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Priya S

Department of Food Safety and Quality Assurance, College of Food Processing Technology and Bioenergy, Anand Agricultural University, Anand, Gujarat, India

KB Kamaliya

Polytechnic in Food Science and Home Economics, Anand Agricultural University, Anand, Gujarat, India

Corresponding Author:

Priya S

Department of Food Safety and Quality Assurance, College of Food Processing Technology and Bioenergy, Anand Agricultural University, Anand, Gujarat, India

Development and optimization of chocolate cake using flours of jackfruit seed, white finger millet and whole wheat through mixture response surface methodology

Priya S and KB Kamaliya

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Abstract

The increasing demand for nutritionally enriched bakery products has encouraged the use of composite flours in traditional formulations. This study aimed to develop and optimize a chocolate cake using jackfruit seed flour, white finger millet flour, and whole wheat flour. The physical and nutritional analysis revealed that jackfruit seed flour had high water and oil absorption capacities and contributed dietary fibre and minerals. White finger millet flour enhanced calcium, iron, and fibre content, while whole wheat flour supported structure through gluten formation. The optimal flour combination (59% white finger millet, 28% jackfruit seed, and 12% whole wheat) was determined using Mixture Response Surface Methodology. The optimized cake showed good overall acceptability, desirable specific volume, moderate hardness, and high springiness. The study demonstrates the potential of composite flours in developing value-added bakery products.

Keywords: Chocolate cake, composite flour, jackfruit seed flour, white finger millet flour, whole wheat flour, mixture response surface methodology

1. Introduction

The bakery industry represents a significant share of the food industries globally. India ranks as the world's second-largest producer after the United States [24]. In 2024, the Indian bakery industry has reached a value of USD 13.8 billion. This is projected to reach USD 31.5 billion by 2033, with a CAGR of 9.12% [6].

Cakes were once reserved as a luxury item that was meant for special occasions. Now it has become a common household good [43]. Cakes typically contain high levels of sugar, fat and calories while being low in dietary fiber. Consequently, excessive consumption of cakes may result in obesity and various health issues. In recent times, there has been a growing consumer demand for bakery products that offer health benefits alongside appealing sensory qualities. Researchers have shown interest in bakery products due to their potential as functional foods. This interest stems from the possibility of substituting wheat flour with alternative ingredients or utilizing composite flours [23].

Jackfruit (*Artocarpus heterophyllus* Lam.) is an underutilized fruit crop indigenous to India. The seeds of jackfruit, which constitute 10-15% of the fruit weight, are rich in starch, dietary fiber, and bioactive compounds with potential health benefits [11]. Due to their perishable nature, jackfruit seeds are often discarded; however, they can be processed into flour and utilized in bakery products as a value-added ingredient [16].

Finger millet (*Eleusine coracana*), a nutrient-dense cereal crop, is recognized for its high calcium, iron, and dietary fiber content and its potential role in addressing nutritional deficiencies [26]. Whole wheat flour (*Triticum aestivum* L.) is widely used in bakery products and contributes essential nutrients as well as functional properties such as gluten formation, which is important for product structure and texture [29].

The incorporation of these flours in composite formulations offers potential for improving the nutritional profile of bakery products while maintaining desirable quality attributes. Therefore, the present study was undertaken to develop and optimize chocolate cake using jackfruit seed flour, white finger millet flour, and whole wheat flour.

2. Materials and methods

2.1 Materials

The raw materials used for the production of the chocolate cake and cake rusk were jackfruit seed flour, white finger millet flour, whole wheat flour, fat spread, xanthan gum powder, cocoa powder, curd, cake gel, powdered sugar, skim milk powder, whey protein concentrate, baking powder, baking soda and vinegar. The raw materials required for the study were procured from local markets and online commercial sources. White finger millet variety (GN-5) were procured from Aranya Agriforest Producer Company Limited (AAFPCL), Gandhinagar.

2.2 Methods

2.2.1 Water absorption capacity and Oil absorption capacity of flours

One gram of the sample was weighed and mixed with 10 mL of water/ vegetable oil in a centrifuge tube. The mixture was allowed to stand undisturbed at room temperature for 30 minutes, followed by centrifugation at 2000 rpm for 30 minutes. After decanting the supernatant, the tubes containing the sediment were weighed. Water and oil absorption capacity were calculated based on the increase in sample weight and expressed as grams of water/oil absorbed per gram of dry sample [30].

2.2.2 Proximate composition of flours

Estimation of the proximate compositions of the flour samples in this study followed the AOAC method [9]. Moisture was determined by weighing loss through moisture evaporation. Proteins were determined using the Kjeldahl method, and fats were estimated using a Soxhlet apparatus. Crude fiber content of the samples was determined using a Fibra-Plus instrument. Ash content was estimated by incinerating (in a pre weighed porcelain dish) each sample in a muffle furnace at 550 °C for 4-5 hours. Carbohydrate content was estimated using difference method.

2.2.3 Mineral analysis

The flour samples were subjected to digestion according to the method described by [20] with slight modifications. The resulting digested samples were analyzed for mineral content using the ICP-OES system at the Micronutrient Research Centre, Anand Agricultural University, Anand.

2.2.4 Optimization of flour levels for the production of chocolate cake

The levels of white finger millet flour, jackfruit seed flour and whole wheat flour was optimized for the development of chocolate cake. The optimization was done using Mixture RSM.

The independent parameters were

- White finger millet flour: 40-60%
- Jackfruit seed flour: 20-40%

- Whole wheat flour: 0-40%

The dependent parameters were:

- Specific volume (cm^3/g)
- Sensory score (Overall acceptability)
- Textural properties - Firmness (g) and Springiness (%)

The optimized chocolate cake was prepared following [25], with slight modifications to accommodate the optimized flour formulation and ensure proper batter consistency and structural stability. First, the flour base, cocoa powder, baking soda, baking powder, and skim milk powder were mixed together and sieved twice. In another bowl, cake gel, curd, xanthan gum powder, and whey protein concentrate were combined and beaten into a uniform mixture. The sieved dry ingredients were then gradually added to the wet mixture while mixing continuously. Next, fat spread was incorporated and mixed well. Water was added, and the mixture was beaten further. Finally, vinegar was added, the batter was poured into a greased pan, and the pan was baked at 165°C for 60 minutes.

2.2.5 Specific volume

Specific volume of the cake was determined using the rapeseed displacement method [1]. Specific volume (cm^3/g) was calculated by dividing the measured volume by the weight of the sample.

2.4. 6 Textural properties

Textural properties were measured by using a TA-HDi plus texture analyzer (Stable Micro Systems), and data were processed by Exponent Connect software. The test was done according to the methodology described by [5] with slight modifications. From the center portion of cakes, slices were made into 4x4x1.5 cm dimensions. A stainless steel cylinder probe (75 mm, p/75) mounted on the texture analyzer with 5 kg load cell and heavy-duty platform (HDP/90) was used. Pre-test speed and test speed were 1.00 mm/sec, whereas post test speed were 10.00 mm/sec with a strain of 25%.

2.4.7 Sensory score: Sensory evaluation of the cake was conducted based on colour and appearance, flavour, taste, body and texture, and overall acceptability. The evaluation was carried out by 10 semi-trained panelists from the College of Food Processing Technology and Bioenergy and the Polytechnic in Food Science and Home Economics. The samples were evaluated using a 9-point hedonic scale.

3. Results and Discussion

3.1 Water absorption capacity and oil absorption capacity of flours

The following table illustrates the water absorption and oil absorption capacities of jackfruit seed flour, white finger millet flour and whole wheat flour respectively.

Table 1: Water absorption and oil absorption capacity of flours

Parameter	Jackfruit seed flour	White finger millet flour	Whole wheat flour
Water absorption capacity (g/g)	1.25±0.02	0.98±0.50	0.86±0.01
Oil absorption capacity (g/g)	1.89±0.04	0.92±0.12	0.94±0.03

The values are represented as mean ± S.D (n=3)

The water absorption capacity (WAC) and oil absorption capacity (OAC) of jackfruit seed flour were found to be 1.25±0.02 g/g and 1.89±0.04 g/g, respectively. These values

were slightly lower than those reported by [21] who observed WAC in the range of 1.79-2.08 g/g and OAC in the range of 1.91-2.04 g/g. The variation may be attributed to differences

in variety and processing methods of the jackfruit seeds. Water absorption capacity is an important functional property influencing batter consistency, while oil absorption capacity contributes to flavour retention and mouthfeel in baked products [17]. The relatively high WAC and OAC values observed indicate the suitability of jackfruit seed flour for bakery applications.

The WAC and OAC of white finger millet flour were 0.98 ± 0.50 g/g and 0.92 ± 0.12 g/g, respectively, which are in close agreement with the values reported by [30].

Similarly, the WAC (0.86 ± 0.01 g/g) and OAC (0.94 ± 0.03 g/g) of whole wheat flour were consistent with the findings of [15] indicating comparable functional properties.

3.2 Proximate composition of flours

The following table illustrates the proximate composition of jackfruit seed flour, white finger millet flour and whole wheat flour respectively.

Table 2: Proximate composition of flours

Parameter	Jackfruit seed flour	White finger millet flour	Whole wheat flour
Moisture (%)	7.23 ± 0.21	9.87 ± 0.05	8.73 ± 0.04
Protein (%)	9.64 ± 0.06	0.39 ± 0.07	8.99 ± 0.08
Crude fiber (%)	3.42 ± 0.12	3.88 ± 0.10	2.95 ± 0.11
Fat (%)	1.10 ± 0.02	1.30 ± 0.03	2.22 ± 0.05
Ash (%)	3.53 ± 0.15	2.28 ± 0.07	1.52 ± 0.04
Carbohydrate (% by difference)	75.03 ± 0.32	72.28 ± 0.28	75.59 ± 0.30

The values are represented as mean $\pm$ S.D (n=3)

The proximate composition of jackfruit seed flour revealed a moisture content of $7.23 \pm 0.21\%$, which is comparable to values reported by [31] and [33] (6.05%). The protein content ($9.64 \pm 0.06\%$) was similar to the 9% reported by [10], with variations attributed to differences in variety, maturity, and environmental conditions [3]. Crude fiber ($3.42 \pm 0.12\%$) was close to the value reported by [7] (3.92%). Fat content ($1.10 \pm 0.02\%$) was identical to that reported by [10]. Ash content ($3.53 \pm 0.15\%$) fell within the range of 3.19-3.70% reported by [13], indicating good mineral presence. Carbohydrate content ($75.03 \pm 0.32\%$) was also comparable to 73.8% reported by [40].

White finger millet flour showed moisture, protein, crude

fiber, fat, ash, and carbohydrate contents of $9.87 \pm 0.05\%$, $10.39 \pm 0.07\%$, $3.88 \pm 0.10\%$, $1.30 \pm 0.03\%$, $2.28 \pm 0.07\%$, and $72.28 \pm 0.28\%$, respectively. These values were largely consistent with the ranges reported by [39], with minor variations likely due to varietal and agro-climatic differences.

Whole wheat flour exhibited moisture ($8.73 \pm 0.04\%$), protein ($8.99 \pm 0.08\%$), crude fiber ($2.95 \pm 0.11\%$), fat ($2.22 \pm 0.05\%$), ash ($1.52 \pm 0.04\%$), and carbohydrate ($75.59 \pm 0.30\%$). These values fall within the ranges reported by [27], indicating comparable compositional characteristics.

3.3 Mineral analysis

Table 3: Mineral analysis of flours

Parameter	Jackfruit seed flour	White finger millet flour	Whole wheat flour
Iron (mg/100g)	12.00 ± 0.05	4.47 ± 0.11	3.82 ± 0.08
Calcium (mg/100g)	111.34 ± 0.03	258 ± 0.05	21.3 ± 0.04
Magnesium (mg/100g)	126.40 ± 0.10	149 ± 0.07	90.5 ± 0.06
Zinc (mg/100g)	1.89 ± 0.04	2.79 ± 0.50	2.71 ± 0.02

The values are represented as mean $\pm$ S.D (n=3)

Jackfruit seed flour exhibited iron (12.00 ± 0.05 mg/100 g), calcium (111.34 ± 0.03 mg/100 g), magnesium (126.40 ± 0.10 mg/100 g), and zinc (1.89 ± 0.04 mg/100 g), while white finger millet flour showed higher calcium content (258 ± 0.05 mg/100 g) along with iron (4.47 ± 0.11 mg/100 g), magnesium (149 ± 0.07 mg/100 g), and zinc (2.79 ± 0.50 mg/100 g). Whole wheat flour contained comparatively lower mineral values, with iron (3.82 ± 0.08 mg/100 g), calcium (21.3 ± 0.04 mg/100 g), magnesium (90.5 ± 0.06 mg/100 g), and zinc (2.71 ± 0.02 mg/100 g). The observed values were generally comparable with those reported in earlier studies [7, 2, 32, 41, 42, 38, 39, 34]. Minor variations may be attributed to differences in geographical origin, soil composition, and processing conditions.

3.4 Optimization of flour levels for the development of chocolate cake

The following table 4 illustrates the design given by mixture RSM using Design Expert software (v.13.0.5.0) where A: White finger millet flour (%), B: Jackfruit seed flour (%) and C: Whole wheat flour (%)

Table 4: Factors and responses of experimental chocolate cake

Run	Factors			Responses			
	A	B	C	Specific volume (cm ³ /g)	Firmness (g)	Springiness (%)	Sensory score (O.A)
1	40	33	27	1.59	839.53	36.94	7.57
2	60	37	3	1.34	1536.16	34.76	7.32
3	40	40	20	1.41	699.02	38.18	8.16
4	60	20	20	1.55	990.06	36.74	7.40
5	53	20	27	1.48	1582.95	39.63	7.75
6	51	28	20	1.70	1166.85	38.15	7.58
7	51	28	20	1.72	1251.30	38.07	7.90
8	47	40	13	1.41	1376.22	40.21	7.30
9	46	26	29	1.60	1506.66	28.64	7.71
10	40	33	27	1.52	837.96	37.45	7.60
11	43	20	37	1.41	1790.75	38.10	7.95
12	47	40	13	1.30	1570.79	41.94	7.40
13	60	37	3	1.36	1639.85	35.67	7.33
14	60	27	13	1.50	1240.06	40.52	7.80
15	55	34	11	1.48	1657.66	38.80	7.45
16	43	20	37	1.42	1804.46	38.05	7.90

3.4.1 Effect of flour levels on the specific volume of chocolate cake

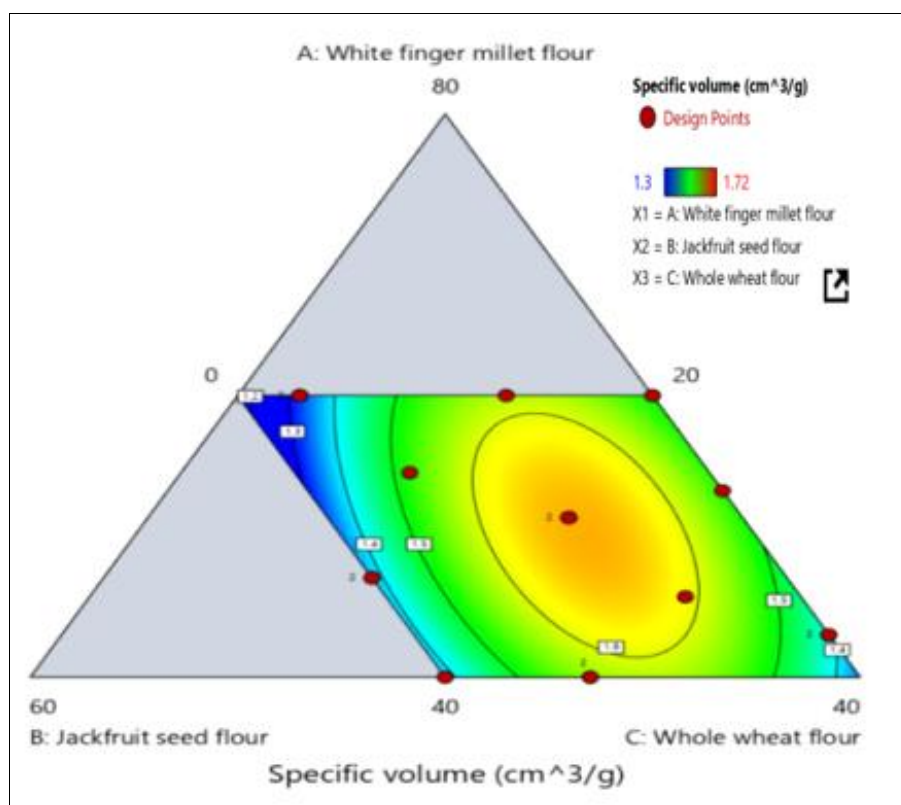


Fig 1: Contour graph on effect of flour levels on specific volume of chocolate cake

The specific volume of chocolate cakes ranged from 1.30 to 1.72 cm³/g. The highest specific volume (1.72 cm³/g) was observed in run 7 (51% white finger millet flour, 28% jackfruit seed flour, and 20% whole wheat flour), while the lowest value (1.30 cm³/g) was recorded in run 12 (47% white finger millet flour, 40% jackfruit seed flour, and 20% whole wheat flour) (Table 4).

Figure 1 illustrates the effect of flour proportions on specific volume through a ternary contour plot. The plot represents variations in specific volume as a function of white finger millet flour (A), jackfruit seed flour (B), and whole wheat flour (C), where each point within the triangle corresponds to a formulation totaling 100%. The colour gradient indicates response variation, with blue representing lower specific volume (1.30 cm³/g), green indicating intermediate values (1.40-1.60 cm³/g), and red representing higher specific volume (1.72 cm³/g).

Lower specific volume values (blue region) were associated with higher proportions of jackfruit seed flour and lower levels of whole wheat flour. This may be attributed to the reduction in gluten content, leading to decreased structural integrity and gas retention during baking. Similar observations were reported by previous studies [4, 18].

In contrast, increasing the proportion of whole wheat flour

(green region) resulted in improved specific volume, likely due to the presence of gluten, which enhances the viscoelastic network and gas retention capacity [35].

The red region represents the optimum formulation zone, where a balanced combination of the three flours produced the highest specific volume. This indicates a synergistic effect, in which whole wheat flour contributes to gluten network formation, while jackfruit seed flour and white finger millet flour provide a complementary starch-protein matrix that supports structural stability.

3.4.2 Effect of flour levels on the firmness of chocolate cake

Firmness is the maximum force required to compress the cake during the first compression cycle in texture profile analysis. It represents the resistance of the cake to deformation and is an indicator of its textural hardness. The firmness of chocolate cake varied from 699.02 - 1804.46 g. The maximum value of firmness (1804.46 g) was obtained for run 16, where white finger millet flour is 43%, jackfruit seed flour is 20% and whole wheat flour is 37%. The minimum value of firmness (699.02 g) was obtained for run 3, where white finger millet flour is 40%, jackfruit seed flour is 40% and whole wheat flour is 20% (Table 4).

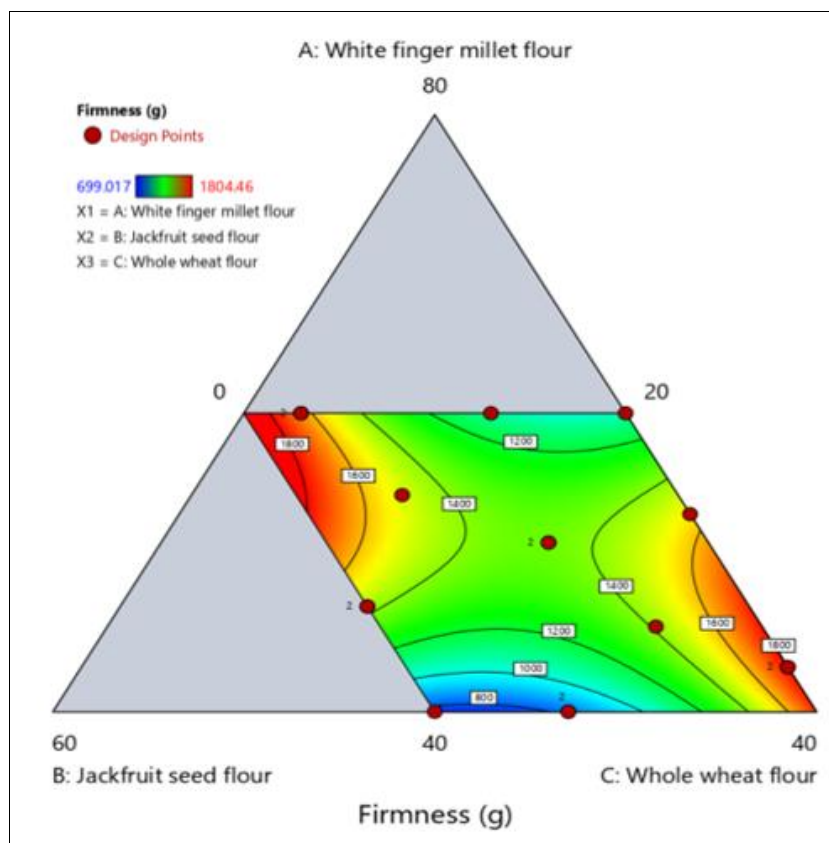


Fig 2: Contour graph on effect of flour levels on firmness of chocolate cake

Figure 2 depicts the effect of flour levels on firmness of chocolate cake. The dark blue region at the base of the plot represents low firmness, observed at lower levels of white finger millet flour and relatively higher, balanced proportions of jackfruit seed flour and whole wheat flour. However, previous studies have reported that increasing levels of finger millet flour can contribute to increased hardness in baked products [36].

The green to yellow regions indicate intermediate firmness, where all three flours are present in moderate and balanced proportions.

High firmness values are represented by the red regions. The lower left region indicates increased firmness at higher levels of jackfruit seed flour combined with lower levels of white finger millet and whole wheat flour. Similarly, the lower right region shows high firmness when whole wheat flour content is high, with moderate to high levels of white finger millet flour and minimal jackfruit seed flour.

The increase in firmness can be attributed to the higher dietary fibre content of whole wheat flour, as well as the combined effect of fibre and protein in jackfruit seed flour. During baking, protein coagulation and fibre interactions contribute to the formation of a denser structure, resulting in increased hardness. Similar trends have been reported in earlier studies [4, 12].

3.4.3 Effect of flour levels on the springiness of chocolate cake

Springiness is defined as the ability of a product to recover its original structure following deformation during the initial compression [19]. It is an important quality attribute of cakes, because higher springiness is associated with a soft, spongy

texture and greater consumer acceptability, whereas lower springiness indicates a dense and less desirable structure.

The springiness of chocolate cake ranged from 28.64 to 41.94%. The highest springiness (41.94%) was observed in run 12 (47% white finger millet flour, 40% jackfruit seed flour, and 13% whole wheat flour), while the lowest value (28.64%) was recorded in run 9 (46% white finger millet flour, 26% jackfruit seed flour, and 29% whole wheat flour) (Table 4).

Figure 3 illustrates the effect of flour proportions on springiness using a ternary contour plot. The blue region represents lower springiness values, corresponding to formulations with lower levels of white finger millet flour and intermediate proportions of jackfruit seed flour and whole wheat flour.

Higher springiness values (red regions) were observed under two conditions: (i) at intermediate to high levels of white finger millet flour combined with high whole wheat flour and low jackfruit seed flour, and (ii) at higher levels of jackfruit seed flour with lower proportions of white finger millet and whole wheat flours. This suggests that both gluten contribution from whole wheat flour and the starch-protein interactions from jackfruit seed flour can positively influence elastic recovery.

The green to yellow regions indicate intermediate springiness, where all three flours are present in moderate proportions. Similar findings have been reported, where incorporation of jackfruit seed flour at moderate levels maintained acceptable springiness [37], and partial substitution with whole wheat flour preserved desirable textural characteristics in cakes [14].

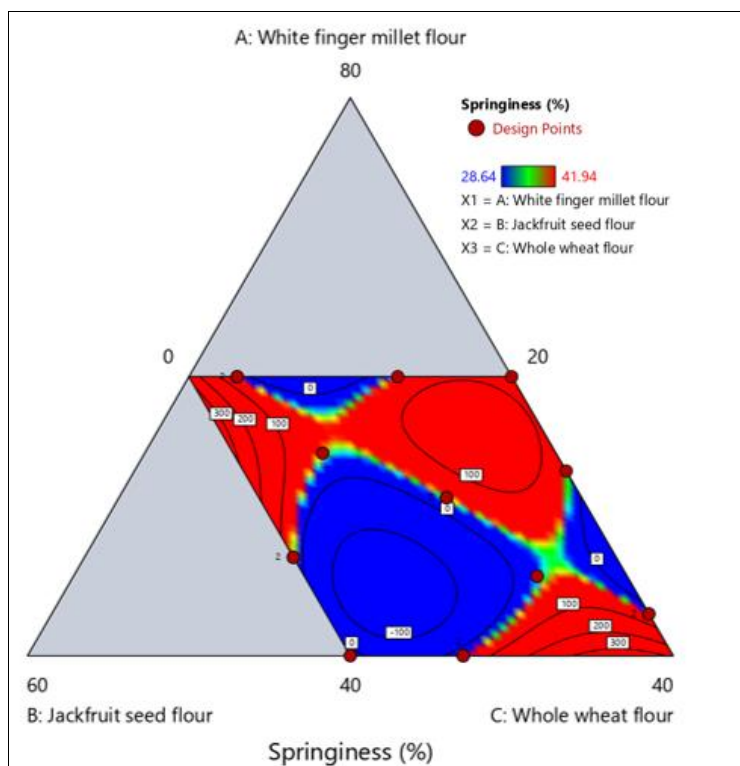


Fig 3: Contour graph on effect of flour levels on springiness of chocolate cake

3.4.4 Effect of flour levels on the sensory score (O.A) of chocolate cake

The sensory score (O.A) of chocolate cake varied from 7.30-8.16. The maximum value of sensory score (O.A) (8.16) was obtained for run 3, where white finger millet flour is 40%, jackfruit seed flour is 40% and whole wheat flour is 20%. The minimum value of O.A (7.30) was obtained for run 8, where white finger millet flour is 60%, jackfruit seed flour is 37% and whole wheat flour is 3% as from (Table 4).

Figure 4 illustrates the effect of flour proportions on sensory score (O.A). Lower sensory scores (blue regions) were observed in formulations with either high levels of jackfruit seed flour combined with low levels of the other flours, or formulations where white finger millet flour and whole wheat flour were present in moderate to high proportions with minimal jackfruit seed flour. These trends suggest that excessive incorporation of jackfruit seed flour or imbalance in flour proportions may negatively affect sensory quality.

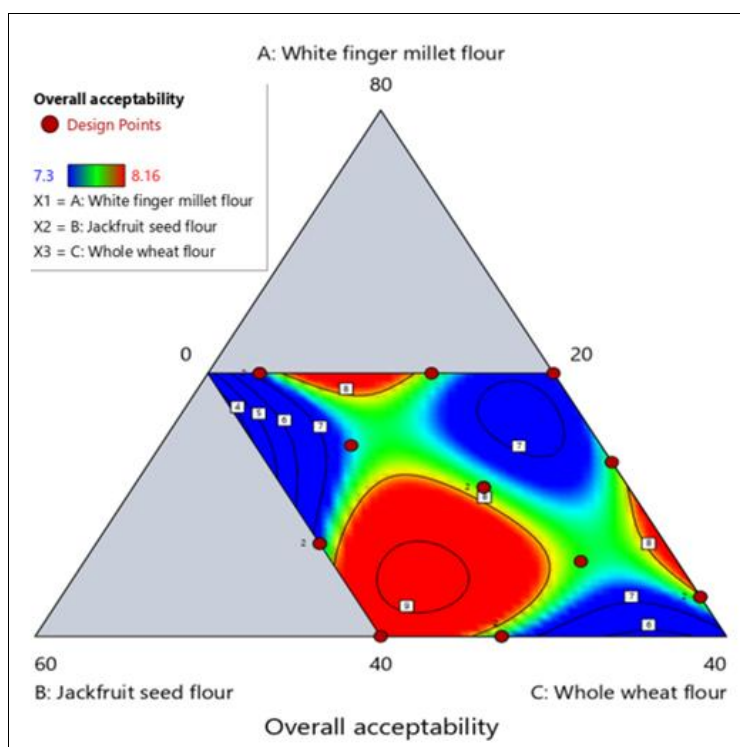


Fig 4: Contour graph on effect of flour levels on sensory score (O.A) of chocolate cake

Intermediate sensory scores (green-yellow regions) were obtained when white finger millet flour was present at low to moderate levels, with jackfruit seed flour and whole wheat flour maintained at intermediate proportions.

Higher sensory scores (red regions) were achieved with formulations containing moderate levels of jackfruit seed flour, intermediate to high levels of whole wheat flour, and lower levels of white finger millet flour. This indicates that a balanced incorporation of flours is essential for achieving desirable sensory characteristics.

These findings are consistent with previous studies. It has been reported that moderate substitution of jackfruit seed flour (around 10-30%) yields acceptable sensory scores, while higher levels may negatively impact colour, flavour,

and texture due to bitterness and grittiness [23, 8, 22]. Similarly, increased incorporation of finger millet flour has been associated with reduced sensory quality in baked products, although acceptable quality can be maintained up to certain levels with appropriate formulation adjustments [36]. The preference for intermediate to higher levels of whole wheat flour is also supported by earlier findings, where formulations containing higher proportions of whole wheat flour exhibited improved overall acceptability [28].

3.4.5 Optimized solution for chocolate cake as suggested by RSM

The optimum formulation recommended by Mixture RSM is given in the table 5.

Table 5: Optimized solution for chocolate cake as suggested by Mixture RSM

Optimized Factors			Optimized responses				Desirability of the model
A (%)	B (%)	C (%)	S. V. (cm ³ /g)	Firmness (g)	Springiness (%)	O.A.	
59	28	12	1.58	1154.41	41.94	7.85	0.720

The optimum formulation suggested by RSM are 59% white finger millet flour, 28% jackfruit seed flour and 12% whole wheat flour and the responses were 1.53 cm³/g for specific volume, 1154.41 g for firmness, 41.94% for springiness and 7.85 for sensory score (O.A).

3.4.6 Validation of the optimized RSM Model for chocolate cake

Triplicates of optimized formulations were conducted and responses were measured for validation. Table 6 shows the validation of responses for the chocolate cake. From the table, we can infer that the actual values of responses closely align with the predicted values. This indicates that the model is well fitted and accurate.

Table 6: Validation of the optimized RSM model for chocolate cake

Analysis	Predicted value	95% PI low	Actual value	95% PI High
Specific volume	1.58	1.48	1.56	1.68
Sensory score (O.A)	7.85	7.63	7.91	8.07
Firmness	1154.41	934.22	1156.51	1374.79
Springiness	41.94	40.38	41.56	43.50

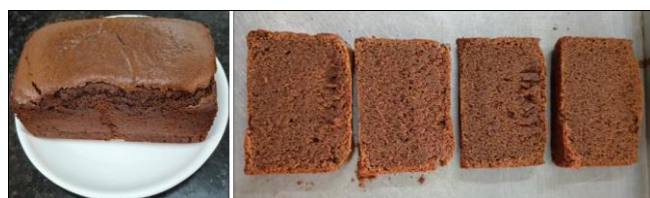


Fig 5: Optimized chocolate cake

4. Conclusion

The present study successfully demonstrated the development and optimization of a chocolate cake using composite flours of jackfruit seed, white finger millet, and whole wheat through Mixture Response Surface Methodology. The incorporation of these flours showed promising functional properties, with jackfruit seed flour contributing to improved water and oil absorption capacities, while finger millet enhanced the nutritional potential due to its mineral-rich composition.

The optimized formulation (59% white finger millet flour,

28% jackfruit seed flour, and 12% whole wheat flour) resulted in a product with desirable sensory attributes, acceptable texture, and good overall quality. The findings indicate that the use of composite flours can be an effective approach for developing value-added bakery products while utilizing underutilized ingredients such as jackfruit seed flour.

Further studies may focus on evaluating the nutritional composition and storage stability of the developed product to strengthen its application in functional food development.

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