Nutritional and storage stability of wheat-based crackers incorporated with brown rice flour and carboxymethyl cellulose (CMC)

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ABSTRACT

A study was conducted to develop brown rice flour (BRF) incorporated wheat-based crackers. Central composite rotatable design with three independent variables – BRF (10–40%), carboxymethyl cellulose (CMC) (1–3%), and shortening (5–12%) – produced 20 different combinations. Response surface methodology was used to study the effect of different levels of BRF, CMC, and shortenings on product characteristics like spread ratio, volume index, density, width, thickness, and puffiness. All the three independent variables significantly \((p < 0.05)\) affected the product characteristics. However, BRF had more pronounced effect on product characteristics than other two independent variables. The optimum level of ingredients obtained by numerical optimization for development of crackers was – BRF to wheat flour ratio (10:90), CMC (1.8%), and shortening (5%). The optimized product packed in cellophane bags was found shelf stable for a period of 3 months under ambient conditions. The present study, therefore, confirms the feasibility of BRF incorporation (10%) in development of wheat-based crackers.

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Introduction

Bakery products with good nutritional profile, sensory characteristics, and texture are relished by present day consumers and are most popular among all age groups. \([1]\) Due to growing consumer demands for convenience foods, crackers represent one of the fast-growing segment of bakery products. \([2]\) Long shelf-life, good eating quality, and attractive appearance of crackers makes their large-scale production and distribution possible. \([3]\) However, wheat is basic ingredient in crackers and has low content of essential amino acids like lysine, methionine, and threonine. \([4]\) Also in recent years, consumers’ concern over potential health problems caused by eating bakery products has grown due to gluten, a protein found in wheat. \([5]\) Due to health benefits of fibre, the cereal bran, legume husk, and other potential sources of dietary fibre are being explored in food processing world-wide. \([6]\) Many bakery products incorporated with dietary fibre sources have been developed by various researchers. Bose and Shams-ud-din \([6]\) conducted a study to evaluate the effect of chickpea incorporation on physical parameters of wheat-based crackers. A similar study conducted by Jauharah \([7]\) has examined the effect of substituting wheat flour by young corn flour for development of fibre-rich biscuits and muffins. Cashew pomace flour-supplemented biscuits were developed by Akubor. \([8]\)

Brown rice is highly nutritious, fibre rich, and a good source of protein and minerals. Incorporation of brown rice flour (BRF) in bakery products gives a characteristic nutty flavour and chewy texture. \([9]\) In addition, rice flour is gluten free and possesses unique attributes such as
bland taste, ease of digestion, hypoallergenic properties, and easily digestible carbohydrates, which make it an ideal ingredient for development of bakery products, particularly for celiac patients.\textsuperscript{[10]}

However, rice flour lacks gluten-forming protein and has, therefore, poor functional properties. Many researchers have used hydrocolloids to improve the quality characteristic of bakery products. The basic reason behind this is the ability of hydrocolloids to modify the rheology and improve the sensory quality of the foods.\textsuperscript{[11]} Therefore, hydrocolloids have an important role as food additives in bakery industry.

Therefore, considering cracker quality, consumer interest, and role of ingredients, there was need to optimize the levels of different ingredients for development of crackers from the blend of wheat and BRFs. The optimization can be done by various techniques. One of the most effective and commonly used techniques for this purpose is response surface methodology (RSM), which combines statistical and mathematical techniques and is useful for developing, improving, and optimizing the processes.\textsuperscript{[12]} RSM is a faster and economical method for gathering research results than classic one variable at a time or full-factors experimentation. It has important application in the design, development, and formulation of new products, as well as in the improvement of existing designs.\textsuperscript{[13]} The present study was aimed to optimize the levels of ingredients like BRF: wheat flour, CMC, and shortenings for development of nutritious crackers, which will open a new horizon for development of bakery products like crackers from BRF.

**Material and methods**

**Raw material**

Paddy (variety: \textit{Jhelum}) and wheat (variety: SKW-355) were procured from Mountain Research Centre for Field Crops, Khudwani, SKUAST-Kashmir. Paddy was subjected to milling in modern rice mill (Model ASR RM 209, Australia) at Division of Food Science and Technology, SKUAST-Kashmir to obtain brown rice. Both brown rice and wheat were ground separately in a mill (Model 3303, Perten Sweden) to the fineness that passed through 200-µm sieve. Both the flours were packed in a low-density polythene bags and stored under refrigerated conditions for further use.

**Preparation of crackers**

Crackers were prepared by following the procedure of Mir\textsuperscript{[10]} as per the treatment combinations listed in Table 1. Dry ingredients were mixed in a mixer, whilst the liquid ingredients were mixed separately to form emulsion. Concentration of salt (1g/100 g) was kept constant for each treatment. The emulsion was incorporated into the dry ingredients and mixing was done through high-speed mixer. Dough was wrapped in polythene bags and left at room temperature for 30 min to ensure uniform distribution of liquid. Dough sheeting was done manually to a thickness of 2.5 mm and press mould was used to cut sheets to a width of 35 mm. Baking was done in double-deck baking oven at 170°C for 10 min. After cooling for 5 min at room temperature, the crackers were wrapped in plastic pouches and kept at room temperature for further investigation.

**Experimental design for development of crackers**

Central composite rotatable design (CCRD) was used to incorporate the three selected independent variables – BRF, CMC, and shortening. This design required 20 experimental runs with eight ($2^3$) factorial points, six-star corner points (two for each variable), and six central points. Overall, the design yielded five levels for each variable.\textsuperscript{[14]} The central composite rotatable design coded levels and experimental ranges of the three independent variables are shown in Table 1.
Determination of product responses

Physical characteristics: Width and thickness of crackers were measured by digital calliper of 0.001-mm accuracy. Density was determined as the ratio of mass to volume. Spread ratio of crackers was calculated by dividing the average value of diameter by average value of thickness. Volume index of sample was measured by following the procedure of Turabi. Percentage puffiness was determined using the following equation:

$$\text{Puffiness(\%)} = \frac{\text{thickness of baked cracker} - \text{thickness of cracker dough}}{\text{thickness of cracker dough}} \times 100 \quad (1)$$

Proximate composition analysis: Protein, moisture, ash, fibre, and fat were determined according to the standard methods of AOAC. Carbohydrate content was estimated by difference method using the following equation:

$$\text{Carbohydrate(\%)} = 100 - (\%\text{Protein} + \%\text{Moisture} + \%\text{Fat} + \%\text{Ash} + \%\text{Fibre}) \quad (2)$$

Instrumental texture profile analysis

A TA-XT2 Texture Analyser (Perkin Elmer Private Limited, Godalming, Surrey UK) with 5-kg load cell was used for texture profile analysis (TPA) of crackers. The testing conditions for determination of TPA were – pre-test speed: 1 mms⁻¹; post-test speed: 10 mms⁻¹, test speed: 3 mms⁻¹, trigger force: 50 g, and travel distance of the probe kept as 5 mm. The texture was measured by adjusting the compression plunger until it barely touched the surface of cracker at the centre of sample. The plunger was lowered at a constant speed until it compressed the sample to a pre-determined degree (percentage of compression). The test was performed in accordance with the procedure given by Chung.

Mineral content and total sugar content

Mineral content was determined by following the standard procedures of AOAC using Atomic Absorption Spectrometer. Total sugar content was determined by anthrone method.

### Table 1. Effect of ingredients on physical characteristics of crackers.

| Runs | BRF* (%)(x₁) | CMC* (%)(x₂) | Shortening (%)(x₃) | Spread Ratio(y₁) | Volume Index (cm³)(y₂) | Density (g/cm³)(y₃) | Thickness (mm)(y₄) | Width (mm)(y₅) | Puffiness (mm)(y₆) |
|------|--------------|--------------|--------------------|------------------|------------------------|---------------------|-------------------|---------------|------------------|
| 1    | (–1) 10      | (–1) 1.5     | (–1) 5.0           | 6.6              | 1.89                   | 0.669               | 6.2               | 35.3          | 49.0             |
| 2    | (+1) 30      | (–1) 1.5     | (–1) 5.0           | 5.2              | 1.68                   | 0.702               | 6.4               | 35.4          | 35.5             |
| 3    | (–1) 10      | (+1) 3.0     | (–1) 5.0           | 6.1              | 1.83                   | 0.672               | 4.9               | 37.0          | 46.9             |
| 4    | (+1) 30      | (–1) 1.5     | (–1) 5.0           | 5.3              | 1.75                   | 0.681               | 6.7               | 35.0          | 32.2             |
| 5    | (–1) 10      | (+1) 1.5     | (+1) 12            | 6.9              | 1.87                   | 0.667               | 6.9               | 35.4          | 30.0             |
| 6    | (+1) 30      | (–1) 1.5     | (+1) 12            | 5.7              | 1.65                   | 0.678               | 6.9               | 35.8          | 20.0             |
| 7    | (–1) 10      | (+1) 3.0     | (+1) 12            | 6.6              | 1.74                   | 0.669               | 5.1               | 37.2          | 30.0             |
| 8    | (+1) 30      | (+1) 3.0     | (+1) 12            | 5.9              | 1.44                   | 0.675               | 6.8               | 36.8          | 20.0             |
| 9    | (–1.682) 2.5 | (0) 2.0      | (0) 8.5            | 7.1              | 2.02                   | 0.657               | 4.7               | 37.4          | 52.7             |
| 10   | (+1.682) 40  | (0) 2.0      | (0) 8.5            | 5.0              | 1.45                   | 0.718               | 7.2               | 34.6          | 15.0             |
| 11   | (0) 20       | (–1.682) 1.0 | (0) 8.5            | 5.6              | 1.93                   | 0.697               | 7.1               | 35.8          | 50.0             |
| 12   | (0) 20       | (+1.682) 3.5 | (0) 8.5            | 5.7              | 1.51                   | 0.656               | 5.6               | 36.7          | 21.0             |
| 13   | (0) 20       | (0) 2.0      | (–1.682) 2.5       | 5.7              | 2.00                   | 0.694               | 5.7               | 34.5          | 60.0             |
| 14   | (0) 20       | (0) 2.0      | (+1.682) 14        | 6.8              | 1.47                   | 0.651               | 7.2               | 37.1          | 19.0             |
| 15   | (0) 20       | (0) 2.0      | (0) 8.5            | 6.7              | 1.63                   | 0.688               | 6.3               | 36.0          | 30.0             |
| 16   | (0) 20       | (0) 2.0      | (0) 8.5            | 6.7              | 1.63                   | 0.688               | 6.3               | 36.0          | 30.0             |
| 17   | (0) 20       | (0) 2.0      | (0) 8.5            | 6.7              | 1.63                   | 0.688               | 6.3               | 36.0          | 30.0             |
| 18   | (0) 20       | (0) 2.0      | (0) 8.5            | 6.7              | 1.63                   | 0.688               | 6.3               | 36.0          | 30.0             |
| 19   | (0) 20       | (0) 2.0      | (0) 8.5            | 6.7              | 1.63                   | 0.688               | 6.3               | 36.0          | 30.0             |
| 20   | (0) 20       | (0) 2.0      | (0) 8.5            | 6.7              | 1.63                   | 0.688               | 6.3               | 36.0          | 30.0             |

*BRF: Brown rice flour; *CMC = Carboxymethyl cellulose
Sensory evaluation

Sensory evaluation was done by a panel of 30 semi-trained judges on 5-point scale (5- excellent; 4- very good; 3- good; 2- fair; 1- poor). The different sensory attributes evaluated during evaluation were colour, appearance, taste, aroma, texture, and overall acceptability.

Free fatty acids

Standard AOAC procedure \cite{17} was followed for determination of free fatty acids (FFA) in crackers during storage. A 5-g sample was taken in a flask to which 50-mL benzene was added and kept for 30 min for extraction of FFA. 5-mL extract, 5-mL benzene, 10-mL alcohol, and phenolphthalein as indicators were taken in a flask and titrated against 0.02N KOH till colour disappeared.

The FFA value was calculated by using the following equation:

\[
\text{FFA (as oleic acid)} = \frac{282 \times 0.02N\text{KOH} \times \text{mL of alkali} \times D.F}{1000 \times \text{weight of sample (g)}} \times 100
\] (3)

Microbiological analysis

The stored samples were analysed for bacterial growth by standard serial dilution plate count method using nutrient agar as a medium for growth. \cite{20}

Statistical analysis

Responses obtained as a result of proposed experimental design (CCRD) were subjected to regression analysis to access the effect of BRF incorporation, CMC, and shortenings on product characteristics of wheat-based crackers. Second-order polynomial models were established for the dependent variables to fit experimental data for each response with Statistical Software Design Expert 9 (Stat-ease Inc, Minneapolis, MN, USA). The optimum-condition criteria applied for numerical optimization were to maximize spread ratio, volume index, and puffiness and to minimize thickness, width, and density. Storage experiment was carried out in triplicate and data were analyzed using design factorial in completely randomized design as suggested by Snedecor and Cochran. \cite{21}

Result and discussion

Models

Models for all the selected physical parameters were highly significant (\(p < 0.05\)) with high coefficient of determination (\(R^2 = 0.99 – 0.67\)), which indicates that developed models could be used to navigate the design space and for prediction of responses correctly. For all the parameters, predicted and adjusted \(R^2\) were in reasonable agreement with each other. Coefficient of variation range (1.08 – 15.81) depicted the accuracy and reproducibility of models. High adequate precision range (11.58 – 46) indicates the adequate model discrimination for all the parameters. All the models showed non-significant lack of fit, which indicated that all second order polynomial models correlated well with the measured data.

Effect of ingredients on physical characteristics of crackers

Spread ratio

Spread ratio is correlated with texture, grain finenesse, bite, and overall mouth feel and is considered one of the most important quality parameter of crackers. \cite{1} High spread ratio is desirable in case of crackers. \cite{22} The spread ratio of developed crackers varied from 5 to 7.1 (Table 1). The regression model for spread ratio is shown in Eq. (4).
The fitted model indicates the significant \((p < 0.05)\) quadratic effect with all the three independent variables whilst BRF and shortenings also showed significant \((p < 0.05)\) linear effects and a significant \((p < 0.05)\) interactive effect was also observed for BRF and CMC with spread ratio. The negative coefficient of the linear terms of \(x_1\) and \(x_2\) indicate that spread ratio decreased significantly \((p < 0.05)\) with the increase in concentration of BRF \((x_1)\) and CMC \((x_2)\) whilst the positive coefficient for linear term of shortening \((x_3)\) depicted a significant \((p < 0.05)\) increase in spread ratio with the increase in shortening concentration.

Higher concentration of BRF increases the number of available hydrophilic sites for limited free water in dough. Islam \cite{23} reported that the number of hydrophilic sites in composite flour increases due to formation of aggregates. Rapid partitioning of free water in hydrophilic sites occurs during dough mixing, which increases dough viscosity, thereby limiting the spread of crackers. \cite{15} The decrease in spread ratio with the addition of BRF in the present study may also be due to the decrease in total gluten content and increase in protein-rice content. Singh \cite{24} have also reported a decrease in the spread ratio of cookies with the increase in non-wheat protein content. Similar findings were reported by Islam \cite{20} for spread ratio when wheat flour was substituted with BRF.

Further, the inference drawn from the fitted model and response surface plots (Fig. 1b) was that spread ratio increased with the shortening addition. Addition of shortening increases the dough extension by enhancing the elasticity, tenderness, and extensibility of dough, which increases the spread ratio of crackers. However, the negative coefficient of quadratic term of shortening represent that at high shortening levels, spread ratio of cracker decreases. Fat, when present in larger amount, surrounds the protein and starch granules, which reduce the dough spread by limiting the continuity of protein matrix. \cite{20} The results are in concomitance with the findings reported by Singh \cite{24} in corn-and-potato-flour biscuits and Sudha \cite{25} in oats and wheat bran incorporated biscuits.

**Volume index**

Volume index is an indicator of cracker volume. It is a vital index which governs the quality of crackers and generally influenced by the ingredients used. \cite{26} Cracker with high volume index has better consumer acceptability. \cite{22} The volume index of developed cracker was found in range of 1.44 to 2 cm (Table 1).

\[
\text{Volume index} = 1.68 - 0.14x_1 - 0.066x_2 - 0.099x_3
\]

Equation (5), representing the fitted model for volume index, indicates that volume index of cracker was significantly \((p < 0.05)\) affected by BRF, CMC, and shortening addition. The effects were, however, only linear with all the three independent variables. The negative coefficients of linear terms of BRF \((x_1)\), CMC \((x_2)\) and shortening \((x_3)\) indicates the negative relationship of all the three independent variables with volume index. Thus, with the increase in concentration of any of these variables, volume index of crackers was decreased, the same can be observed in response surface plots (Fig. 1c) as well. However, BRF incorporation had most prominent negative effect than other two independent variables.

More the BRF levels, more the gluten dilution and mechanical disruption of gluten network, which leads to poor gas retention and thus, lowers the ability of dough to enclose air. This may be the possible reason for decrease in volume index with the increase in levels of BRF. \cite{27,28} Kohajdová \cite{15} also found the negative relation of pea-flour incorporation with volume index in wheat-based crackers. The negative correlation of CMC and shortening with volume index may be attributed to decrease in cohesive protein matrix, elasticity, and dough extensibility with the increase in CMC and shortening. \cite{29}

**Density**

Density is an important quality parameter in crackers. Light weight and less dense crackers are highly desirable by consumers. \cite{30} The density of the developed crackers was found in range from
0.651 to 0.718 g cm$^{-3}$ (Table 1). The fitted regression model for density, shown in Eq. (6), indicates that density was linearly affected by all the three independent variables as no quadratic and interactive effects were observed.

\[
\text{Density} = 0.68 + 0.013x_1 - 0.0071x_2 - 0.078x_3 \tag{6}
\]

The response surface plots (Fig. 1d) also illustrate a relationship between independent variables and density. The negative coefficient of linear terms of $x_2$ and $x_3$ in Eq. (6) suggests that density was...
significantly (p < 0.05) decreased with increase in CMC and shortening concentration. The positive coefficient of linear term of BRF (x₁) indicates a significant increase in density of crackers with increase in BRF percentage.

Replacement of wheat flour with BRF lowers the gas retention power of flour mixture, which leads to more compact and denser product formation. [9] The result are in accordance with the findings reported by Islam [23] in biscuits developed from blend of brown rice and wheat flours. Shortenings increase the air incorporation at the dough stage; whereas, addition of CMC enlarges volume, decreases crumb falling, and prevents collapse during baking process. These reasons could be related to low density of crackers upon addition of CMC (x₂) and shortening (x₃). [29,31]

**Width**

The width of developed cracker was found to be in the range of 34.5 to 37.4 mm (Table 1). The fitted regression model shown in Eq. (7) indicates significant linear effects of all the three independent variables with the width of crackers. Response surface plots (Fig. 1f) and regression Eq. (7) show that with the increase in level of BRF, width of crackers was decreased. The linear coefficients for CMC and shortening, as represented in Eq. (7), are positive, which indicates a significant increase in width of cracker with increase in CMC and shortening concentration.

\[
\text{Width} = 36.04 - 0.53x_1 + 0.40x_2 + 0.50x_3
\]  

(7)

Inverse relation of cracker width with BRF was possibly due to large particle size of BRF, which adversely affected the width of crackers. [6] Islam [23] have also reported a decrease in width and increase in thickness of crackers when wheat flour was substituted with BRF. Eissa [32] and Tiwari [33] have also reported the similar effects on the thickness and diameter of wheat-based biscuits substituted with different proportions of chickpea, kidney pea, and pigeon pea flours.

Increased concentrations of shortening and CMC increased the width of crackers. CMC is reported to unexpectedly decrease the height of dough [34] and fat incorporation increases the elasticity of the dough, [25] which possibly increased the width and reduced the thickness of crackers. Similar findings have been reported by Pareyt [31] in wheat-based cookies. Kamal [11] also reported an increase in width and decrease in thickness upon addition of CMC in whole wheat flour biscuits supplemented with rice bran.

**Thickness**

Crackers with less thickness are generally preferred by the consumers. The thickness values of developed crackers varied from 4.7 to 7.2 mm (Table 1). The fitted regression equation for thickness shown in Eq. (8) indicates that thickness of cracker was linearly affected by BRF, CMC, and shortening addition; whereas, significant (p < 0.05) interactive effect was shown by BRF and CMC only.

\[
\text{Thickness} = 6.20 + 0.61x_1 - 0.37x_2 - 0.30x_3 + 0.39x_1x_2
\]  

(8)

Fitted model and response surface plots (Fig. 1e) reveal an inverse relationship of CMC (x₂) and shortening (x₃) and positive relationships of BRF (x₁) with the thickness.

Both regression Eqs. (7) and (8) and response surface plots (Figs. 1e and 1f) show inverse relationship between width and thickness values. Change in thickness values is due to change in width values, which is also reflected in spread ratio values. [23]

**Percentage puffiness**

From consumer’s point of view, puffiness is one of the most important attributes in crackers. Percentage puffiness recorded in developed crackers was in the range of 15 to 60 (Table 1). Eq. (9) represents the fitted model for puffiness.

\[
\text{Puffiness} = 32.23 - 8.62x_1 - 3.76x_2 - 9.90x_3
\]  

(9)
The equation represents significant linear effects of BRF \((x_1)\), CMC \((x_2)\), and shortening \((x_3)\) with the puffiness percentage. The negative coefficients of linear terms of independent variables indicate that puffiness percentage was decreased with the increase in BRF, CMC, and shortening concentration (Fig. 1g). Out of the three selected independent variables, the effect of shortening was most predominant on puffiness percentage.

Decrease in puffiness upon addition of BRF can be adduced to the fact that rice flour lacks the ability to hold air cells due to absence of gluten. Addition of CMC makes the dough rigid, which prevents the air incorporation. Further, the interaction between hydrocolloids and proteins limits the free expansion of dough during proofing. Puffiness in crackers also decreased with the increase in shortening Eq. (9). High fat content may inhibit the dough rising during proofing, which may have resulted in the decreased puffiness of crackers.

**Optimization**

The desirability function of the response surface for determining optimum level of ingredients for development of BRF-incorporated wheat-based crackers is shown in Fig. 1a. By applying the desirability function method and covering our criteria, the best solution obtained for development of desired crackers was selected. The desirability value obtained was 0.74 and optimum levels of BRF, CMC, and shortenings for development of crackers were estimated as BRF (10%), CMC (1.8%), and shortening (5%). Following the optimum ingredient levels, the crackers with spread ratio- 6.52, volume index- 1.89 cm, density- 0.66 gcm\(^{-3}\), width- 37.24 mm, thickness- 5.73 mm, and puffiness- 54.67% were developed (Fig. 2). It can be observed from Table 2 that predicted response values and actual obtained values were almost similar with a variation of less than 4%. The crackers prepared from optimized level of ingredients were analysed for proximate composition, total sugar content, and mineral content.

The moisture content was found to be 2.2%, protein 8.4%, fat 20.5%, ash 1.67%, fibre 1.76%, carbohydrates 65.44%, and total sugars 1.96%. The iron, magnesium, phosphorus, calcium, potassium, and sodium were recorded as 0.025%, 0.13%, 0.36%, 0.21%, 0.42%, and 0.0032%, respectively, in the optimized product. The proximate composition values of crackers are more or less similar to those reported by Kabirullah for different types of biscuits.

The crackers developed from optimized level of ingredients were packed in cellophane bags and kept under ambient storage conditions for a period of 90 days to determine the shelf stability of the crackers.

**Table 2. Predicted response levels and actual response levels.**

| Values   | Spread Ratio | Volume Index (cm) | Density (gcm\(^{-3}\)) | Width (mm) | Thickness (mm) | Puffiness (%) |
|----------|--------------|-------------------|-------------------------|------------|----------------|---------------|
| Predicted| 6.675        | 1.952             | 0.680                   | 35.830     | 5.512          | 52.70         |
| Actual   | 6.52         | 1.89              | 0.66                    | 37.24      | 5.73           | 54.67         |
| Variation (%) | 2.09       | 3.07              | 2.94                    | 3.78       | 3.83           | 3.14          |
Table 3. Effect of storage on different quality attributes of BRF incorporated wheat-based crackers.

| Days of Storage | Moisture (%) | FFA (%) | TPC (cfu/g) × 10^2 | TPA | Sensory evaluation |
|----------------|--------------|--------|-------------------|-----|-------------------|
|                |              |        |                   |     | Hardness (N)      |
|                |              |        |                   |     | Fracturerability (mm) |
|                |              |        |                   |     | Cohesiveness |
|                |              |        |                   |     | Adhesiveness |
|                |              |        |                   |     | Springiness |
|                |              |        |                   |     | Appearance |
|                |              |        |                   |     | Colour |
|                |              |        |                   |     | Taste |
|                |              |        |                   |     | Aroma |
|                |              |        |                   |     | Texture (Hardness) |
|                |              |        |                   |     | Over all Acceptability |
| 0              | 2.22 ± 0.025 | 0.81 ± 0.36 | 3.136 ± 2.12 | 23.73 ± 1.33 | 9.53 ± 0.24 | 0.79 ± 0.06 | 0 | 3.12 ± 0.14 | 4.3 ± 0.1 | 4.7 ± 0.0 | 4.8 ± 0.2 | 4.3 ± 0.1 | 4.6 ± 0 | 4.7 ± 0.3 |
| 30             | 2.51 ± 0.04 | 1.22 ± 0.09 | 20.53 ± 1.38 | 18.88 ± 1.73 | 10.46 ± 0.09 | 0.65 ± 0.13 | −0.07 ± 0.003 | 2.27 ± 0.22 | 4.3 ± 0.0 | 4.7 ± 0.4 | 4.5 ± 0.2 | 4.3 ± 0.3 | 4.1 ± 0.3 | 4.5 ± 0.1 |
| 50             | 2.97 ± 0.13 | 1.52 ± 0.58 | 47.24 ± 0.57 | 15.54 ± 2.08 | 11.13 ± 0.31 | 0.54 ± 0.002 | −0.10 ± 0.001 | 1.98 ± 0.16 | 4.1 ± 0.2 | 4.5 ± 0.1 | 4.3 ± 0.5 | 4.1 ± 0.2 | 4 ± 0.1 | 4 ± 0.5 |
| 70             | 3.20 ± 0.07 | 1.74 ± 1.73 | 75.46 ± 1.95 | 13.91 ± 0.65 | 13.86 ± 0.07 | 0.37 ± 0.18 | −0.13 ± 0.005 | 1.71 ± 0.09 | 4.1 ± 0.1 | 4.5 ± 0.3 | 4 ± 0.2 | 4.1 ± 0.3 | 3.8 ± 0.3 | 3.8 ± 0.2 |
| 80             | 3.41 ± 0.01 | 1.91 ± 0.41 | 92 ± 0.98 | 13.16 ± 0.32 | 13 ± 0.03 | 0.24 ± 0.08 | −0.2 ± 0.001 | 1.47 ± 0.21 | 4 ± 0.1 | 4.5 ± 0.1 | 4 ± 0.4 | 4 ± 0.2 | 3.6 ± 0.2 | 3.6 ± 0.4 |
| 90             | 3.57 ± 0.1 | 2.07 ± 0.12 | 111.66 ± 1.54 | 12.59 ± 1.17 | 13.26 ± 0.54 | 0.13 ± 0.038 | −0.23 ± 0.125 | 1.25 ± 0.12 | 4 ± 0.3 | 4.3 ± 0.2 | 3.8 ± 0.3 | 4 ± 0.3 | 3.4 ± 0.3 | 3.4 ± 0.3 |
| C. D.          | 0.073        | 0.046 | 0.077 | 1.21 | 0.517 | 0.051 | N. S | 0.074 | N. S | N. S | 0.46 | N. S | 0.55 | 0.49 |

The values are mean ± S.D. of three independent determinations. N. S: Non-Significant.
The crackers were evaluated for moisture content, FFA, total plate count (TPC), TPA, and sensory evaluation on 0, 30, 50, 70, 80, and 90 days of storage. The storage results are depicted in Table 3.

**Moisture content and FFA**
Gradual increase in moisture content from 2.2 to 3.57% (Table 3) was observed during 90 days of storage. The increase in moisture content during storage may be attributed to the hygroscopic nature of crackers. Butt [37] stated that the increase in moisture content of flour during storage period of 90 days was due to relative humidity and hygroscopic properties of flour. Likewise, Nagi [1] correlated moisture gain in snacks during storage with hygroscopicity. FFA was significantly (p < 0.05) affected by storage time. The FFA content was increased from 0.81 to 2.07% during 90 days of storage. The highest value of FFA (2.07%) recorded in crackers on 90th day of storage was within the permissible limit. A similar increasing trend in FFA was also observed by Uma [38] in deep-fried snacks developed from rice brokens.

**Total plate count**
TPC was estimated to detect the presence of microorganisms in BRF-incorporated crackers during storage. Length of storage had a significant (p ≤ 0.05) effect on TPC of crackers. TPC was found to increase with the increase in storage period from $3.36 \times 10^2$ to $111.66 \times 10^2$ cfu/g. The increase in TPC may be attributed to increase in moisture content during storage. [39] The maximum TPC ($111.66 \times 10^2$) recorded on 90th day of storage was within the safe limit of 50,000 prescribed by Indian standard for high-protein biscuits. [1]

**Texture profile analysis**
Textural property is one of the major factors contributing to the eating quality of crackers. Length of storage period significantly affected all the parameters of TPA except adhesiveness (Table 3). Hardness, which is the most important textural characteristics for crackers, was measured as the peak force to snap the crackers. Due to increase in moisture content, hardness of crackers decreased with the increase in storage time from 23.73 to 12.59N. [40] Distance at which the cracker breaks gives the fracturability. Crackers that break at shorter distances have higher fracturability. [7] The decrease in fracturability of crackers was observed from an initial value of 9.53 at 0 day to 13.26 mm on 90th day of storage, which was possibly due to the increase in moisture content and decrease in hardness during storage. A measure of how well the structure of product withstands compression gives the cohesiveness of the product. [41] The cohesiveness was found to decrease from an initial value of 0.79 to 0.13 at the end of storage. The decrease in cohesiveness was probably due to increase in crystallinity of fat structure over storage time. [42] Springiness indicates the ability of sample to recover its height that elapses before the end of first compression and start of other. [41] Springiness was found to decrease in crackers from an initial value of 3.12 to 1.25 during storage. Decrease in springiness has been related to the loss of porous structure in crackers during storage.

**Sensory evaluation of stored product**
Out of six sensory attributes studied, storage period had significant effect on only taste, texture, and overall acceptability of crackers. All the three sensory attributes (taste, texture, and overall acceptability) were found to decrease with the increase in storage time. The decrease in the texture score was due to moisture gain and reduced crispiness of crackers during storage. Rancid taste was reported to have developed in crackers on 90th day by some panellists, which may have been due to increase in FFA content during storage. [38] Due to decreasing trend in all the sensory attributes, a decreasing trend in overall acceptability was observed.
Conclusion

RSM revealed significant ($p < 0.05$) effects of all the three independent variables (BRF, CMC, and shortening) on the physical characteristics of crackers. Further, the regression models for all the responses were highly significant ($p < 0.05$) with coefficient of determination ($R^2 \geq 0.67$), which confirms the validity of models for providing adequate information regarding the behaviour of the responses upon variation in ingredients levels. Within the experimental range, BRF was found to be a dominant factor for spread ratio, volume index, thickness, and width; whereas, for density and puffiness, shortening was the dominating factor. However, out of three independent variables, BRF was found to be the most dominating factor governing the quality characteristics of crackers. The optimum conditions obtained by numerical optimization for development of BRF incorporated wheat-based crackers were found as BRF: wheat flour (10:90), CMC (1.8%), and shortening (5%). The storage studies revealed that crackers developed from optimized level of ingredients and packed in cellophane bags were shelf stable for a period of 3 months under ambient conditions.

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