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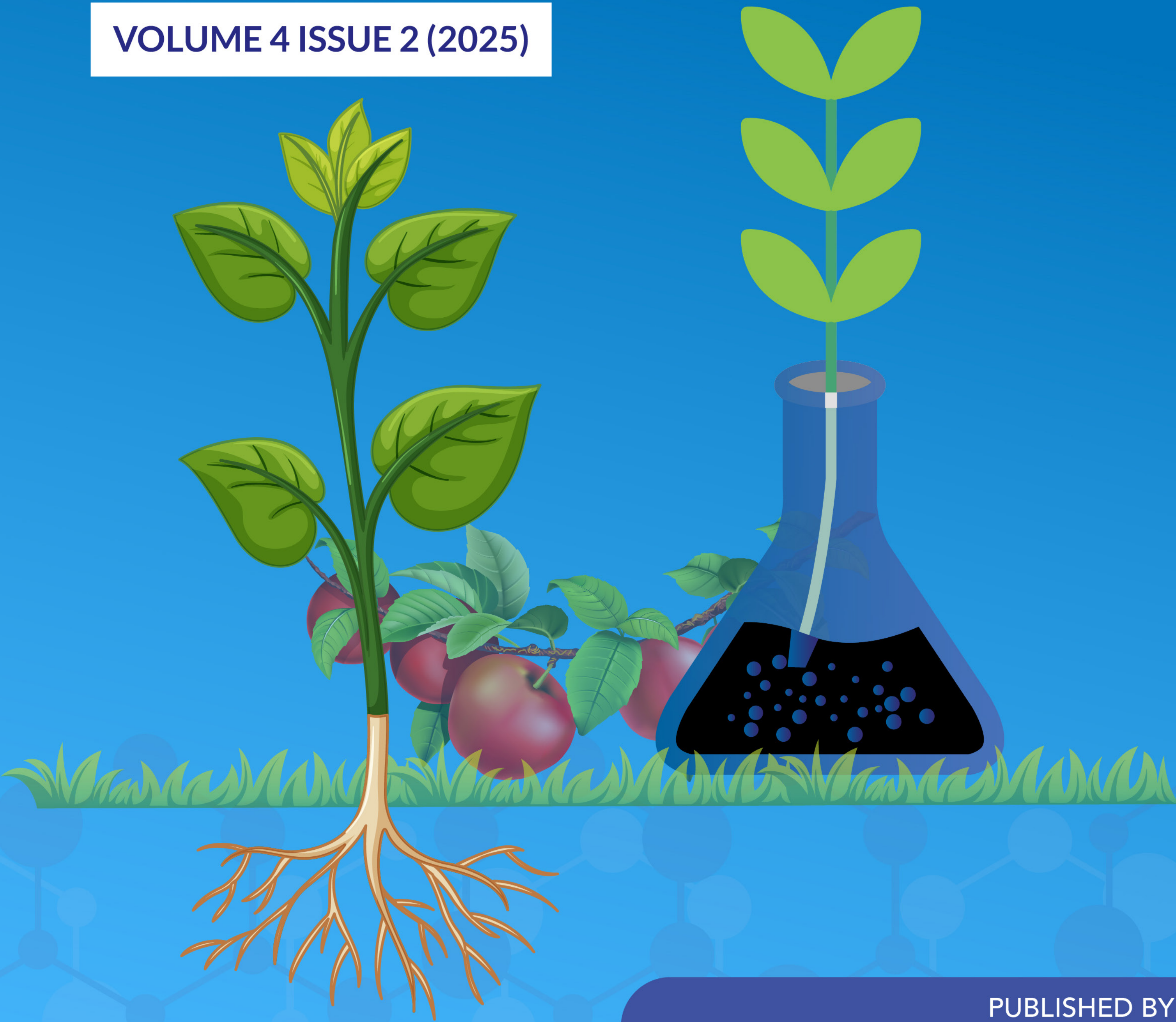

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Optimization of the Proximate Composition and Functional Properties of a Composite Flour Formulated from Malted Sorghum, Sprouted Mung Bean and Date Fruit Using Response Surface Methodology

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ABSTRACT

This study evaluated the effects of varying proportions of malted sorghum flour (MSF), sprouted mung bean flour (SMF), and date fruit powder (DFP) on the functional and nutritional properties of composite flour blends. A D-optimal mixture design was used to generate fourteen formulations, varying MSF (60–80%), SMF (10–30%), and DFP (5–10%). The blends were assessed for functional attributes including bulk density, foaming capacity, wettability, gelatinization temperature, water and oil absorption capacities, and swelling capacity as well as proximate composition (moisture, protein, fat, ash, fiber, carbohydrate, and energy). Significant differences ($p < 0.05$) were observed across samples, reflecting the influence of blend ratios on product characteristics. Increased levels of SMF and DFP significantly improved nutritional quality and functional properties, including protein content, foaming ability, and fiber enrichment. Response surface plots revealed that higher proportions of SMF and DFP enhanced most quality attributes. Regression models (linear to quartic) were statistically significant ($p < 0.05$) for the majority of responses, though gelatinization temperature and water absorption capacity did not fit well. Model performance metrics including high R^2, adjusted R^2, predicted R^2, low lack-of-fit, and adequate precision validated model reliability. Numerical optimization using Response Surface Methodology (RSM) identified an optimal formulation of 69.93% MSF, 21.38% SMF, and 8.69% DFP, with a composite desirability of 0.620. The optimized blend demonstrated desirable shelf stability, nutritional density, and functional performance, making it suitable for health-oriented foods such as snack bars and other bakery products. This research highlights the potential of underutilized, climate-resilient crops in developing nutrient-rich, functional food systems for improved dietary diversity and food security.

INTRODUCTION

The rising demand for health-promoting, sustainable, and gluten-free food products has intensified interest in nutrient-rich composite flours, which serve as versatile functional ingredients across various food systems. Composite flours, typically combining cereals, legumes, and fruits, offer a promising strategy to improve the nutritional, functional, and sensory properties of food while promoting food security and dietary diversity especially in regions relying on underutilized crops (Ubbor & Akobundu, 2022; Ezeama *et al.*, 2023; Edima-Nyah *et al.*, 2023; Ntukidem *et al.*, 2025. Sorghum (*Sorghum bicolor*), a resilient, gluten-free cereal, is valued for its dietary fiber, phenolic content, and slowly digestible starch. Malting enhances its nutritional and functional attributes by increasing enzyme activity, reducing antinutritional factors, and improving starch gelatinization and fermentation potential (Agu *et al.*, 2017; Musa *et al.*, 2022). Mung bean (*Vigna radiata*), a protein-rich legume, gains further nutritional and functional benefits through sprouting, which improves vitamin content, bioavailability of nutrients, and reduces antinutrients. Sprouted mung bean flour also exhibits enhanced foaming, water absorption, and emulsifying capacities (Saini *et al.*, 2021; Olagunju *et al.*, 2023). Date fruit (*Phoenix dactylifera*) contributes natural sugars, fiber, minerals, and antioxidants. Its addition improves the energy value, taste, and consumer appeal of food products while promoting gut health and glycemic control (Al-Hooti *et al.*, 2020; El Sohaimy & Hafez, 2021; Khan *et al.*, 2022). The combination of malted sorghum, sprouted mung bean, and date fruit flours offers synergistic advantages enhancing protein, fiber, and functional properties like bulk density, absorption capacity, and emulsification. However, to achieve optimal formulation, a statistical approach such as Response Surface Methodology (RSM) is essential. RSM, through designs like D-optimal and Central Composite Design, enables the modeling of complex interactions between ingredients while minimizing experimental runs (Myers *et al.*, 2016; Adebo & Oyedeji, 2021; Ifesan *et al.*, 2024). Therefore, this study aims to optimize the proximate and functional properties of this composite flour using RSM, contributing to the development of high-quality, gluten-free functional food ingredients.

MATERIAL AND METHODS

Source of Raw Materials

Sorghum grains improved variety (KSV-15) was obtained

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from the Seed Production Unit of the Institute of Agricultural Research (I.A.R), Ahmadu Bello University, Samaru, Zaria, Kaduna State, Nigeria. Mung bean seeds were obtained, identified, and authenticated at the Department of Agronomy, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria, as *Vigna radiata* L. Wilczek species (NM 94 Variety). Dried Date Palm Fruit was purchased from Nassarawa Market, Mbak Itam III, Akwa Ibom State, Nigeria, and was identified and authenticated as *Phoenix dactylifera* L. species (*Dabinoin Hausa* Variety) under the Voucher Number: UUPH 8(h) at University of Uyo Pharmacy Herbarium. Baking ingredients were bought from Etaha Itam Market in Itu Local Government Area. Akwa Ibom State, Nigeria. All the reagents used throughout the study were of analytical grade.

Processing of Malted Sorghum Flour

The method of Bello *et al.* (2020) was used for malted sorghum flour production. Five (5) kg of sorghum grains were sorted to remove foreign matter and soaked for 12 h in portable water (w/v; 1:2). Soaked grains were drained and sprouted by spreading out on a covered jute bag in a germination box. Water was sprinkled on it daily until sprouting began. After 48 h of sprouting, sprouted sorghum was in an oven (NAAFCO BS, OVH – 102, China) at 65˚C for 6 h, sprouts were removed by rubbing through palms. The dried malted sorghum was milled using a laboratory hammer mill (Cu – 600 Glufex Medicals and scientific, UK), and sieved through a 425 μm mesh sieve, the flour was cooled and packaged in a polyethylene bag for further use.

Processing of sprouted Mung Bean Flour

Sprouted mung bean flour was carried out using the method described by Offia-Olua and Akubuo, (2019). Three (3) kg of mung bean seeds were sorted, cleaned, steeped in a portable water for 12 hours. The steeped beans were spread on a moistened muslin cloth and sprinkled with water daily while allowed to sprout for 48 hours. The water sprinkled on the mung bean seeds contained a small amount of sodium hypochlorite to destroy or discourage the growth of microorganisms while the seeds were allowed to germinate at 30^{o}C in the germination box. After 48 h of sprouting, the sprouted seeds were kilned in an oven (NAAFCO BS, OVH – 102, China) at 65^{0}C for 4 h to terminate germination, sprouts were removed on palm by abrasion and winnowing. The dried malted mung bean seeds were milled using using hammer mill (Cu – 600 Glufex Medicals and scientific, UK), sieved through a sieve-shaker, cooled and packaged in an air-tight container for further use.

Processing of Date Palm Fruit Powder

Three (3) kg of dried date fruits were cleaned, pitted and then cut in small pieces and dried in the oven (NAAFSCO BS, OVH – 102, China) at 65^{0}C for 4 h to obtain constant weight and then milled in a grinder (M-20, KA – Werke, GMBH and Co. KG, Staufen Germany) to obtain date powder. The date powder was packaged in an air-tight container for further use, as described by Oraby *et al.* (2021).

Experimental Design for the Preparation of the Flour Blends

D-optimal mixture design of Response Surface Methodology (Design- Expert Software Version 12.0.3.0., Stat- Ease Inc., Minneapolis, USA) was used for the formulation of the flour blends from malted sorghum flour, sprouted mung bean flour and date fruit powder. The proportion of each flour was expressed as a fraction of the blend form to make the sum of the component ratio as 100%. The independent variables and their constraints limits were malted sorghum flour (60 - 80%), sprouted mung bean flour (10 - 30%) and date fruit powder (5 - 10%). The responses were (physical properties - weight, diameter, thickness, width and spread ratio). The range obtained here were selected based on information obtained from literature and preliminary experiments. Table 1. shows the formulated mixture runs generated from the design.

Table 1: Composite Flour Formulation of Malted Sorghum, Sprouted Mung Bean and Date Fruit Powder Blends using D-Optimal Mixture Design

Experimental runs	Samples	Malted Sorghum flour (%)	Sprouted Mung bean flour (%)	Date fruit powder (%)
1	MSD 1	70.00	20.00	10.00
2.	MSD 2	80.00	10.00	10.00
3	MSD 3	80.00	15.00	5.00
4	MSD 4	65.00	30.00	5.00
5	MSD 5	80.00	10.00	10.00
6	MSD 6	65.63	25.62	8.75
7	MSD 7	75.63	15.63	8.75
8	MSD 8	62.50	30.00	7.50
9	MSD 9	75.63	18.13	6.25
10	MSD 10	65.00	30.00	5.00

11	MSD11	60.00	30.00	10.00
12	MSD 12	60.00	30.00	10.00
13	MSD13	80.00	15.00	5.00
14	MSD 14	72.50	22.50	5.00

MSD 1-14 = Malted Sorghum, Sprouted Mung Bean and Date Fruits

Functional properties determinations

Bull density, foaming capacity, wettability, gelatinization temperature, water absorption capacity, oil absorption capacity and swelling capacity were performed following the methods of AOAC, (2010). The experiment was done in triplicate.

Proximate composition determinations

Moisture, ash, crude fiber, crude protein, crude fat was performed following the methods of AOAC, (2010) carbohydrate calculated by difference. The experiment was done in triplicate.

Statistical Analysis

Analysis of data was performed using IBM SPSS (version 23 software). One-way Analysis of Variance (ANOVA) was used to determine significant ($p<0.05$) differences between means which were separated using New Duncan multiple range test (NDMRT) to perform multiple comparism between means at $P < 0.05$. All statistical analysis, mixture design, generation of response surfaces, desirability functional analysis, and optimization were accomplished using Design-Expert (12.0.3.0) software (Stat-Ease, Minneapolis, United States) software, significant at $p < 0.05$.

RESULTS AND DISCUSSION

Effect of Mixture Component On the functional properties of flour blends from Malted Sorghum, Sprouted Mung Bean and Date Fruit

Bulk density is an essential functional property in flour-based food systems, influencing texture, packaging efficiency, and transportation costs. In this study, bulk density values of the composite flour blends ranged from 0.83 to 0.86 g/mL. The highest values (0.86 g/mL) were recorded in formulations such as MSD 2, MSD 4, MSD 5, MSD 6, MSD 7, MSD 9, and MSD 14, all containing at least 65% malted sorghum flour (MSF). This suggests that MSF enhances bulk density due to its fine particle size and high starch content, which facilitate tighter packing. In contrast, MSD 8 had the lowest bulk density (0.83 g/mL), attributed to its higher sprouted mung bean flour (SMF) content and lower MSF inclusion. Germination increases SMF porosity, reducing particle compaction. Additionally, the presence of date fruit powder (DFP), though nutritionally beneficial, may reduce cohesiveness due to its hygroscopic nature. These observations align with findings that cereal-based flours tend to have greater compactness compared to legume or fruit-derived flours (Adebowale *et al*., 2020). The bulk density data fit well to a special quartic response surface model, which was statistically significant ($F = 14.97$, $p < 0.05$) and exhibited a high R^2 value (0.9599). However, the predicted R^2 (0.5025) was considerably lower than the adjusted R^2 (0.8958), suggesting the model may not generalize well to new data. Despite this, the low coefficient of variation (0.3764%) and high adequate precision (11.96) support model reliability. A non-significant lack-of-fit ($F = 0.1215$) further validated model adequacy. Among the components, DFP had the most substantial positive effect on bulk density (+1.98), followed by SMF (+0.8599) and MSF (+0.8451). Negative binary interactions and synergistic higher-order effects (e.g., A^2BC, AB^2C) were also observed. The 3D surface plot effectively visualized these interactions, aiding formulation optimization (Njapndounke *et al*., 2023).

$$\text{Bulk density} = + 0.8451A + 0.8599B + 1.98C - 0.0506AB - 1.44AC - 1.55BC + 4.57A^2BC + 4.04AB^2C - 11.50ABC^2 \quad ....(1)$$

Where, A = malted sorghum flour, B = sprouted mung bean flour, and C = date fruit powder

Foaming capacity is a vital functional attribute in flour blends, particularly for baked goods where air incorporation and gas retention are crucial for structure and texture. In this study, foaming capacity varied significantly among the formulations, ranging from 5.66% to 7.68% ($p < 0.05$). The highest values were observed in MSD 10, MSD 3, MSD 4, and MSD 13, which contained 15%–30% sprouted mung bean flour (SMF). The improved foaming in these samples is likely due to enzymatic hydrolysis of storage proteins during germination, which enhances protein solubility and surface activity two key factors in foam formation and stability (Saini *et al*., 2021; Olagunju *et al*., 2023). In contrast, lower foaming capacities were recorded in samples such as MSD 1, MSD 2, and MSD 5, each with malted sorghum flour (MSF) levels ≥70%. This can be attributed to the presence of kafirins hydrophobic, tightly packed proteins in sorghum that are less effective at stabilizing foams (Musa *et al*., 2022). Although malting improves sorghum's enzymatic activity, it has limited impact on enhancing foaming potential (Agu *et al*., 2017). While date fruit powder (DFP) contributes minimal protein, its presence may modify viscosity and dispersion characteristics, subtly supporting foaming in mixed systems. Statistical modeling using a special quartic response surface model confirmed a strong fit ($F = 16.75$, $p < 0.05$), explaining 91.28% of the variation in foaming capacity ($R^2 = 0.9128$). The adjusted R^2 (0.8583) and predicted R^2 (0.7281) were well-aligned, indicating strong model performance (Abasiekong *et al*., 2023; Anchang and Okafor, 2022). The model's robustness was further supported by a low coefficient of variation (CV = 5.09%) and high adequate precision (10.53). However, a significant lack-of-fit (F = 34.82) suggests that higher-order interactions were not fully captured (Elochukwu *et al*., 2019). Linear effects showed DFP (C) had the strongest positive influence (+34.91), while binary interactions (AB, AC, BC) were antagonistic. These relationships were clearly visualized in the 3D response surface plots (Njapndounke *et al*., 2023).

Foam capacity = + 5.91A + 5.85B + 34.91C - 1.89AB - 29.26AC - 30.63BC ....(2)

Where, A = malted sorghum flour, B = sprouted mung bean flour, and C = date fruit powder

Wettability is a crucial functional property that affects how quickly flour particles absorb water and disperse, directly influencing the preparation ease and consumer acceptance of instant foods. In this study, wettability times ranged from 70.33 to 77.33 seconds, with significant differences among samples ($p < 0.05$). The shortest wetting times were observed in MSD 7, MSD 8, and MSD 10 (70.33 s), which had higher levels of sprouted mung bean flour (SMF ≥ 15%) and lower levels of malted sorghum flour (MSF < 75%). The enhanced wettability in these samples is linked to the enzymatic modifications from sprouting, which increase flour porosity and hydrophilicity through the breakdown of cell walls and proteins (Saini *et al*., 2021; Olagunju *et al*., 2023). Conversely, samples MSD 11 and MSD 12 both containing 10% date fruit powder (DFP) exhibited the longest wetting times (77.33 and 75.66 s, respectively). This reduced wettability may be due to DFP's high sugar and fiber content, which can create a sticky, hygroscopic surface layer that delays water absorption (El Sohaimy and Hafez, 2021). These results emphasize the importance of ingredient balance in instant flour blends (Adebowale *et al*., 2020). The quadratic model fitted to the data was statistically significant (F = 24.00, $p < 0.05$), explaining 93.75% of the variation in wettability ($R^2 = 0.9375$). The adjusted R^2 (0.8984) and predicted R^2 (0.8084) were closely aligned, indicating good predictive reliability (Anchang and Okafor, 2022; Abasiekong *et al*., 2023). The low coefficient of variation (0.94%) and high adequate precision (13.99) further confirmed model precision. The non-significant lack-of-fit (F = 0.5740) supports its validity (Elochukwu *et al*., 2019). Coefficient estimates revealed that DFP (C) had the strongest positive effect on wettability (+207.59), followed by MSF (+76.41) and SMF (+72.14), though DFP interactions (AC, BC) negatively influenced rehydration—highlighting its dual role in water absorption.

Wettability = + 76.41A + 72.14B + 207.59C + 1.53AB - 205.37AC - 180.12BC ....(3)

Where A = malted sorghum flour, B = sprouted mung bean flour, and C = date fruit powder

Gelatinization temperature (GT) is a critical functional property reflecting the heat required for starch granules to absorb water, swell, and rupture key processes influencing texture, consistency, and processing behavior in flour-based products. In this study, GT values of the composite flour blends ranged from 80.00°C to 84.66°C, with statistically significant differences observed across samples ($p < 0.05$). The highest GT (84.66°C) occurred in MSD 3, which contained 80% malted sorghum flour (MSF), 15% sprouted mung bean flour (SMF), and 5% date fruit powder (DFP). This result is attributed to the dominance of MSF, whose partially malted starches retain crystalline integrity, making them more resistant to thermal disruption. Additionally, SMF may contribute through resistant starch and protein-starch interactions formed during germination (Saini *et al*., 2021; Musa *et al*., 2022). Conversely, samples like MSD 4 through MSD 7 with higher SMF (≥30%) and DFP (7.5–10%) recorded lower GTs (80.33–80.66°C). The enzymatic breakdown of starches in SMF and the presence of sugars and fibers in DFP likely disrupted starch–water interactions, thereby reducing gelatinization energy requirements (Olagunju *et al*., 2023; El-Sohaimy and Hafez, 2021). The quadratic model for GT had limited explanatory power, with an F-value of 2.38 ($p = 0.1325$) and $R^2 = 0.5976$. Adjusted and predicted R^2 values (0.3461 and −0.2513, respectively) indicated weak predictive reliability (Abasiekong *et al*., 2023). Despite this, the model's precision (4.51) and low coefficient of variation (1.27%) suggest acceptable experimental consistency (Elochukwu *et al*., 2019). Among factors, DFP had the strongest positive effect (+95.28), followed by MSF (+81.83) and SMF (+80.83). However, interactions such as AC (–25.36) and BC (–5.12) reduced GT, highlighting the complex interplay of components. A 3D response plot was not generated due to the model's low statistical significance.

Gelatinization Tempt: + 81.83A + 80.83B + 95.28 - 1.25AB - 25.36AB - 5.12BC ....(4)

Where A = malted sorghum flour, B = sprouted mung bean flour, and C = date fruit powder

Water absorption capacity (WAC) is a vital functional property of flour blends, influencing dough handling, product texture, and shelf life. In this study, WAC values of the composite flours ranged from 1.70 to 2.33 mL/g, though differences among the samples were not statistically significant ($p > 0.05$), as indicated by shared superscripts. Despite this, clear formulation trends emerged. The highest WAC (2.33 mL/g) was observed in samples such as MSD 1, MSD 2, MSD 4, MSD 9, and MSD 10, all of which had ≥70% malted sorghum flour (MSF). The enhanced WAC in these samples likely stems from MSF's partially degraded starches and fibrous structure developed during malting, which increases water-binding capacity (Musa *et al*., 2022; Agu *et al*., 2017). In contrast, lower WAC values (1.70–1.79 mL/g) were recorded in samples with higher levels of sprouted mung bean flour (SMF) and/or date fruit powder (DFP), such as MSD 3, MSD 6, MSD 7, MSD 8, and MSD 14. Germination of SMF may decrease WAC by breaking down macromolecules, while DFP's high sugar and fiber content may reduce hydration by limiting water accessibility (Olagunju *et al*., 2023; El-Sohaimy and Hafez, 2021). The cubic model used to describe WAC variation was not statistically significant ($F = 3.24$, $p = 0.1348$), suggesting limited predictive reliability. While the R^2 value was relatively high (0.8794), the wide discrepancy between adjusted R^2 (0.6080) and predicted R^2 (−0.3421) indicates potential overfitting (Abasiekong *et al.*, 2023). Nonetheless, model diagnostics revealed acceptable experimental consistency, with a coefficient of variation of 8.71% and an adequate precision of 4.32. Coefficient analysis showed that DFP (C) had the strongest linear positive effect (+2.10), followed by MSF (A, +1.83), while SMF (B) had a strong negative effect (−378.84), possibly due to scaling issues. Positive interactions were observed in AB (+1.47) and AB(A–B) (+3.17), although model limitations precluded generation of a response surface plot.

$$WAC = + 1.83A + 2.10B - 378.84C + 1.47 AB + 662.41 AC - 582.43 ABC + 3.17 AB(A-B) - 304.36 AC(A-C) - 262.30 BC(B-C) \quad ....(5)$$

Where, A = malted sorghum flour, B = sprouted mung bean flour, and C = date fruit powder

Oil absorption capacity (OAC) is a key functional property influencing flavor retention, mouthfeel, and texture in low-moisture food products such as snack bars. In this study, OAC values of the composite flours varied significantly ($p < 0.05$), ranging from 0.83 to 1.23 mL/g, depending on the formulation. The highest OAC (1.23 mL/g) was recorded in MSD 1, MSD 4, and MSD 12, which contained higher proportions of sprouted mung bean flour (SMF) and/or date fruit powder (DFP). These ingredients are rich in proteins, fibers, and sugars with polar side chains and hydrophilic structures, enhancing oil retention (Adebowale *et al.*, 2012; Mohammed *et al.*, 2022). Conversely, the lowest OAC (0.83 mL/g) in MSD 8 may be attributed to its limited DFP content, despite high SMF levels. Samples like MSD 3, MSD 5, and MSD 14 also exhibited low OAC, likely due to a reduced presence of oil-binding components. The results reflect the differing oil-holding capacities of the ingredients: malted sorghum flour (MSF), being starch-rich, tends to have lower OAC, while legumes like mung bean improve lipid interaction through protein structures (Kaur and Singh, 2005; Aremu *et al.*, 2020). ANOVA revealed that the data fitted well to a special quartic model ($F = 4.83$, $p = 0.0367$), explaining 84.93% of the variation ($R^2 = 0.8493$). However, a large gap between adjusted R^2 (0.6736) and predicted R^2 (0.1020) indicated limited predictive strength, possibly due to overfitting or weak correlation among variables. Despite this, the model showed good reproducibility with a low coefficient of variation (6.73%) and strong signal-to-noise ratio (adequate precision = 7.21). The non-significant lack-of-fit ($F = 0.26$) confirmed the model's suitability (Elochukwu *et al.*, 2019). Coefficient analysis identified DFP (Factor C) as the most impactful on OAC (+17.60), while interactions like AB^2C (+42.70) were synergistic, and AC and BC showed antagonistic effects.

$$OAC = + 1.18A + 0.9746B + 17.60C + 0.5577AB - 21.98AC - 22.05BC + 42.70 AB^2C - 88.39 ABC^2 \quad ....(6)$$

Where, A = malted sorghum flour, B = sprouted mung bean flour, and C = date fruit powder

Swelling capacity is a crucial functional property that reflects the ability of flour particles to absorb water and expand, influencing texture and hydration in food applications. In this study, swelling capacity values ranged significantly ($p < 0.05$) from 48.80% to 59.98% across the composite flour formulations. The highest values were observed in MSD 3 (59.98%), MSD 12 (59.92%), and MSD 11 (59.70%), which contained moderate levels of sprouted mung bean flour (SMF) and higher proportions of date fruit powder (DFP). These combinations enhance water uptake and volumetric expansion due to improved hydration and matrix structure (Ojo *et al.*, 2021). Malted sorghum flour (MSF), rich in partially hydrolyzed starch, facilitates water absorption and granule swelling. SMF contributes solubilized proteins and disrupted cell walls, improving hydration (Eneche *et al.*, 2020; Ocheme *et al.*, 2022). However, excessive SMF, as seen in MSD 10 and MSD 4, reduced swelling capacity (48.80–49.90%), likely due to denser protein matrices that bind water without expansion. Similarly, high MSF content in MSD 2 (80%) led to lower swelling (50.93%). DFP, known for its soluble sugars and fiber, positively influenced swelling through enhanced gelation and water retention (Gbadamosi *et al.*, 2019). ANOVA confirmed a highly significant special quartic model ($F = 71.48$, $p = 0.0001$), with an excellent fit ($R^2 = 0.9913$, adjusted $R^2 = 0.9775$, predicted $R^2 = 0.8122$). The low coefficient of variation (1.20%) and adequate precision (20.01) demonstrated strong reliability and signal strength. The non-significant lack-of-fit ($F = 0.2636$) validated the model's accuracy. DFP (C) had the strongest positive effect on swelling (+95.68), while MSF (A) and SMF (B) followed. Significant interactions included synergistic AB (+10.42) and A^2BC (+372.88), while AC, BC, AB^2C, and ABC^2 had antagonistic effects. These findings emphasize the critical role of DFP and optimal blend balance in maximizing swelling performance (Njapndounke *et al.*, 2023).

$$\text{Swelling Capacity} = + 59.83A + 51.56B + 95.68C + 10.42AB - 103.72AC - 16.52BC + 372.88 A^2BC - 387.39 AB^2C - 611.23 ABC^2 \quad ....(7)$$

Where, A = malted sorghum flour, B = sprouted mung bean flour, and C = date fruit powder.

Effect of Mixture Component On the proximate composition of flour blends from Malted Sorghum, Sprouted Mung Bean and Date Fruit Powder

The proximate composition analysis of the composite flour samples offers valuable insights into their nutritional quality and suitability for developing health-enhancing snack bars.

Moisture content is a vital quality attribute in snack formulations due to its influence on shelf-life, microbial stability, and sensory characteristics such as texture and mouthfeel. In this study, moisture levels in composite flour blends of malted sorghum, sprouted mung bean, and date fruit powder ranged from 8.58% to 9.52%, remaining within the safe storage threshold (<10%) recommended for ready-to-eat cereal-based snacks (Nwanekezi *et al*., 2023). The lower moisture in MSD 2 indicates reduced spoilage risk, while the slightly higher value in MSD 4 is likely due to the water-binding capacity of sprouted mung bean flour, which is rich in fiber and protein (Fekadu *et al*., 2022). Analysis of variance (ANOVA) for the special cubic model confirmed statistical significance ($F = 12.34$, $p = 0.0020$), suggesting that the model effectively explains moisture variability. Significant linear effects of malted sorghum (A), sprouted mung bean (B), and date fruit powder (C), along with the AB interaction, were identified ($p < 0.05$), while AC, BC, and ABC interactions were non-significant. The model showed good fit (non-significant lack of fit: $F = 0.08$, $p = 0.9701$), with strong performance metrics ($R^2 = 0.9136$, adj. $R^2 = 0.8396$, pred. $R^2 = 0.6730$). High adequate precision (10.853) and low coefficient of variation (1.21%) confirm its robustness. Date fruit powder (C) had the greatest positive influence on moisture (+10.73), followed by malted sorghum (A) and sprouted mung bean (B). However, high variance inflation factors (VIF > 200) for AC and BC suggest potential multicollinearity, warranting caution. A 3D surface plot visualized the interaction effects, especially between A and B, supporting the model's predictive

Table 2: Functional properties of composite flours

Samples	**MSF (%)**	**SMF (%)**	**DFP (%)**	**Bulk density (g/mL)**	**Foaming capacity (%)**	**Wettability (Sec.)**	**Gel. Temperature (c^0)**	**WAC (mL/g)**	**OAC (mL/g)**	**Swelling Capacity (%)**
MSD 1	70.00	20.00	10.00	$0.84^{cd}\pm0.01$	$5.66^{f}\pm0.01$	$74.33^{bc}\pm0.57$	$81.66^{bc}\pm0.57$	$2.33^{a}\pm0.57$	$1.23^{a}\pm0.05$	$58.35^{c}\pm0.04$
MSD 2	80.00	10.00	10.00	$0.86^{a}\pm0.00$	$5.77^{def}\pm0.11$	$72.33^{de}\pm0.57$	$81.33^{bcd}\pm0.57$	$2.33^{a}\pm0.57$	$1.03^{abc}\pm0.05$	$50.93^{e}\pm0.73$
MSD 3	80.00	15.00	5.00	$0.85^{abc}\pm0.00$	$7.64^{a}\pm0.03$	$72.66^{cd}\pm1.15$	$84.66^{a}\pm057$	$1.70^{a}\pm0.01$	$0.93^{bc}\pm0.05$	$59.98^{a}\pm0.03$
MSD 4	65.00	30.00	5.00	$0.86^{ab}\pm0.00$	$7.61^{a}\pm0.02$	$70.66^{ef}\pm0.57$	$80.00^{d}\pm0.00$	$2.33^{a}\pm0.57$	$1.23^{a}\pm0.05$	$49.90^{ef}\pm0.08$
MSD 5	80.00	10.00	10.00	$0.86^{a}\pm0.01$	$5.85^{de}\pm0.06$	$72.33^{de}\pm0.57$	$80.33^{cd}\pm0.57$	$1.86^{a}\pm0.05$	$0.93^{bc}\pm0.05$	$52.26^{d}\pm0.32$
MSD 6	65.63	25.62	8.75	$0.86^{ab}\pm0.01$	$5.85^{d}\pm0.02$	$72.33^{de}\pm0.57$	$81.33^{bcd}\pm0.57$	$1.79^{a}\pm0.01$	$1.01^{abc}\pm0.02$	$58.54^{bc}\pm0.05$
MSD 7	75.63	15.63	8.75	$0.86^{a}\pm0.01$	$5.67^{ef}\pm0.01$	$70.33^{f}\pm0.57$	$80.33^{cd}\pm0.57$	$1.79^{a}\pm0.00$	$1.06^{abc}\pm0.11$	$53.03^{d}\pm0.25$

MSD 8	62.50	30.00	7.50	$0.83^{d}\pm0.01$	$6.68^{c}\pm0.02$	$70.33^{f}\pm0.57$	$80.66^{cd}\pm0.57$	$1.73^{a}\pm0.05$	$0.83^{c}\pm0.05$	$52.94^{d}\pm0.12$
MSD 9	75.63	18.13	6.25	$0.86^{a}\pm0.0$	$5.77^{def}\pm0.01$	$70.66^{ef}\pm0.57$	$82.66^{b}\pm0.57$	$2.33^{a}\pm0.57$	$1.10^{abc}\pm0.17$	$50.69^{e}\pm0.06$
MSD 10	65.00	30.00	5.00	$0.86^{ab}\pm0.01$	$7.68^{a}\pm0.00$	$70.33^{f}\pm0.57$	$81.33^{bcd}\pm0.57$	$2.33^{a}\pm0.57$	$1.10^{abc}\pm0.17$	$48.80^{f}\pm0.07$
MSD11	60.00	30.00	10.00	$0.85^{abc}\pm0.01$	$5.82^{def}\pm0.01$	$77.33^{a}\pm0.57$	$80.66^{cd}\pm0.57$	$1.83^{a}\pm0.01$	$1.13^{ab}\pm0.05$	$59.70^{ab}\pm0.26$
MSD 12	60.00	30.00	10.00	$0.84^{bcd}\pm0.01$	$5.67^{ef}\pm0.01$	$75.66^{ab}\pm0.57$	$82.66^{b}\pm0.57$	$1.83^{a}\pm0.05$	$1.23^{a}\pm0.05$	$59.92^{a}\pm0.08$
MSD13	80.00	15.00	5.00	$0.85^{abc}\pm0.00$	$7.52^{a}\pm0.02$	$71.33^{def}\pm0.57$	$82.66^{b}\pm0.57$	$1.83^{a}\pm0.06$	$1.06^{abc}\pm0.11$	$58.99^{abc}\pm1.07$
MSD 14	72.50	22.50	5.00	$0.86^{ab}\pm0.01$	$7.19^{b}\pm0.20$	$72.33^{de}\pm0.57$	$80.66^{cd}\pm0.57$	$1.70^{a}\pm0.01$	$0.93^{bc}\pm0.05$	$50.23^{e}\pm0.33$

Values are means of the triplicate determination ± standard deviation. Means with different superscript in the same column are significantly ($p<0.05$) different. MSF = Malted Sorghum flour, SMF = Sprouted Mung Bean Flour, DFP = Date Fruit Powder, MSD = Malted Sorghum, Sprouted Mung Bean and Date Fruits, OAC = Oil Abasorption Capacity, WAC = Water Absorption Capacity

Table 3: Diagnostic parameters for the fitted model of the functional properties of the composite flours

Parameters	**model**	**R-squared**	**Adjusted R-squared**	**Pred. R-Squared**	**Lack of fit**	**PRESS**	**Adequate Precision**	**p- value**
Bulk density (g/mL)	Special quartic	0.9599	0.8958	0.5025	0.7450	0.0006	11.9688	0.0043*
Foam capacity (%)	Quadratic	0.9128	0.8583	0.7281	0.0023	2.69	10.5341	0.0005*
Wettability (Sec)	Quadratic	0.9375	0.8984	0.8084	0.6980	11.26	11.1315	0.0001*
Gelatinization temperature (° C)	Quadratic	0.5976	0.3461	-0.2513	0.6907	26.58	4.5056	0.1325NS

WAC (mL/g)	Cubic	0.8794	0.6080	-	-	NA	4.3236	0.1348NS
OAC (mL/g)	Reduced Special Quartic	0.8493	0.6736	0.1020	0.7838	0.1811	7.2130	0.0367*
swelling capacity (%)	Special Quartic	0.9913	0.9775	0.8122	0.6347	46.27	20.0075	0.0001*

**: Means in the same row are significantly different at p<0.05, respectively. NS: Means in the same row are not significantly (p>0.05) different*

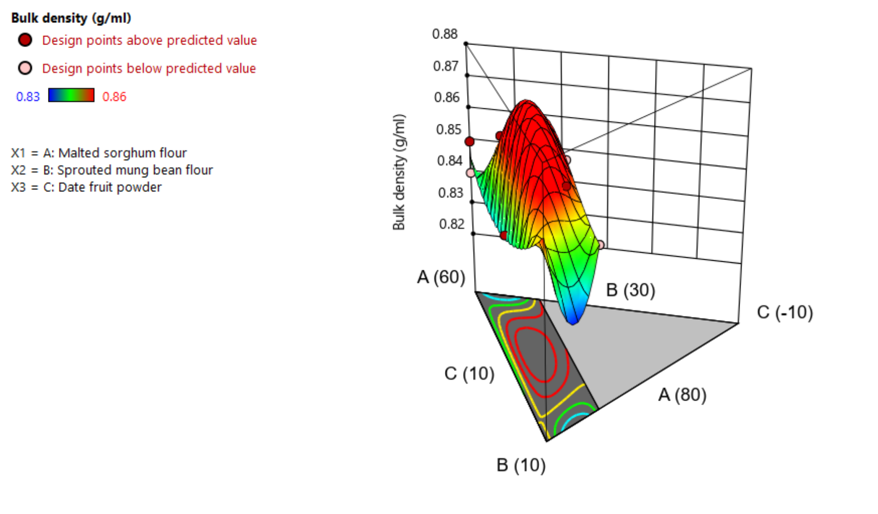

Figure 1: Response surface plot for the effects of mixture components on the bulk density of malted sorghum-sprouted mung bean-date flour.

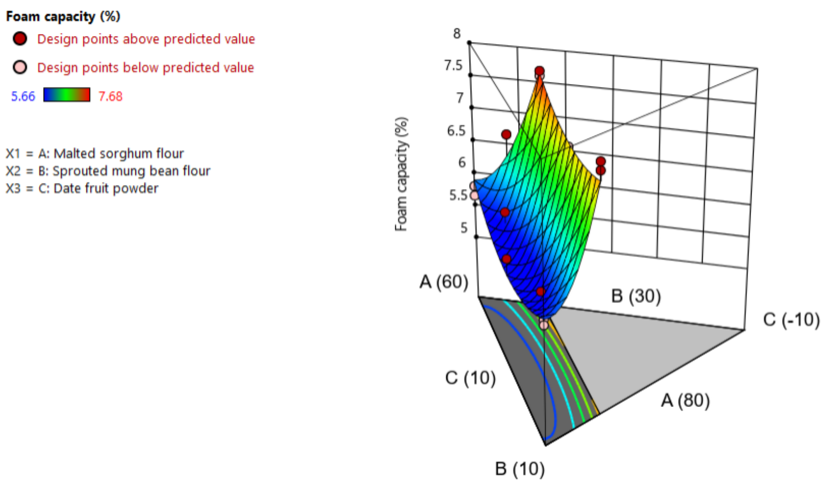

Figure 2: Response surface plot for the effects of mixture components on the foam capacity of malted sorghum-sprouted mung bean-date flour.

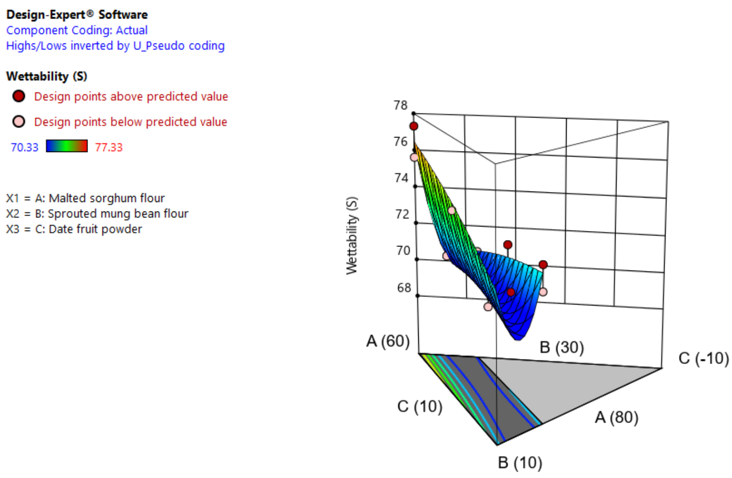

Figure 3: Response surface plot for the effects of mixture components on the wettability of malted sorghum-sprouted mung bean-date flour.

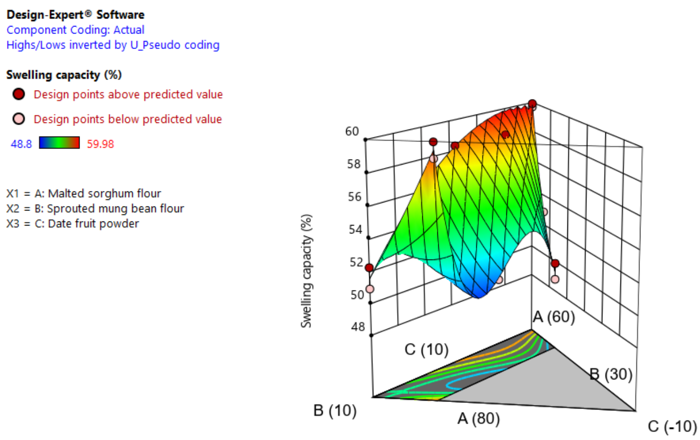

Figure 4: Response surface plot for the effects of mixture components on the swelling capacity of malted sorghum-sprouted mung bean-date flour.

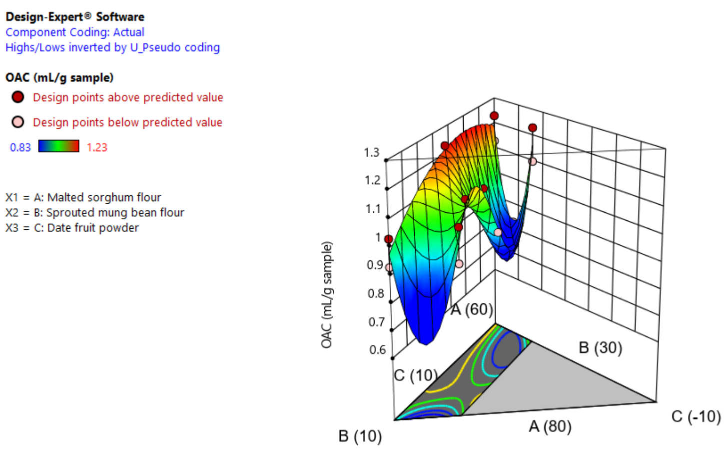

Figure 5: Response surface plot for the effects of mixture components on the oil absorption capacity of malted sorghum-sprouted mung bean-date.

strength.

Moisture = +8.93A+8.61B+10.73C+1.19AB+0.3578AC-1.79BC ....(8)

Where A = malted sorghum flour, B = sprouted mung bean flour, and C = date fruit powder

Protein content, a critical macronutrient essential for growth, maintenance, and repair, varied significantly ($p<0.05$) across the composite flour samples, ranging from 12.38% in MSD 2 to 21.92% in MSD 11 and MSD 12. The notable increase in protein content was primarily linked to the inclusion of sprouted mung bean flour (SMF), which is known to enhance protein digestibility and bioavailability through enzymatic modification during sprouting (Nkhata *et al*., 2018; Onuorah *et al*., 2024). Additionally, sprouting improves lysine levels a limiting amino acid in cereals like sorghum thereby boosting the overall protein quality of the blends (FAO, 2023). This improvement holds relevance for combating protein-energy malnutrition, particularly in low-resource regions. ANOVA results for the special cubic model used to evaluate protein content demonstrated a highly significant fit (F = 2070.16, $p < 0.0001$), with an exceptionally low probability of results arising from random variation. The linear terms for malted sorghum (A), sprouted mung bean (B), and date fruit powder (C), along with the binary interactions AB, AC, and BC, were significant ($p < 0.05$), while the ternary interaction (ABC) was not. The model's robustness was confirmed by high R^2 (0.9994), adjusted R^2 (0.9990), and predicted R^2 (0.9956), all within the acceptable deviation range (<0.2). A low coefficient of variation (0.64%) and high adequate precision (118.25) further reinforced the model's precision and predictive power (Mehmood *et al*., 2018). Among the ingredients, date fruit powder (C) had the strongest positive effect on protein content (+36.98), followed by malted sorghum (A: +21.94) and sprouted mung bean (B: +12.41). AB had a synergistic effect, while AC and BC interactions were antagonistic (–23.00 and –19.61). High VIFs (>230) for AC and BC suggest multicollinearity, requiring careful interpretation. A 3D surface plot highlighted the AB interaction as critical in protein optimization.

Protein Content = + 21.94A + 12.41B + 36.98C + 1.53AB - 23.00AC - 19.61BC + 7.01ABC ....(9)

Where A = malted sorghum flour, B = sprouted mung bean flour, and C = date fruit powder

Fat content, a key determinant of energy density, mouthfeel, and oxidative stability, ranged from 1.67% to 2.85% across the composite flour samples. The lower fat levels observed in MSD 10 and MSD 4 are desirable for extending shelf life and aligning with growing consumer preferences for low-fat, health-conscious snacks. Conversely, the highest fat content in MSD 13 is likely due to the inclusion of date fruit powder, which contributes minor lipid quantities alongside natural sugars (Al-Farsi and Lee, 2022). While reduced-fat formulations are beneficial for cardiovascular health, moderate fat levels remain important for flavor and caloric adequacy (Obinna-Echem *et al*., 2024). The ANOVA for the reduced cubic model applied to fat content yielded a highly significant fit (F = 404.98, $p < 0.0001$), confirming the model's strong explanatory power. Significant contributors included the linear effects of malted sorghum (A), sprouted mung bean (B), and date fruit powder (C), along with interaction terms AB, ABC, and AB(A–B). Although AC and BC were not statistically significant ($p > 0.05$), they were retained to preserve model hierarchy. The model exhibited excellent performance metrics: R^2 = 0.9979, adjusted R^2 = 0.9954, and predicted R^2 = 0.9849. A low coefficient of variation (1.27%) and high adequate precision (55.576) confirm the model's precision and reliability (Mehmood *et al*., 2018; Abasiekong *et al*., 2023). Among the ingredients, date fruit powder had the greatest positive effect on fat content (+3.23), followed by sprouted mung bean (+2.56) and malted sorghum (+1.88). Notably, AB(A–B) enhanced fat content (+1.79), while AB and ABC had negative effects (−0.6165 and −7.54). High variance inflation factors (>240) for AC and BC indicate multicollinearity, warranting cautious interpretation.

Fat = + 1.88A + 2.56B + 3.23C - 0.6165AB - 2.85AC + 0.5283BC - 7.54ABC + 1.79AB(A - B) ....(10)

Where, A = malted sorghum flour, B = sprouted mung bean flour, and C = date fruit powder

Ash content, which represents the total mineral composition of food products, varied significantly across the snack bar formulations. The highest ash content was observed in MSD 11 and MSD 12 (3.67%), while the lowest was found in MSD 5 (2.49%). Elevated ash levels suggest higher mineral content, largely contributed by sprouted mung bean flour (SMF) and date fruit powder (DFP), both rich in essential minerals such as calcium, magnesium, potassium, and iron (Ocheme *et al*., 2020). The inclusion of legumes like mung bean enhances the micronutrient density of composite flours, supporting dietary adequacy and helping to address micronutrient deficiencies in vulnerable populations (Afolayan *et al*., 2023). The ANOVA for the special quartic model revealed a highly significant fit (F = 620.59, $p < 0.0001$), indicating strong explanatory power for ash content variability. Key significant terms included the linear effects of malted sorghum (A), sprouted mung bean (B), and date fruit powder (C), along with higher-order interactions AC, BC, AB^2C, and ABC^2. The A^2BC term was nearly significant ($p = 0.0556$), while AB showed no significant impact. A non-significant lack of fit (F = 0.24, $p = 0.6488$) indicated that model errors were mostly due to random variation (Elochukwu *et al*., 2019; Kumari *et al*., 2022). Model performance was excellent, with R^2 = 0.9990, adjusted R^2 = 0.9974, and predicted R^2 = 0.9796. A low coefficient of variation (0.65%) and high adequate precision (71.67) confirmed strong precision and signal strength (Mehmood *et al*., 2018). While DFP had the most positive effect on ash content (+19.30), its interactions with A and B were strongly negative (−21.80 and −21.00). The AB^2C term increased ash content (+34.89), but ABC^2 significantly decreased it (−67.04). High VIFs (>1000) for some terms indicate multicollinearity, warranting cautious interpretation.

Ash = + 3.67A + 2.52B + 19.30C - 0.0050AB - 21.80AC - 21.00BC + 10.23 A^2BC + 34.89AB^2C - 67.04 ABC^2 ....(11)

Where, A = malted sorghum flour, B = sprouted mung bean flour, and C = date fruit powder

Crude fiber content across the composite snack formulations ranged from 4.01% to 8.66%, with the highest values recorded in samples with greater proportions of date fruit powder (DFP) and sprouted mung bean flour (SMF). Dietary fiber plays an essential role in digestive health, regulating blood glucose, supporting cholesterol reduction, and promoting regular bowel movements (Wolever, 2023). The elevated fiber content in samples such as MSD 5 and MSD 1 suggests their potential utility as functional foods, especially for managing non-communicable diseases like diabetes and obesity. Furthermore, the integration of cereal-legume-fruit components may enhance the solubility and fermentability of dietary fiber, improving prebiotic potential and gut health benefits (Chinma *et al*., 2022), in line with WHO (2022) recommendations on increasing fiber intake for chronic disease prevention. The quadratic model used to analyze fiber content in the blends demonstrated a statistically significant fit (F = 10.38, p = 0.0024), indicating reliable model performance. Linear terms for malted sorghum (A) and sprouted mung bean (B) were both significant ($p < 0.05$), underscoring their individual contributions to fiber content. Interaction terms AB, AC, and BC were not significant but retained to preserve model hierarchy. The non-significant lack of fit (F = 0.31, p = 0.8594) confirmed model adequacy (Elochukwu *et al*., 2019; Kumari *et al*., 2022). The model's R^2 (0.8664), adjusted R^2 (0.7829), and predicted R^2 (0.5915) reflect acceptable reliability, as the difference between adjusted and predicted R^2 remains within 0.2 (Abasiekong *et al*., 2023). Adequate precision (8.82) and a CV of 11.82% further support model robustness. DFP had the most substantial positive influence on fiber (+19.29), though its high VIF (511.04) and those of AC and BC (>228) suggest multicollinearity. Future modeling should address this to improve parameter stability (Mehmood *et al*., 2018).

Crude fibre = + 7.72A + 8.44B + 19.29C - 0.5515AB - 35.01AC - 27.68BC ....(12)

Where A = malted sorghum flour, B = sprouted mung bean flour, and C = date fruit powder

Carbohydrate content, calculated by difference, varied inversely with the levels of protein and fiber across the composite flour blends. Samples MSD 3 and MSD 2 recorded the highest carbohydrate contents 65.82% and 65.62%, respectively which correlates with their lower inclusion of sprouted mung bean flour (SMF), a component known for its high protein and fiber content. Carbohydrates are essential in snack formulations, serving as a primary energy source and contributing to texture, flavor, and satiety. The natural sugars in date fruit powder (DFP) offer a healthier alternative to refined sugars, enhancing sweetness while aligning with global dietary trends aimed at reducing added sugar intake, particularly in products targeted at children and adolescents (Al-Farsi *et al*., 2022). The ANOVA results for the quadratic model assessing carbohydrate content demonstrated a highly significant model fit, with an F-value of 48.41 and a p-value < 0.0001. This signifies that the model reliably explains the variation in carbohydrate content with only a 0.01% chance of the results occurring randomly. Significant linear terms included malted sorghum (A) and sprouted mung bean (B) ($p < 0.0001$), while interaction terms AB, AC, and BC were not statistically significant ($p > 0.05$). These were retained to preserve the model hierarchy, as recommended in mixture design analysis (Elochukwu *et al*., 2019; Kumari *et al*., 2022). The model's adequacy was further confirmed by a non-significant lack of fit (F = 0.39, p = 0.8064) and strong performance metrics: R^2 = 0.9680, adjusted R^2 = 0.9480, and predicted R^2 = 0.9008. A minimal difference between adjusted and predicted R^2 (<0.2) indicates strong predictive capability (Abasiekong *et al*., 2023). Adequate precision (18.99) and a low coefficient of variation (1.26%) highlight excellent model precision and reliability (Mehmood *et al*., 2018). Coefficient estimates showed sprouted mung bean (B) had the highest impact on carbohydrate content (+65.46), followed by malted sorghum (A, +55.84). Date fruit powder (C) had the lowest effect (+13.68), with a high VIF (511.04), indicating multicollinearity, also seen in AC and BC terms. These findings underscore the dominant role of individual components in determining carbohydrate content, consistent with prior studies (Njapndounke *et al*., 2023; Ukoha *et al*., 2022).

Carbohydrate = + 55.84A + 65.46B + 13.68C - 1.59AB + 78.32AC + 65.44BC ....(13)

Where A = malted sorghum flour, B = sprouted mung bean flour, and C = date fruit powder

Energy content, calculated using Atwater factors, ranged from 328.28 to 348.16 KCal/100g, with the highest value recorded in MSD 3, likely due to its elevated carbohydrate and fat composition. These energy values fall within the recommended range for nutrient-dense snack bars targeted at children, athletes, and individuals facing undernutrition. Such formulations are suitable for school feeding programs and emergency nutrition responses, offering a portable and cost-effective source of calories (FAO, 2023). The blend of energy-yielding macronutrients carbohydrates, fats, and proteins alongside fiber-induced satiety and plant-based protein quality, supports the development of functional snacks that can address both undernutrition and emerging lifestyle-related diseases. The ANOVA for the quadratic model evaluating energy values in blends of malted sorghum (A), sprouted mung bean (B), and date fruit powder (C) revealed a statistically significant model fit (F = 8.21, p = 0.0052). This suggests that the model adequately explains variation in energy content, with only a 0.52% chance of random influence. Linear terms A, B, and C were significant ($p < 0.05$), while interactions AB, AC, and BC were not but were retained for structural integrity (Elochukwu *et al.*, 2019; Kumari *et al.*, 2022). The model's lack of fit was non-significant ($F = 0.23$, $p = 0.9079$), affirming its validity. Model performance was moderate, with $R^2 = 0.8369$, adjusted $R^2 = 0.7350$, and predicted $R^2 = 0.5192$. The >0.2 difference between adjusted and predicted R^2 suggests issues like high variability or outliers, implying that model refinement may be necessary (Mehmood *et al.*, 2018; Abasiekong *et al.*, 2023). Despite this, the model showed strong experimental consistency, with a low coefficient of variation (CV = 0.86%) and adequate precision (7.36). Among the components, sprouted mung bean (B) contributed most to energy (+335.05 kcal/100g), followed by malted sorghum (A, +329.01) and date fruit powder (C, +317.64). However, the estimate for C had a high standard error and VIF (>511), indicating multicollinearity. Similar caution applies to AC and BC terms. These results support prior findings on energy-enhancing properties of cereal-legume-fruit blends (Njapndounke *et al.*, 2023; Ukoha *et al.*, 2022).

$$Energy = + 329.01A + 335.05B + 317.64C - 11.22AB + 80.71AC + 65.43BC \quad ....(14)$$

Where, A = malted sorghum flour, B = sprouted mung bean flour, and C = date fruit powder.

Optimization of Numerical values

Optimization of Numerical values of independent variables and simultaneous optimization of the multiple responses with significant models were carried out by choosing the desired goals for each variable and response by using Design Expert software (Design- Expert Software Version 12.0.3.0., Stat- Ease Inc., Minneapolis, USA). The ingredients (Malted sorghum flour, sprouted mung bean flour and Date fruit powder) were set in ranges. The relative importance of "3" was assigned to all the parameters. The optimization goal of for the design specifications are presented in Table 6.

Optimization formulation for the functional properties and proximate composition of Composite flour from malted sorghum flour, sprouted mung bean flour and date powder

Stat-Ease Inc (2023) showed that the response optimizer of the software generated six (6) solutions in the ingredient value with desirability of 0.178 to 0.620 and their respective responses values as shown in Tables 7 and Table 8. Optimization solutions presented in in Tables 7 and Table 8, suggested that Composite flour made with 69.925 % Malted sorghum flour, 21.382 % sprouted mung bean flour and 8.693 % Date fruit powder was selected as the best solution for this combination of variables with a desirability of 0.620 which is 62 % for all the responses evaluated.

CONCLUSION

This study demonstrated the significant influence of varying proportions of malted sorghum flour (MSF), sprouted mung bean flour (SMF), and date fruit powder (DFP) on the nutritional and functional characteristics of composite flour blends. Using a mixture design with fourteen formulations, the research revealed notable differences ($p < 0.05$) across key properties such as bulk density, foaming capacity, swelling, wettability, oil and water absorption capacities, gelatinization temperature, and proximate composition (moisture, protein, fat, ash, fiber, carbohydrate, and energy). Response Surface

Table 4: Proximate analysis on the composite flour samples

Samples	MSF (%)	SMF (%)	DFP (%)	Moisture content (%)	Protein (%)	Fat (%)	Ash (%)	Fibre (%)	Carbohydrate (%)	Energy (KCal/100g)
MSD1	70.00	20.00	10.00	$9.07^{abcde}\pm0.05$	$17.64^{c}\pm0.14$	$2.08^{e}\pm0.02$	$3.09^{d}\pm0.00$	$8.25^{b}\pm0.11$	$59.87^{e}\pm0.10$	$328.76^{f}\pm0.78$
MSD 2	80.00	10.00	10.00	$8.58^{e}\pm0.02$	$12.38^{h}\pm0.57$	$2.59^{b}\pm0.06$	$2.54^{g}\pm0.08$	$8.29^{b}\pm0.23$	$65.62^{b}\pm0.00$	$336.11^{d}\pm0.82$
MSD 3	80.00	15.00	5.00	$8.85^{cde}\pm0.08$	$14.88^{g}\pm0.04$	$2.80^{a}\pm0.05$	$2.79^{f}\pm0.92$	$4.86^{h}\pm0.10$	$65.82^{a}\pm0.06$	$348.16^{a}\pm0.53$
MSD4	65.00	30.00	5.00	$9.52^{a}\pm0.08$	$21.45^{b}\pm0.19$	$1.69^{f}\pm0.07$	$3.48^{b}\pm0.46$	$4.01^{i}\pm0.02$	$59.85^{e}\pm0.29$	$340.41^{b}\pm0.30$

MSD5	80.00	10.00	10.00	8.64^{de}±0.04	12.45^{h}±0.08	2.53^{b}±0.04	2.49^{g}±0.70	8.66^{a}±0.08	65.23^{b}±0.25	333.49^{d}±1.03
MSD6	65.63	25.62	8.75	9.10^{abcd}±0.63	19.70^{c}±0.01	1.95^{d}±0.06	3.23^{c}±0.03	7.07d±0.02	58.95f±0.12	332.15^{e}±0.06
MSD7	75.63	15.63	8.75	8.88^{cde}±0.09	15.09^{g}±0.98	2.11^{c}±0.02	2.81^{ef}±0.23	6.69^{e}±0.09	64.42^{c}±0.09	337.03^{d}±0.55
MSD8	62.50	30.00	7.50	9.17^{abc}±1.44	21.47^{b}±0.15	1.76^{ef}±0.01	3.24^{c}±0.00	5.64^{f}±0.02	58.79^{f}±0.28	336.88^{d}±0.10
MSD9	75.63	18.13	6.25	8.99^{bcde}±0.04	16.28^{f}±0.08	2.13^{c}±0.04	2.93^{e}±0.02	5.28^{g}±0.06	64.39^{c}±0.03	337.10^{d}±0.73
MSD10	65.00	30.00	5.00	9.40^{ab}±0.01	21.23^{b}±0.19	1.67^{f}±0.03	3.50^{b}±0.01	4.02^{i}±0.01	60.18^{g}±0.19	341.85^{b}±0.13
MSD11	60.00	30.00	10.00	8.76^{cde}±0.57	21.92^{a}±0.01	1.88^{de}±0.00	3.67^{a}±0.02	7.50^{c}±0.02	56.27^{g}±0.05	329.68^{f}±0.33
MSD12	60.00	30.00	10.00	9.12^{abcd}±0.04	21.92^{a}±0.01	1.88^{de}±0.00	3.67^{a}±0.23	7.49^{c}±0.00	55.92^{g}±0.05	328.28^{f}±0.24
MSD13	80.00	15.00	5.00	8.75^{cde}±0.00	14.88^{g}±0.04	2.85^{a}±0.03	2.76^{f}±0.041	7.49^{c}±0.00	63.27^{a}±0.05	338.25^{c}±0.23
MSD14	72.50	22.50	5.00	9.11^{abcd}±0.11	18.68^{d}±0.20	1.91^{d}±0.00	3.14^{cd}±0.02	4.74^{h}±0.05	62.42^{d}±0.08	341.59^{b}±0.40

Values are means of the triplicate determination ± standard deviation. Means with different superscript in the same column are significantly ($p<0.05$) different. MSF = Malted Sorghum flour, SMF = Sprouted Mung Bean Flour, DFP = Date Fruit Powder, MSD = Malted Sorghum, Sprouted Mung Bean and Date Fruits

Table 5: Diagnostic parameters for the fitted model of the proximate composition of the composite flour from malted sorghum flour, sprouted mung bean flour and date fruit powder

Parameters	**model**	**R-squared**	**Adjusted R-squared**	**Pred. R-Squared**	**Lack of fit**	**PRESS**	**Adequate Precision**	**p- value**
Moisture (%)	Special cubic	0.9136	0.8396	0.6730	0.9701	0.0006	10.8530	0.0020*
Protein (%)	Special cubic	0.9994	0.9990	0.9956	0.1441	0.7042	118.2537	0.0001*
Fat (%)	reduced cubic	0.9979	0.9954	0.9849	0.5422	0.0315	55.5756	0.0001*
Ash (%)	Special quartic	0.9990	0.9974	0.9796	0.6488	0.0408	71.6652	0.0001*
Crude fibre (%)	Quadratic	0.8664	0.7829	0.5915	0.8594	14.11	8.8206	0.0024*
Carbohydrate (%)	Quadratic	0.9680	0.9480	0.9008	0.8064	14.86	18.9924	0.0001*
Energy Value (%)	Quadratic	0.8369	0.7350	0.5192	0.9079	197.92	7.3591	0.0052*

**: Means in the same row are significantly different at p<0.05, respectively. NS: Means in the same row are not significantly (p>0.05) different*

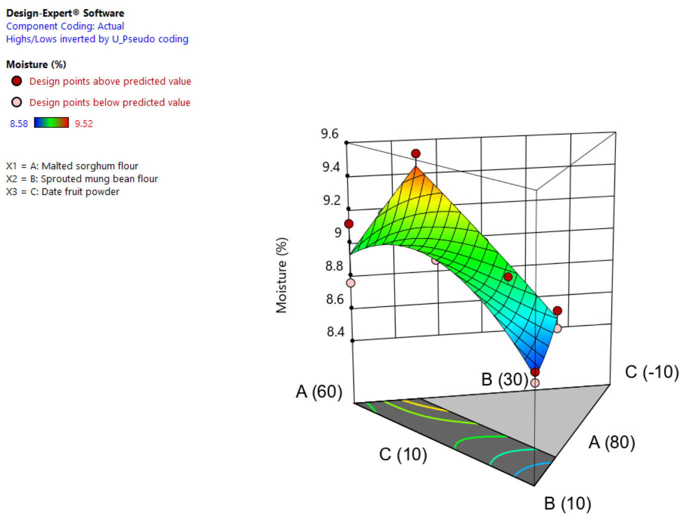

Figure 6: Response surface plot for the effects of mixture components on the moisture content of malted sorghum-sprouted mung bean-date flour.

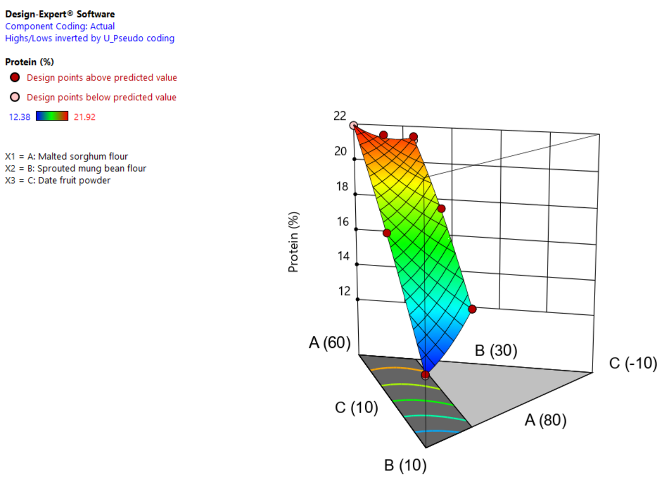

Figure 7: Response surface plot for the effects of mixture components on the protein content of malted sorghum-sprouted mung bean-date flour.

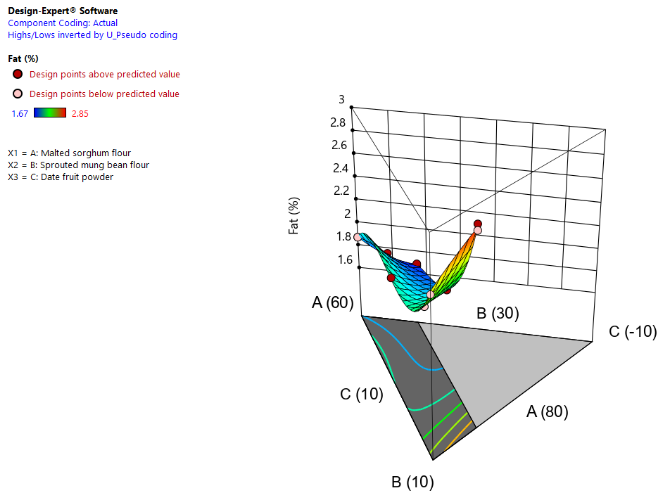

Figure 8: Response surface plot for the effects of mixture components on the fat content of malted sorghum-sprouted mung bean-date flour.

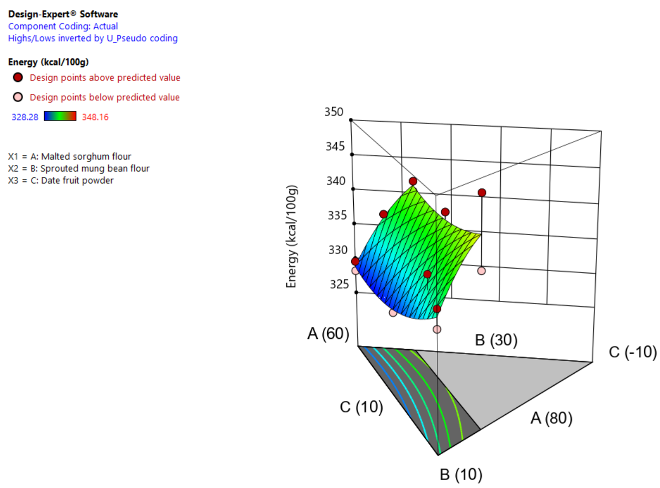

Figure 9: Response surface plot for the effects of mixture components on the ash content of malted sorghum-sprouted mung bean-date flour.

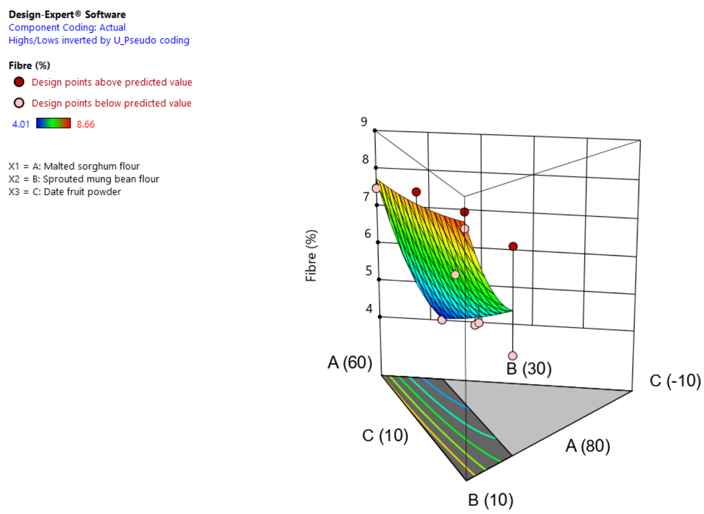

Figure 10: Response surface plot for the effects of mixture components on the fibre content of malted sorghum-sprouted mung bean-date.

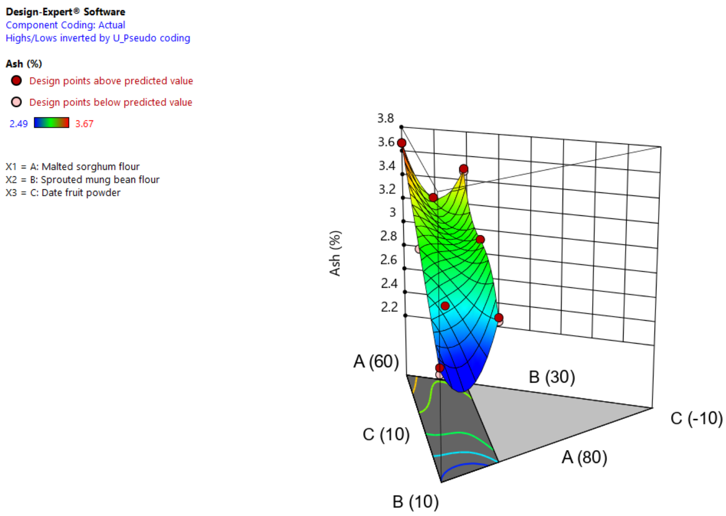

Figure 11: Response surface plot for the effects of mixture components on the carbohydrate of malted sorghum-sprouted mung bean-date.

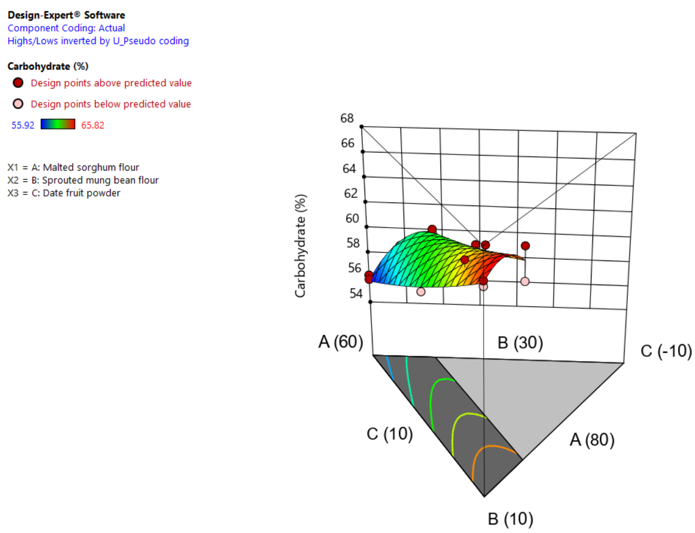

Figure 12: Response surface plot for the effects of mixture components on the energy value of malted sorghum-sprouted mung bean-date.

Methodology (RSM) effectively guided the optimization process, resulting in a gluten-free, nutrient-dense flour blend with improved functional performance. MSF contributed to higher bulk density and energy value, SMF enhanced foaming and wettability due to its modified protein structure from germination, while DFP increased fiber and sugar content, promoting energy availability and digestive benefits. The optimized formulation comprising 69.93% MSF, 21.38% SMF, and 8.69% DFP achieved a composite desirability score of 0.620, meeting criteria for nutritional adequacy and shelf stability. These findings support the use of underutilized, climate-resilient

Table 6: Optimization constraints for the functional properties, nutrient content and caloric value of malted sorghum-sprouted mung bean-date flour

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A: Malted sorghum flour	Is in range	60	80	1	1	3
B: Sprouted mung bean flour	Is in range	10	30	1	1	3
C: Date fruit powder	Is in range	5	10	1	1	3
Bulk density	Maximize	0.83	0.86	1	1	3
Foam capacity	Minimize	5.66	7.68	1	1	3

Wettability	Minimize	70.33	77.33	1	1	3
OAC	Maximize	0.83	1.23	1	1	3
Swelling capacity	Maximize	48.8	59.98	1	1	3
Moisture	Minimize	8.58	9.52	1	1	3
Protein	Maximize	12.38	21.92	1	1	3
Fat	Is in range	1.67	2.85	1	1	3
Ash	Maximize	2.49	3.67	1	1	3
Fibre	Maximize	4.01	8.66	1	1	3
Carbohydrate	Is in range	55.92	65.82	1	1	3
Energy	Maximize	328.28	348.16	1	1	3

ingredients in functional food development, especially for health-targeted products like snack bars and other baked products. The statistical models showed strong predictive accuracy (R^2 values > 0.80), and 3D surface plots effectively visualized ingredient interactions, underscoring the strength of RSM in food formulation optimization.

Table 7: Optimization solutions for the functional properties of malted sorghum-sprouted mung bean-date flour blends.

Number	**Malted sorghum flour**	**Sprouted mung bean flour**	**Date fruit powder**	**Bulk density**	**Foam capacity**	**Wettability**	**OAC**	**Swelling capacity**	**Desirability**	
1	69.925	21.382	8.693	0.871	5.545	71.641	1.121	56.720	0.620	Selected
2	60.350	30.000	9.650	0.840	5.918	75.172	1.092	58.673	0.535	
3	74.085	15.915	10.000	0.845	5.476	73.722	1.152	56.176	0.501	
4	78.277	16.556	5.167	0.850	7.184	71.796	1.105	53.432	0.491	
5	64.507	29.551	5.942	0.847	7.023	69.856	0.903	51.272	0.368	
6	65.000	30.000	5.000	0.860	7.675	70.697	1.164	49.344	0.178	

Table 8: Optimization solutions for the Proximate composition and caloric value of malted sorghum-sprouted mung bean-date flour blends

Number	**Malted sorghum flour**	**Sprouted mung bean flour**	**Date fruit powder**	**Moisture**	**Protein**	**Fat**	**Ash**	**Fibre**	**Carbohydrate**	**Energy**	**Desirability**	
1	69.925	21.382	8.693	9.069	17.939	1.971	3.108	6.735	61.308	332.934	0.620	Selected
2	60.350	30.000	9.650	8.970	21.810	1.857	3.568	7.325	56.447	330.196	0.535	
3	74.085	15.915	10.000	8.955	15.547	2.078	2.856	8.111	62.286	330.926	0.501	
4	78.277	16.556	5.167	8.876	15.689	2.487	2.920	5.740	64.289	341.980	0.491	
5	64.507	29.551	5.942	9.343	21.126	1.712	3.276	4.448	60.082	339.626	0.368	
6	65.000	30.000	5.000	9.449	21.388	1.686	3.490	4.051	59.984	341.300	0.178	

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