as responses for representing the main parameters of GF bread quality: loaf volume (Y1), crumb firmness (Y2), and sensory score (Y3). After preliminary experiment, the upper and lower limits for the independent variables were established. Xanthan gum levels were from 0.5–1.5 kg/100 kg Extruded rice flour levels were 15–35 kg/100 kg and Corn starch level from 15-35 kg/100 kg. Five levels of each variable were chosen and twenty baking trials were performed for the evaluation of the optimized formulation. Six replicates at the centre of the design were used

to allow for estimation of the pure error at sum of the square. The experimental data for each response variable were fitted to the quadratic Model. The regression parameters for the equations are calculated**.**

Results and Discussion

The analyses of variance were performed to determine the lack of fit and the significance of the linear, quadratic and interaction effects of the independent variables on the dependent variables. The lack of fit test is ameasure of the failure of a model to represent data in the experimental domain at which points were not included in the regression. Coefficient of determination is the proportion of variation in the response attributed to the model rather than to random errorand was suggested that for good fit model. The results showed that the models for all the response variables were highly adequate because they have satisfactory levels of R^2 of more than 80% and lack of fit is insignificant. The regression coefficients are shown in the equations for each of the response variables could be derived from the predicted values of each response variable.

Table 2: Experimental design and response

Xanthan Gum	Pre-gel rice flour	Corn starch	Specific Volume	Crumb firmness	Over all acceptability
0.5	25	25	2.52	7.6	6.5
0.703	19.05	19.1	2.38	7.2	6.5
0.703	30.95	19.1	2.48	6.9	6.4
0.703	19.05	30.9	2.5	7.3	6.5
0.703	30.95	30.9	2.56	6.5	6.6
1	35	25	2.41	6.4	6.1
1	15	25	2.36	6.2	6.3
1	25	35	2.39	6.5	6.4
1	25	25	2.94	5.7	7.5
1	25	15	2.56	6.1	6.6
1	25	25	3.02	6	7.3
1	25	25	2.95	5.6	7.3
1	25	25	2.97	5.3	6.9
1	25	25	3.11	5.5	7.6
1	25	25	3.05	5.4	7
1.297	30.95	19.1	2.12	9	6.2
1.297	30.95	30.9	2.45	8.8	6.4
1.297	19.05	30.9	2.4	8.3	6.4
1.297	19.05	19.1	2.34	7.7	6.3
1.5	25	25	2.02	8.1	6.3

Response Surface Plots

Effect of Independent variables on Specific Volume

The relationship between the independent variable and specific volume is mentioned by the equation and fig below.

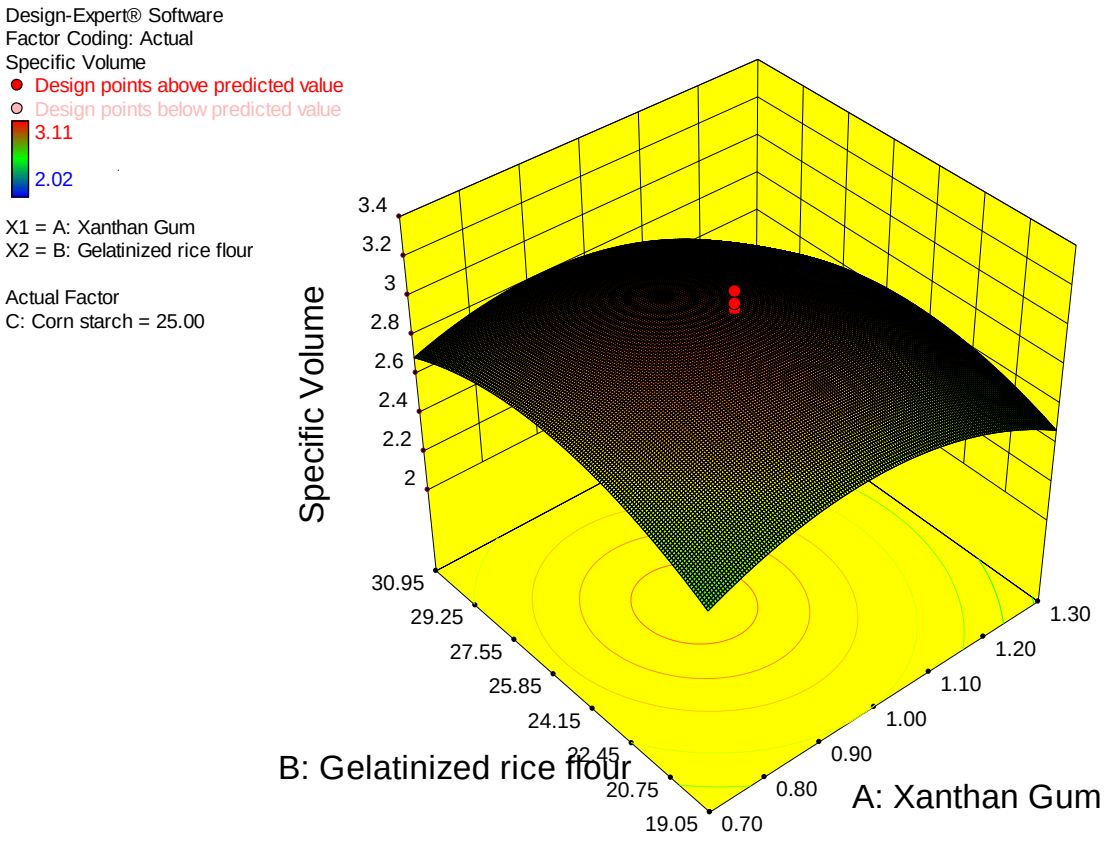


Fig 1 Response surface plot showing the effect of additive X ,Y and Z on specific volume.

Specific Volume =-6.00570+5.47168 * XG+0.29526 * Grf+0.21633 * Cs-0.023335 * XG * Grf+0.013435* XG * Cs+8.13173E-004 * Grf * Cs-2.79077 * XG^2-5.82692E-003 * Grf^2-4.92692E-003* C s^2

(R^2=0.93)…….(1)

Analysis of variance for each response showed that a significant effect (P<0.05) was found for specific volume, with regard to xanthan gum, pre-gel rice flour and corn starch. All the three variables exhibited positive linear and negative quadratic effect as seen from the equation. The combination of medium levels of three independent factors resulted in the highest specific volume.

Addition of extreme levels of xanthan gum, pre gel rice flour and corn starch resulted in the decrease in the specific volume of the gluten free bread. Reason may be attributed to the fact that interaction of xanthan gum with starch decreased gas retention capacity of the gluten free batter and thus modified the rheological behavior of batter to the lower consistency of and high plasticity of the structure.

Effect of Independent variables on Crumb firmness

The resistance of the bread crumb to deformation is the textural attribute referred to as firmness and it is an important factor in bakery products since it is strongly correlated with consumers' perception of bread freshness.

The relationship between the independent variable and crumb firmness can be seen from the fig.2. Analysis of variance shows that a significant effect ($P<0.05$) is found for crumb firmness, with regard to all the three independent variables. All the variables exhibited positive linear and quadratic effect.(equation 2)

Crumb firmness = 32.94161-26.75737 * XG-0.68075 * GRF-0.52843 * CS + 0.20506 * XG* GRF+0.049497 * XG * CS-4.59619E-003 * GRF * CS+11.02682 * XG^2+0.012067 * GRF^2+0.012067 * CS^2……..(2)

Addition of the corn starch, pre gel rice flour and xanthan gum at the extreme end decreased the crumb firmness of the gluten free bread.

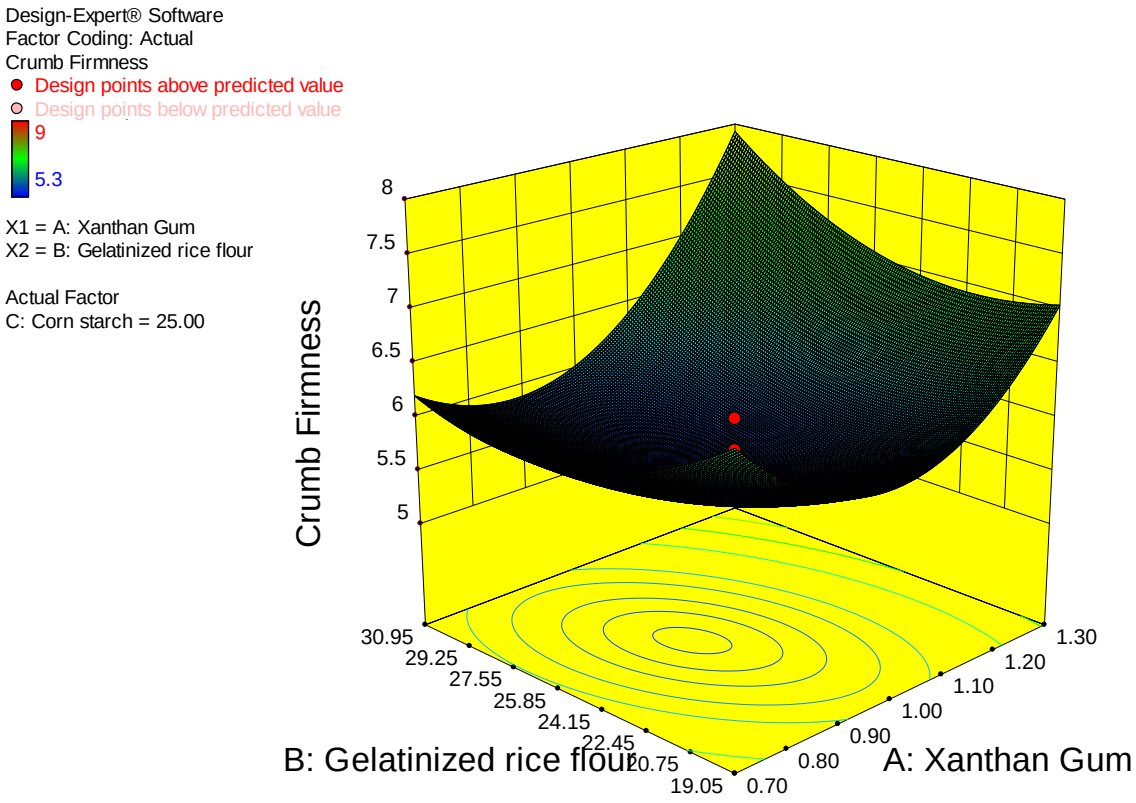


Fig 2 Response surface plot showing the effect of additive X ,Y and Z on crumb firmness.

Effect of Independent variables on overall acceptability

The relationship between the overall acceptability and independent variables are shown in the equation. Breads containing middle levels of the independent variables were rated high due to their good taste and flavour. Response surface plot (Fig. 3) shows that up to a certain limit acceptability increased as the independent variable interacted among each other. The combination of medium levels of both factors resulted in the highest scores in terms of overall acceptability.

Over all acceptability =

-5.67042+6.19855 * XG+0.47854 * Grf+0.32179 * Cs-7.07107E-003 * XG * Grf+7.07107E-003 * XG* Cs+1.06066E-003 * Grf * Cs -3.22690 * XG^2-0.010067 * Grf^2-7.06725E-003 * Cs^2……(3)

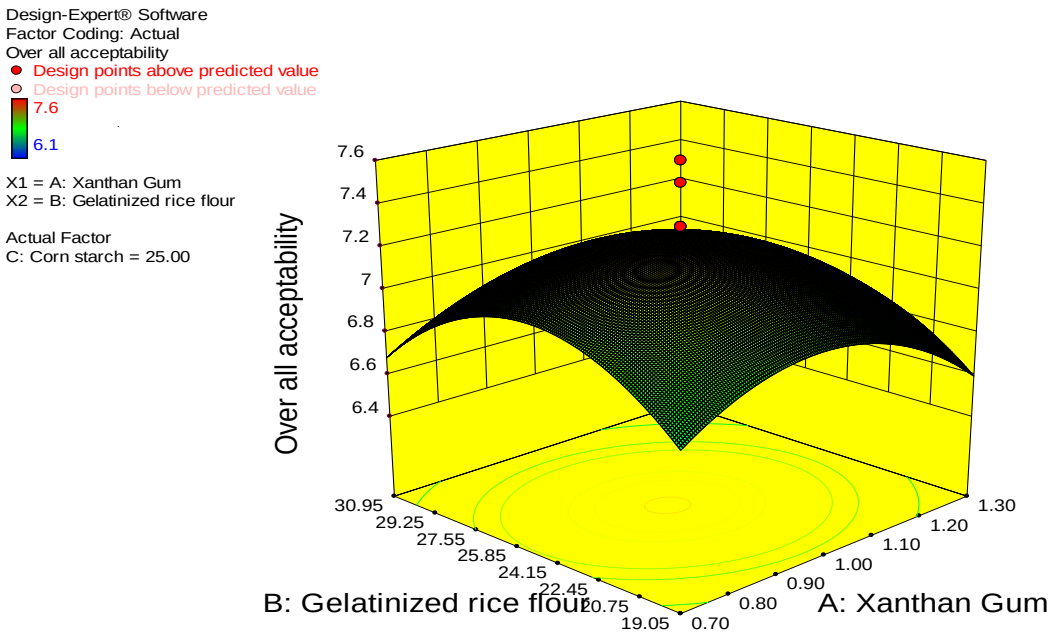


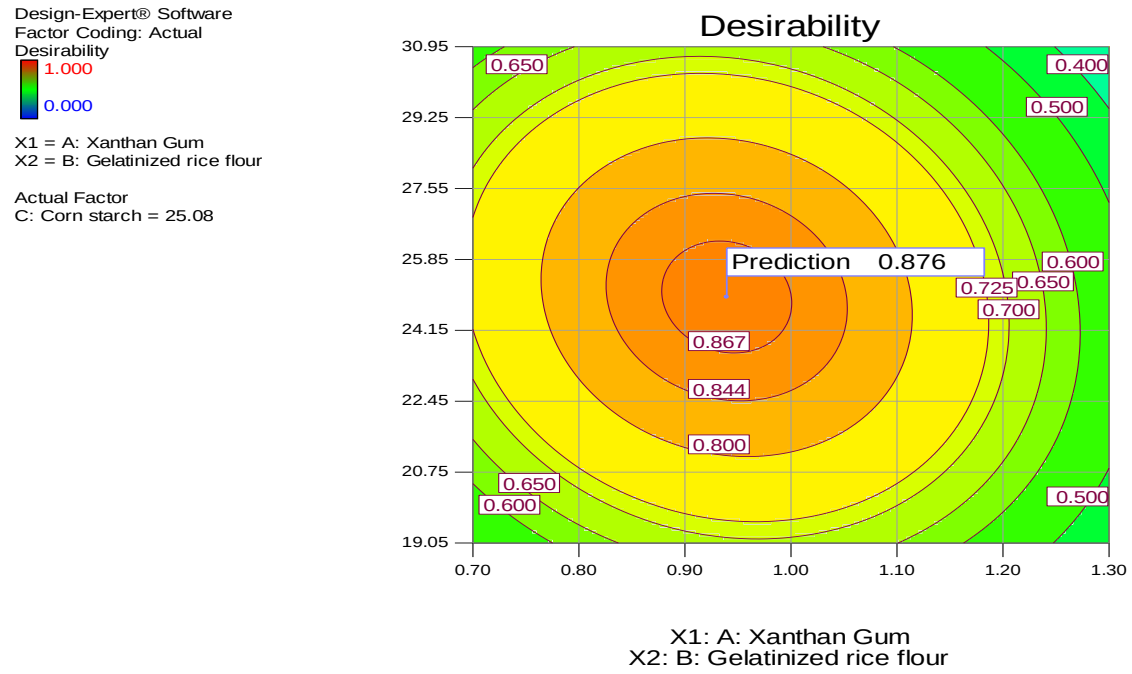
Fig 3 Response surface plot showing the effect of additive X ,Y and Z on over all acceptability.

Optimization

The result obtained from the RSM plot indicated the dependence of combination of independent factor on the quality attributes of gluten free bread. Response surface plots were taken into account in the optimization, considering that the optimal solution arises from an interaction among the different responses. The criteria of optimization were selected on the basis of for widely accepted breads quality criteria like large volume, soft crumb, and high overall acceptability. Thus considering the above mentioned approach, the objective was to maximize the responses for loaf-specific volume and sensory score and to minimize crumb firmness.

Optimization was performed on the basis of a multiple response method called desirability. This optimization method incorporates desires and priorities for each of the variables. This procedure involved transforming scores on each of the dependent variables into desirability scores that could range from 0.0 for undesirable to 1.0 for very desirable. After transforming the predicted values of the dependent variables at different combinations of levels of the predictor variables into individual desirability scores, the overall desirability of the outcomes at different combinations of levels of the predictor variables can be computed as the geometric mean of the individual desirabilities.

As a result of the optimization step, the best conditions, which were attained for the expected response value were, xanthan gum =0.74%, corn starch =25.08% and pre gel rice flour of 25.155% flour basis. The calculated desirability for this formulation was 0.87 and resulted bread of good quality, which was subsequently analysed in order to compare predicted responses to measured values. The response variables of the bread can be predicted by using the achieved mathematical models.



Conclusion

Response surface methodology was successfully applied to optimize corn starch, xanthan gum and pre gel rice flour in GF bread. The three variables employed in the study had a great effect on thequality of GF bread. Up to a certain limit of xanthan gum addition, the specific volume increasedand crumb firmness decreased. Modeling of experimentaldata allowed the generation of useful equations for general use, to predict the behavior ofthe system under different factor combinations.

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