Formulation and nutritional evaluation of whole wheat-based composite flour for functional food development: A Compatibility-Based Approach

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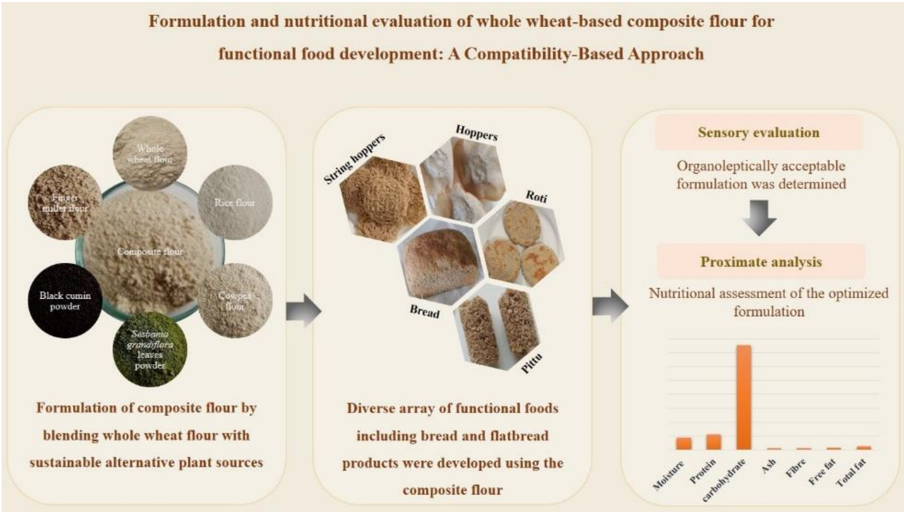

Abstract
The transition of traditional food patterns has led to an escalation of non-communicable diseases which has become a burden across the globe. Hence, healthier dietary alternatives are necessary for the rectification of the nutritional status of the people. This study intends to develop a nutritionally superior whole grain cereal-based composite flour supplemented with sustainable plant sources. Whole wheat flour, rice flour, finger millet flour, cowpea flour, black cumin seed powder and *Sesbania grandiflora* leaves powder were blended according to the Taguchi L8 orthogonal array. The best formula was initially selected through sensory evaluation, and further optimisation was conducted according to the trial and error approach to achieve a standard formula with improved organoleptic properties. Sensory data were analyzed using non-parametric tests, specifically the Friedman and Wilcoxon tests, to compare sensory characteristics at a 95% confidence level. The composite with whole wheat flour, rice flour, finger millet flour, cowpea flour, black cumin seed powder and *Sesbania grandiflora* leaves powder at 50:38:5:5:0.75:0.25 ratio was selected as the highest organoleptically accepted formula. Nutritional profile of the standard formula was evaluated using standard AOAC methods. Proximate compositions represented as moisture (8.96 ± 0.11%), carbohydrate (75.17 ± 0.17 %), ash (1.24 ± 0.02 %), protein (11.16 ± 0.01 %), total fat (2.47 ± 0.13%), free fat (1.45 ± 0.07%), and fibre (1.00 ± 0.00%). The formulated composite flour can be introduced as an appropriate dietary intervention in terms of nutritional and organoleptic properties.

Keywords: *Composite Flour, Non-communicable diseases, Whole wheat flour, Supplementation, Sustainable*

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1. Introduction

Humans need energy throughout their life span to perform vital activities, specifically those involved in development, reproduction, maintenance and movement (Pontzer et al., 2021). Our diets are composed of different macronutrients contributing to the fulfillment of daily caloric requirements. Even though the low-carbohydrate diet concept has been promoted as a weight reduction strategy, narrowed carbohydrate intake has led to more health complications, because fat and protein consumption must be increased accordingly to maintain the optimum daily caloric requirement. Moreover, low-carb diets are associated with ketotic effects, nutritional imbalances and reduced dietary fibre intakes which cause an adverse impact upon gut microbiota (Barber et al., 2021). Starch has been identified as the major carbohydrate component in our diet, and can be categorized as rapidly digestible, slowly digestible and resistant starch. Different food sources with starch as the primary carbohydrate source are wheat, rice, potatoes, cassava and maize (Bojarczuk et al., 2022). Unhealthy diets have escalated the risk of developing chronic diseases and nutritional disorders within the public health segment (Budreviciute et al., 2020).

Non-communicable diseases (NCDs) have become a significant health challenge across the globe due to higher morbidity and mortality rates (Wang and Wang, 2020). Diabetes, cancers, respiratory diseases and cardiovascular diseases are the top four chronic diseases among NCDs (Budreviciute et al., 2020). The foremost risk factors determining NCDs are unhealthy diets, physical inactivity, tobacco and alcohol consumption (Budreviciute et al., 2020; Wang and Wang, 2020). Replacement of healthier and natural traditional foods with high-fibre fractions by processed foods comprised of refined carbohydrates, animal sources, high fat and sugar fractions have led to a swift increment of NCDs in low- and middle-income countries (Budreviciute et al., 2020). Recently, greater focus has been given to whole grains and their products, which promote sustainable plant-based dietary patterns, due to superior nutritional and health benefits compared to refined flour products. Indigestible fraction of resistant starch, categorized under dietary fibre, can be used as an ingredient in functional foods. Increased consumer awareness on relationship between diet and health has led to growing interests in fibre- rich foods (Bojarczuk et al., 2022). Hence, the recommended intake of micronutrients and dietary fibre can be fulfilled by the consumption of whole grains and whole grain-based products in greater amounts (Allai et al., 2022).

Wheat (*Triticum aestivum*) is a vital staple cereal consumed across the globe (Khan et al., 2023). Whole wheat grains are comprised of minerals, B-group vitamins, dietary fibre, and bioactive compounds, which contribute to mitigating the risk of cardiovascular diseases, type 2 diabetes, cancer, and obesity (Zhang et al., 2021; Khan et al., 2023). Partial replacement of wheat flour with affordable and locally available raw materials (i.e. cereals or legumes) to improve the nutritive value of the products while reducing the dependency on the importation of wheat paved the way to composite flour technology (Olagunju et al., 2021; Forwoukeh et al., 2023). Composite flours have been utilized in the formulation of healthy and nutritious baked products, particularly bread, which plays an integral part in daily diets (Olagunju, 2019). This study blended whole wheat flour, rice flour, finger miller flour, cowpea flour, *Sesbania grandiflora* leaves powder, and black cumin seed powder to develop a micronutrient-enriched composite flour.

Supplementation of cereal-based diets with legumes or oilseeds has acquired a greater interest in achieving a complete amino acid profile and complementing the protein. A comparatively higher protein content characterizes legumes, whereas cereals contain a relatively lower protein content. Furthermore, legumes have adequate amounts of lysine and are deficient in sulfur-containing amino acids, while cereals are deficient in lysine and rich in sulfur-containing amino acids (Forwoukeh et al., 2023). Cowpea (*Vigna unguiculata* L. Walp.) is a leguminous crop with a high quantity of high-quality proteins, which makes it an ideal complementary protein source to cereals in food formulations (Akubor et al., 2023). Cowpea can potentially alleviate diseases, particularly diabetes and cancer, owing to the availability of dietary fibre, bioactive peptides, flavonols, and flavan-3-ols (Mba et al., 2023).

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Green leafy vegetables are crucial sources of essential nutrients necessary for the growth and maintenance of the body. Besides, inadequate consumption of green leafy vegetables has led to micronutrient deficiencies (Bhavya and Prakash, 2021). *Sesbania grandiflora* has been recognized as a multipurpose tree bearing edible flowers and leaves with significant therapeutic potential. It possesses antibacterial, antifungal, anti-inflammatory, anti-diabetic, antioxidant, and anti-tumor properties. *Sesbania grandiflora* has been recognized as an effective dietary supplement to act against type 2 diabetes melitus (Thissera et al., 2020). *Sesbania grandiflora* is a promising source of potassium, calcium, phosphorous, magnesium, zinc, iron, and β-carotene. Therefore, *Sesbania grandiflora* can be used in the value addition of food matrices attributable to substantial quantities of micronutrients, dietary fibre, and phytochemicals (Bhokre et al., 2022).

Black cumin seeds (*Nigella sativa* L.) have a wide array of implementations in the cosmetic, food, and pharmaceutical industries. Black cumin seeds have been utilized as a natural flavouring agent in pasta, cheese, pastries, pickles, and bakery products (Albakry et al., 2022). Black cumin seeds defend against asthma, diabetes, hypertension, inflammation, cough, and bronchitis. Further, it possesses anticancer, chemosensitizing, and antioxidant properties (Rozylo et al., 2021; Albakry et al., 2022).

Previous investigations have revealed the successful utilization of composite flours in a wide array of food product formulations with enhanced nutritional, techno-functional and organoleptic properties (Weerarathna and Wansapala, 2024). Anosike et al. (2023) reported that bread formulated with wheat: cassava: green gram at 90:5:5 and 80:10:10 ratios exhibited sensory properties similar to those of 100% whole wheat bread, whereas Millicent (2022) reported that 30 % level of cocoyam and Bambara ground flour substitution with whole wheat displayed comparable sensory attributes. Flat bread formulated with 99.25: 0.75 ratio of whole wheat flour and fenugreek gum exhibited sensory attributes comparable to 100 % whole wheat flatbread (Tandon et al., 2021). Sanni et al. (2020) observed that cookies formulated with wheat: sorrel seed protein: cassava displayed no significant difference upto 45 % substitution, while Uriarte-Frías et al. (2021) revealed that substitution upto 50 % with oyster mushroom, amaranth and nopal had no adverse effect on the sensory properties. Noodles formulated with blend of whole wheat, foxtail millet, mushroom and rice flour exhibited enhanced organoleptic properties, particularly in terms of taste and flavour (Meherunnahar et al., 2023). Ruiz-Capillas and Herrero (2021) accentuated the importance of sensory-oriented formula optimization and highlighted that formulation balance has a strong influence on consumer acceptance, hence assisting in the competitive market positioning of formulated products. Altogether, the prior investigations have underscored the significance of formula optimization, along with systematic sensory analysis, in the promising functional application of composite flours in the food systems.

The escalated incidence of chronic diseases due to increased consumption of refined carbohydrates has led to the necessity of healthy alternative flours. There is limited research carried out on blending whole wheat flour along with non-wheat flours from different plant categories for diverse applications. Therefore, the present study aimed to formulate a composite flour by blending whole wheat flour with nutritionally superior and sustainable plant alternatives, particularly rice, finger millet, cowpea, black cumin and *Sesbania grandiflora.* The formulated flour was evaluated for its organoleptic and nutritional properties to determine its compatibility in the development of diverse functional foods.

2. Materials and methodology

2.1 Sample procurement

Whole wheat flour, rice flour, finger millet, cowpea, black cumin seeds and all the other ingredients required for the product formulations were procured from the local market in Gangodawila, Nugegoda, Sri Lanka. Kathurumurunga (*Sesbania grandiflora)* leaves were obtained from local cultivation in Gangodawila, Nugegoda, Sri Lanka.

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2.2 Preparation of raw materials

Preparation of cowpea flour

Cowpeas were screened to exclude damaged seeds, dirt, foreign materials and stones. Then, the seeds were washed and dried in a hot air oven at 55 ºC for 8 hours (Abdulganiy and Taiwo, 2015). The seeds were pulverised and the derived flour was passed through a 355 micron sieve. Flour was transferred into the airtight containers and stored until subsequent use.

Preparation of finger millet flour

Finger millet grains were winnowed to remove dust and debris. Then grains were washed to remove stones, extraneous materials, adhered dirt and dust. Cleaned grains were dried in a hot air oven at 55 ºC for 8 hours (Paliwal et al., 2022), pulverized and the derived flour was passed through a 355 micron mesh. Flour was packed in airtight containers until further use.

Preparation of black cumin powder

Black cumin seeds were cleaned, washed and oven-dried at 55 ºC for 10 hrs. (Rusmarilin et al., 2019). Dried seeds were powdered and fractionated using a 355 micron mesh. Then the powder is stored in airtight containers for further use.

Preparation of Sesbania grandiflora leaves powder

Sesbania grandiflora leaves were sorted to remove wilted, damaged, discolored leaves and foreign matter. Selected fresh leaves were washed and drained off water. Then the leaves were dried at 50 ºC for 6 hours in a hot air oven (Alakali at al., 2015). Dried leaves were ground into fine powder, sieved through 355 micron sieve and stored in airtight containers for subsequent use.

2.3 Formulation of the composite flour

Each flour with uniform particle size was blended according to the statistical design of the Taguchi L_8 orthogonal array to formulate the composite flour sample, as illustrated in Table 1.

Table 1. Formulation of composite flour according to the ratios of the Taguchi L8 orthogonal array

Sample no	Whole wheat flour	Rice flour	Cowpea flour	Finger millet flour	Black cumin	*Sesbania grandiflora*
1	50	35	2.5	5	0.5	0.5
2	50	35	2.5	7.5	0.75	0.75
3	50	38	5	5	0.5	0.75
4	50	38	5	7.5	0.75	0.5
5	55	35	5	5	0.75	0.5
6	55	35	5	7.5	0.5	0.75
7	55	38	2.5	5	0.75	0.75
8	55	38	2.5	7.5	0.5	0.5

2.4 Product development using the formulated composite flour

Bread and traditional flat bread products (Roti, pittu, hoppers, and string hoppers) were prepared according to the traditional procedures. Eight samples were prepared from each product relevant to the formulations of the Taguchi L_8 orthogonal array. Additional ingredients required for the preparation were determined to conform with the palatability, ensuring consumer acceptability. Procedures of preparation were standardized to eliminate the deviations in product compositions

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throughout the study. The most preferred composite flour formulae for the said products was obtained through sensory evaluation.

Preparation of bread

Composite flour (250 g) was homogenized. Then sugar (12.5 g) was added and mixed for about 3 minutes. The yeast suspension (6.75 g yeast dissolved in 35 ml of water) was introduced and blended for another 3 minutes. Then water (140 ml), fat (6 g) and salt (5.5 g) were added, mixed and the dough kneading was carried out for 10 minutes. Dough was panned and proofed for 75 minutes. Then, it is baked at 220 ºC in a preheated oven for 50 minutes.

Preparation of hoppers

The composite flour sample (150 g) was blended with coconut water (110 ml), baking soda (1.5 g) and sugar (4 g) and allowed to ferment for 8 hours. Later coconut milk (172.5 ml) and salt (4 g) were added to the paste, mixed well and homogenized batter was prepared. Then a thin layer of batter was poured into the heated pan and the pan was covered and cooked for another 3-4 minutes.

Preparation of roti

The composite flour sample (150 g) was blended with shredded coconut (62.5 g) and salt (4 g), mixed and kneaded while adding water (i.e. about 75 ml) to obtain a non-sticky dough. The dough was then flattened on a board dusted with flour. They were placed on a heated roti pan and cooked under medium heat while turning upside down in regular intervals until the required texture and colour was obtained.

Preparation of string hoppers

The composite flour sample (150 g) was pregelatinized, and blended with boiled water (225 ml) and salt (4 g) until the mixture ended up with smooth consistency. Then the mixture was extruded onto the String hopper racks through a hand extruder and steamed in a steamer.

Preparation of pittu

The composite flour sample (150 g) was blended with shredded coconut (62.5 g), salt (5 g), water (62.5 ml) and a granular mixture was prepared. Then the prepared mixture was steamed for about 10 minutes and allowed to cool up to room temperature.

2.5 Sensory evaluation to select the best formula

Determination of the best formula for each flatbread and bread product was conducted with the participation of a sensory panel comprised of 30 randomly selected semi-trained sensory panelists based on their potentials to distinguish basic tastes, sensory aqcuity, prior experiences in sensory analysis as well as willingness to participate persistently. All the panelists freely consented to participate in the investigation and were informed about the evaluation procedures, sensory traits and implementation of standardized rating scales prior to the sensory evaluation to ensure reproducibility and uniform interpretation. Each sample was coded with a randomly generated 3-digit number and placed in a randomized sequence to avoid biasness. A 5-point hedonic scale was applied to assess the acceptability of each product (i.e. 1 and 5 denote “Dislike very much” and “Like very much” respectively). Each product was analyzed for appearance, aroma, texture, taste, aftertaste, and overall acceptability.

Sensory evaluation was conducted for the developed products under 03 stages.

01. Preliminary screening
02. Optimisation of the formula
03. Confirmation of the formula

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Preliminary screening

The objective of this screening was to obtain the optimum formula for each product. Sensory evaluation was conducted at three phases in order to avoid the interruption for discrimination potential of each panelist. First phase was carried out to select the best formula out of Formulation 1-4, while the second phase was carried out to determine the best formula out of Formulation 5-8. Then, the third phase was conducted among the best formulae obtained from phase one and phase two, based on their highest overall acceptability.

Optimisation of the formula

The objective of this step was to decrease the number of suitable formulations obtained from the preliminary screening up to one by optimisation of critical attributes (i.e. Taste and aftertaste with texture) as follows.

All suitable formulations selected from the preliminary screening for the bread and flatbread products were analyzed together, and a standard formulation was developed by optimising the relevant levels on the basis of preliminary sensory analysis. Optimisation was conducted according to the tial and error method, wherein the variables were adjusted systematically to enhance the overall consumer acceptance. The derived optimised formula was tested through the sensory with highly compatible formula (i.e. obtained at the preliminary sensory evaluation) with respect to the sensory properties for bread and flatbread products to confirm its ratio.

Confirmation of the formula

The optimised formula was tested through the sensory with the control (i.e. the products developed using refined wheat flour) to assess the consumer conformity of the formula.

2.6 Proximate composition of derived final formula

The proximate composition (i.e. moisture, protein, ash, fiber, total fat, free fat and carbohydrate) of the derived composite flour formula was evaluated using AOAC methods (Table 2). Moisture content was quantified by the oven-drying method, where 3 g of the homogenized sample was dried at 105 ºC till a consistent weight was achieved. Ash content was quantified using dry ashing method, where sample was incinerated in a muffle furnace at 550 ºC. Crude protein content was quantified using Kjeldahl method by applying nitrogen conversion factor of 6.25. Free fat content was quantified using the soxhlet extraction method wherein the total fat content was quantified using Majonnier method. Crude fibre content was quantified using acid-alkaline digestion method. Carbohydrate content was calculated using the arithmetic difference.

2.7 Statistical analysis

All the experiments of proximate analysis were replicated and the results were expressed as the mean ± standard deviation. The data obtained from each sensory analysis were analyzed by non-parametric tests using the SPSS package. The Friedman test was performed to determine the best formulation as it detected overall differences among samples followed by the Wilcoxon signed rank test for pairwise comparison at a 95 % confidence level.

Table 2. Proximate analysis procedures

Parameter	AOAC (2000) official method
Moisture	925.10
Protein	960.52
Ash	923.03
Total Fat	922.06
Fiber	920.86
Carbohydrate	By arithmetic difference

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3. Results and discussion

The products developed using the composite flour are shown in Figure 1.

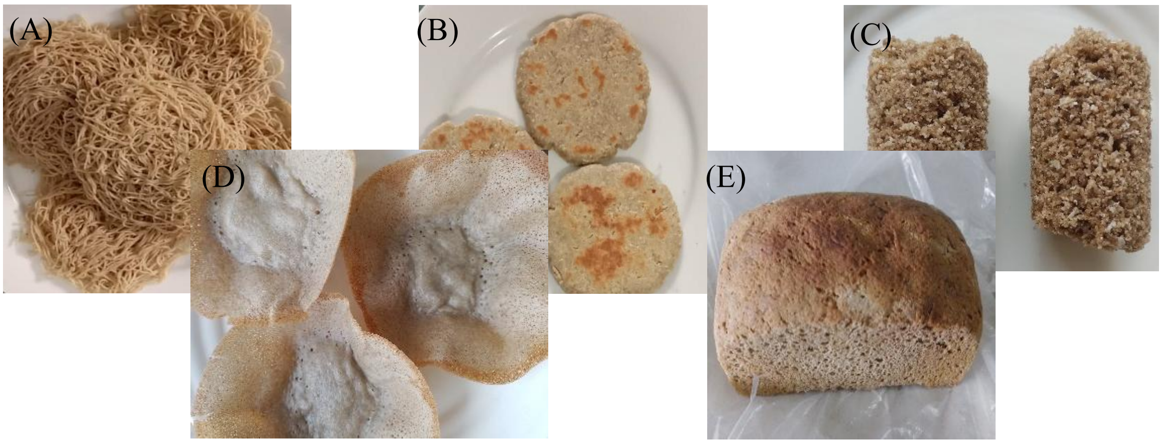

Figure 1. Composite flour based products: (A) string hoppers: (B) roti: (C) pittu: (D) hoppers: (E) bread

Sensory analysis, as a multidimenstional approach that integrates the information gathered from all the human senses along with cognitive factors, has been recognized as a holistic and practical approach over instrumental analysis, which is one dimensional (Stone and Sidel, 2006). Even though several factors such as processing conditions and physicochemical changes occurred throughout the processing, may influence the organoleptic properties of the formulated products, sensory evaluation continues to be the widely accepted approach and the primary criterion in the determination of the acceptable optimum formulation (Adanse et al., 2021; Agu et al., 2023; Dada et al., 2017; Ngwere and Mongi, 2021). Numerous studies have focused on the product-driven sensory evaluation to determine the most preferred composite flour formulation, rather than testing the flour itself (Agu et al., 2023; Bello et al., 2020; Bolaji et al., 2022; Dauda et 2020; Khan et al., 2023; Weerarathna and Wansapala, 2024). Standardized procedures and processing conditions were applied throughout the study to ensure that the flour composition was the primary variable affecting the sensory outcome, thereby eliminating the potential confounding effects.

3.1 Preliminary screening

Sensory properties of the developed products of each formulae were analyzed, and the results obtained for each are presented below. The statistical significance values (P values) of each preliminary screening test was illustrated in the Table 3.

Figure 2 (A) illustrates the sensory results obtained for bread developed according to the first four formulae in Table 1. The statistically analyzed data clearly show that appearance is significantly different ($p < 0.05$), while aroma, texture, taste, aftertaste and overall acceptability are recorded with no significant difference ($p > 0.05$). Figure 2 (B) illustrates the sensory results obtained for the bread developed as the second four formulae in Table 1. The statistically analyzed data show that the overall acceptability, appearance, and texture are significantly different ($p < 0.05$), while aroma, aftertaste and taste are recorded with no significant difference ($p > 0.05$). Formulae 3 and 5 were selected with respect to their high overall acceptability. Figure 2 (C) depicts the sensory analysis for screening the best formulation of bread. The statistically analyzed data show that all sensory properties of formulae are not significantly different ($p > 0.05$). Therefore, the Formula 3 (i.e., Atta flour (50): rice (38): cowpea (5) finger millet (5): Black cumin (0.5): Kathurumurunga leaves (0.75) was selected with respect to their higher overall acceptability.

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Table 3. Statistical significance values (P values) of preliminary screening tests

P value	Appearance	Aroma	Texture	Taste	After Taste	overall acceptability
Bread						
First phase	0.014	0.686	0.509	0.405	0.606	0.087
Second phase	0.000	0.071	0.019	0.297	0.15	0.002
Third phase	0.653	0.448	1.000	0.85	0.358	0.732
Hoppers						
First phase	0.000	0.028	0.269	0.02	0.002	0.000
Second phase	0.003	0.033	0.017	0.007	0.005	0.003
Third phase	0.004	0.003	0.046	0.117	0.002	0.002
Pittu						
First phase	0.359	0.288	0.785	0.001	0.459	0.001
Second phase	0.621	0.465	0.101	0.819	0.268	0.291
Third phase	0.000	0.001	0.000	0.011	0.005	0.009
String hoppers						
First phase	0.004	0.069	0.001	0.013	0.023	0.000
Second phase	0.00	0.518	0.013	0.015	0.873	0.064
Third phase	0.049	0.742	0.201	0.172	0.170	0.088
Roti						
First phase	0.111	0.713	0.229	0.214	0.349	0.381
Second phase	0.024	0.147	0.343	0.123	0.339	0.112
Third phase	0.117	0.131	0.750	0.991	0.707	0.509

Figure 3 (A) illustrates the sensory results obtained for hoppers developed according to the first four formulae in Table 1. The statistically analyzed data show that all sensory attributes except texture are significantly different ($p < 0.05$). Figure 3 (B) illustrates the sensory results obtained for hoppers developed as the second four formulae in Table 1. The statistically analyzed data show that all the sensory attributes are significantly different ($p < 0.05$). The Formulae 4 and 5 were selected with respect to their higher acceptability. Figure 3 (C) depicts the sensory analysis for screening best formulation for hoppers. The statistically analyzed data clearly show that all sensory attributes except taste are significantly different ($p < 0.05$). Therefore, Formula 4 (i.e., Atta flour (50): rice (38): cowpea (5) finger millet (7.5): Black cumin (0.75): Kathurumurunga leaves (0.5) was selected as the best formula for hoppers.

Figure 4 (A) illustrates the sensory results obtained for pittu developed according to the first four formulae in Table 1. The statistically analyzed data clearly show that the taste and overall acceptability are significant ($p < 0.05$), while appearance, aroma, texture and aftertaste are recorded as not significant ($p > 0.05$). Figure 4 (B) illustrates the sensory results obtained for pittu developed as the second four formulae in Table 1. The statistically analyzed data clearly show that all sensory attributes are recorded as not significant ($p > 0.05$). The Formula 1 and 7 were selected with respect to their higher overall acceptability. Figure 4 (C) depicts the sensory analysis for screening best formulation for pittu. The statistically analyzed data show that all the sensory properties are significant ($p < 0.05$). Therefore, Formula 1 was selected with respect to their higher overall acceptability (i.e., Atta flour (50): rice (35): cowpea (2.5) finger millet (5): Black cumin (0.5): Kathurumurunga leaves (0.5) as the best formula for pittu.

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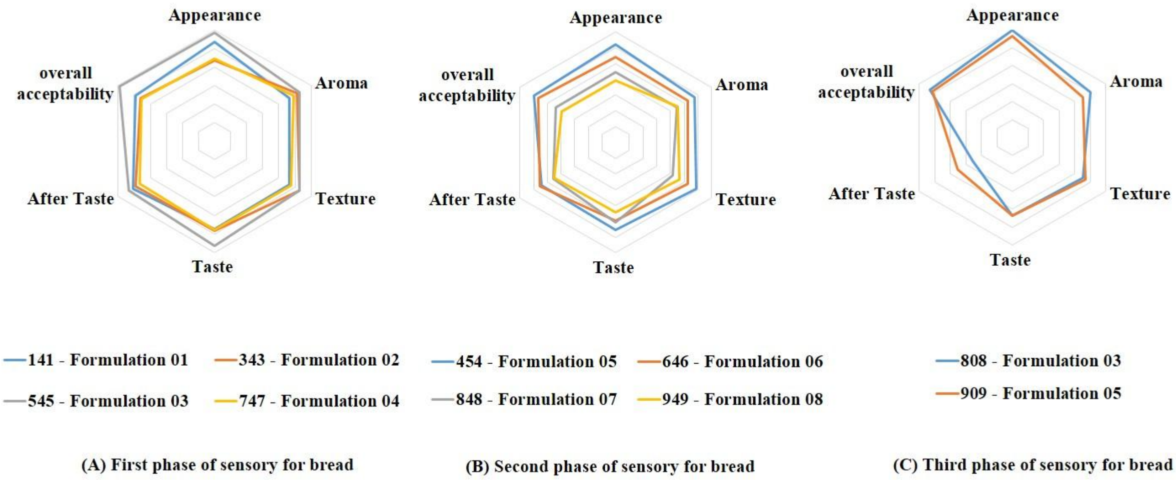

Figure 2. Preliminary screening sensory results for bread

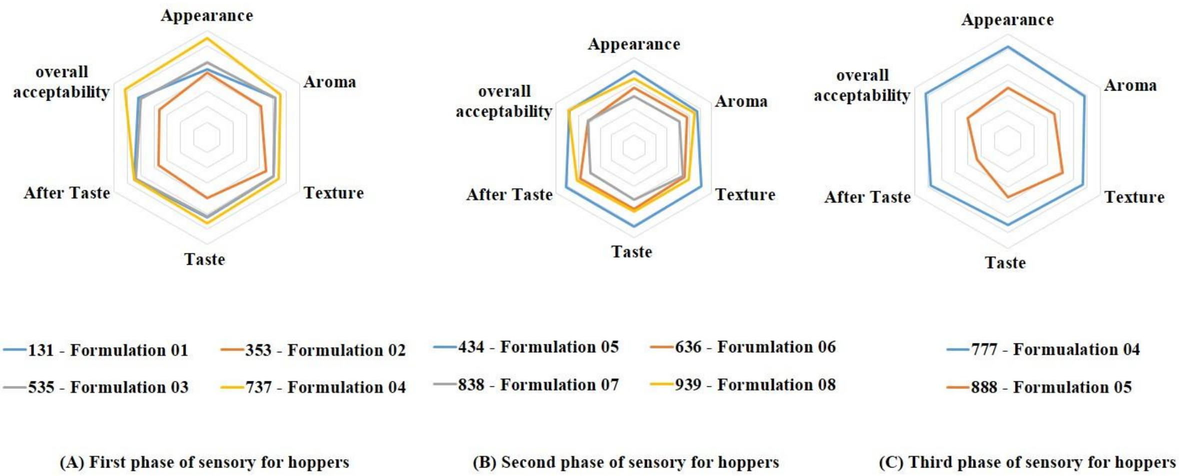

Figure 3. Preliminary screening sensory results for hoppers

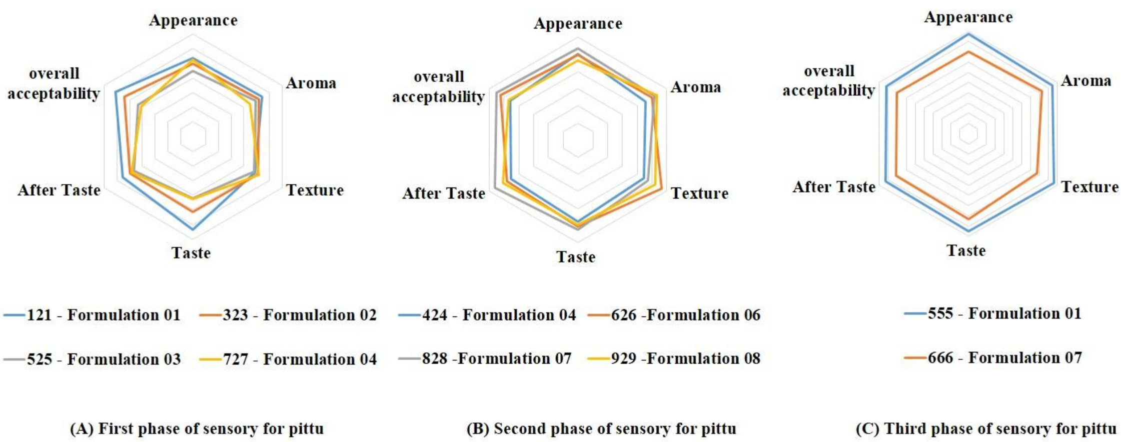

Figure 4. Preliminary screening sensory results for pittu

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Figure 5 (A) illustrates the sensory results obtained for string hoppers developed according to the first four formulae in Table 1. The statistically analyzed data show that all sensory attributes except aroma are significant ($p < 0.05$). Figure 5 (B) illustrates the sensory results obtained for string hoppers developed as second four formulae in Table 1. The statistically analyzed data clearly show that aroma, aftertaste and overall acceptability are not significant ($p > 0.05$), while appearance, texture and taste are significant ($p < 0.05$). The Formula 4 and 7 were selected with respect to their high overall acceptability. Figure 5 (C) depicts the sensory analysis for screening best formulation for string hoppers. The statistically analyzed data clearly showed that all sensory properties except appearance are not significant ($p > 0.05$). Therefore Formula 4 was selected as the best formula with respect to their higher overall acceptability (i.e., Atta flour (50): rice (38): cowpea (5) finger millet (7.5): Black cumin (0.75): Kathurumurunga leaves (0.5).

Figure 6 (A) illustrates the sensory results obtained for roti developed according to the first four formulae in Table 1. The statistically analyzed data clearly show that all sensory attributes are not significant ($p > 0.05$). Figure 6 (B) illustrates the sensory results obtained for roti developed as the second four formulae in Table 1. The statistically analyzed data clearly show that all sensory attributes except appearance are not significant ($p > 0.05$). The Formula 4 and 7 were selected with respect to their higher overall acceptability. Figure 6 (C) depicted the sensory analysis for screening best formulation for roti. The statistically analyzed data clearly show that all sensory properties are not significant ($p > 0.05$). Therefore, the Formula 7 was selected with respect to their higher overall acceptability (i.e., Atta flour (55): rice (38): cowpea (2.5) finger millet (5): Black cumin (0.75): Kathurumurunga leaves (0.75).

3.2 Optimisation of the formula

The optimised formula was shown as follows: Atta flour (50): rice (38): cowpea (5) finger millet (5): Black cumin (0.75): Kathurumurunga leaves (0.25).

The desired final qualities of bread and flatbreads differ significantly. Characteristics such as dough leavening, crumb structure, and texture development in bread are not the same as those in flatbread products. Hence, to achieve the final objective as a common formula, greater focus was given to maintain the specified properties while preserving the expected sensory properties of other flatbread products. Therefore the most compatible formula selected for flatbread and the formula selected for bread was selected for the final evaluation.

The statistical significance values (P values) of each optimisation test was illustrated in the Table 4.

Figure 7 (A) illustrates the sensory results obtained for the bread. The statistically analyzed data clearly show that all sensory attributes are significant ($p < 0.05$). Figure 7 (B) illustrates the sensory results obtained for the hoppers. The statistically analyzed data clearly show that the appearance, taste, aftertaste and overall acceptability are significant ($p < 0.05$), while aroma and texture are recorded as not significant ($p > 0.05$). Figure 7 (C) illustrates the sensory results obtained for pittu.

Table 4. Statistical significance values (P values) of optimisation sensory tests

Product	Appearance	Aroma	Texture	Taste	After Taste	overall acceptability
Bread	0.001	0.015	0.015	0.011	0.002	0.002
Hoppers	0.002	0.313	0.075	0.048	0.008	0.003
Pittu	0.084	0.109	0.147	0.036	0.017	0.022
String hoppers	0.000	0.000	0.000	0.002	0.056	0.000
Roti	0.000	0.536	0.282	0.733	0.654	0.263

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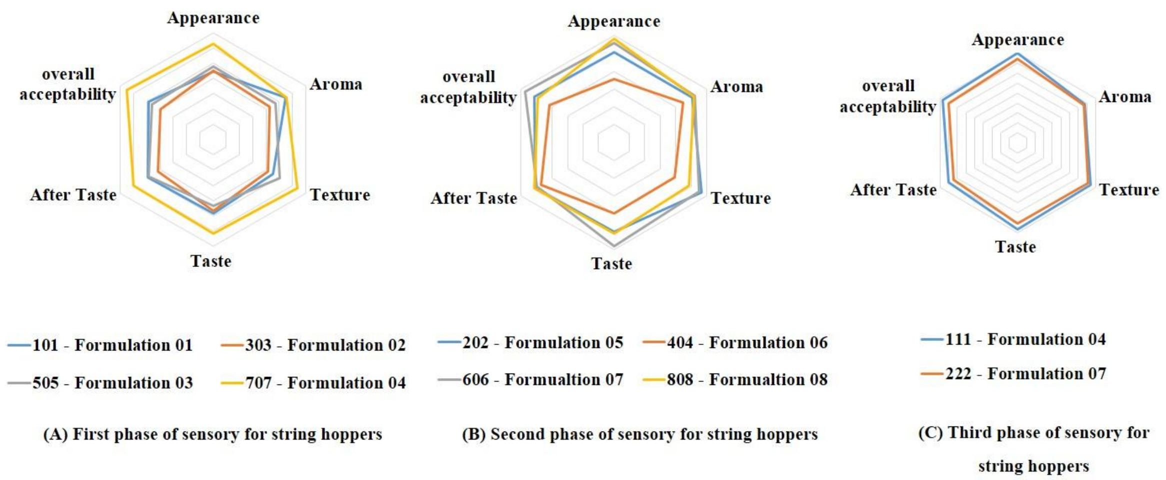

Figure 5. Preliminary screening sensory results for string hoppers

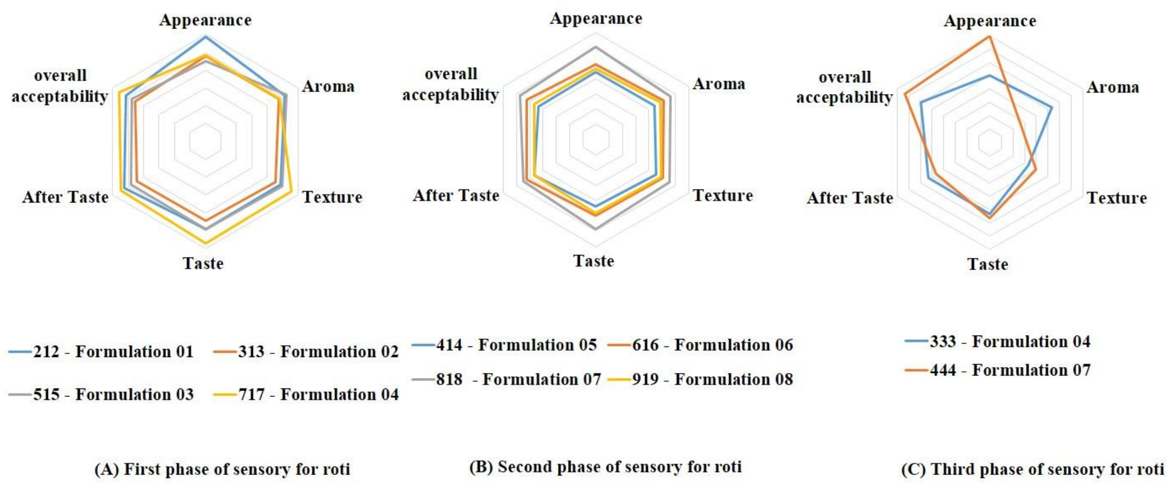

Figure 6. Preliminary screening sensory results for roti

The statistically analyzed data clearly show that the taste, aftertaste and overall acceptability are significant ($p < 0.05$), while appearance, aroma and texture are recorded as not significant ($p > 0.05$). Figure 7 (D) illustrates the sensory results obtained for string hoppers. The statistically analyzed data clearly show that all sensory attributes except after taste are recorded as significant ($p < 0.05$). Figure 7 (E) illustrates the sensory results obtained for the roti. The statistically analysed data clearly show that the all sensory attributes except appearance are recorded as not significant ($p > 0.05$). The results obtained from the sensory tests were further confirmed that the standardized formula is in accordance with acceptable sensory properties.

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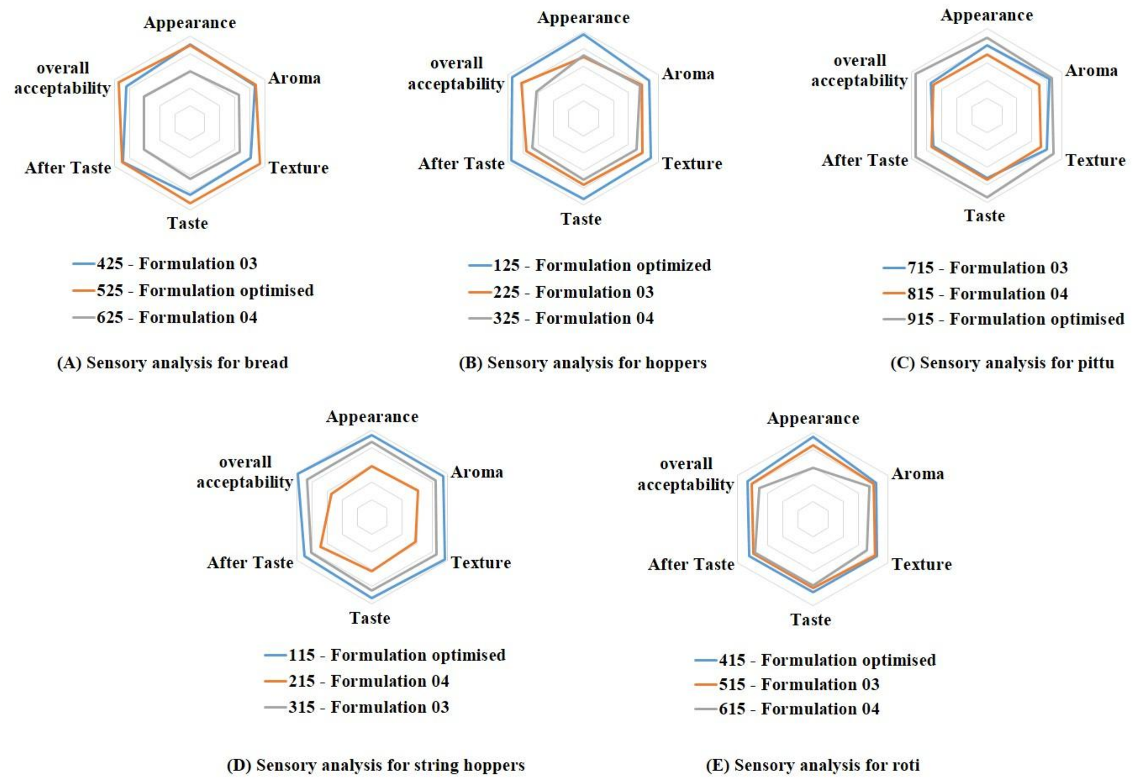

Figure 7. Optimisation of the formula

3.3 Confirmation of the formula

The sensory results obtained from the comparison of the derived optimised formula with the control are presented in Figure 8. The statistical significance values (P values) of each confirmation sensory test was illustrated in the Table 5.

Table 5. Statistical significance values (P values) of confirmation sensory tests

Product	Appearance	Aroma	Texture	Taste	After Taste	overall acceptability
Bread	0.022	0.104	0.284	0.009	0.617	0.106
Hoppers	0.554	0.000	0.027	0.000	0.000	0.000
Pittu	0.297	0.071	0.056	0.486	0.705	0.159
String hoppers	0.217	0.101	0.695	0.007	0.009	0.011
Roti	0.039	0.883	0.499	0.659	0.874	0.979

Bread and flatbread products (roti, pittu, hoppers and string hoppers) prepared with refined wheat flour were used as the controls. Figure 8 (A) illustrates the sensory results obtained for the bread. The statistically analyzed data show that all sensory attributes except appearance and taste are not significant ($p > 0.05$). Forwoukeh et al. (2023) reported that inclusion of legume flour has reduced the appearance of the whole wheat composite bread due to the colour of the raw materials as well as owing to the mailard reaction. Dilution of gluten and fibre with the incorporation of non-wheat flours reduced the sponge structure of bread. This may be the reason for the reduced texture score. Findings further explained that the inclusion of non-wheat flours enahnced the aroma and taste of the composite breads. Figure 8 (B) illustrates the sensory results obtained for the hoppers. The statistically analyzed data show that the all sensory attributes except appearance are significant ($p < 0.05$). Figure 8 (C) illustrates the sensory results obtained for the pittu. The statistically analyzed data depicted that all

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sensory attributes are not significant ($p > 0.05$). Figure 8 (D) illustrated the sensory results obtained for string hoppers. The statistically analyzed data show that the appearance, aroma and texture are recorded as not significant ($p > 0.05$), while taste, aftertaste and overall acceptability are significant ($p < 0.05$). Rukshana and Jemsiya (2023) observed significant differences in flavour, mouthfeel and overall acceptability with the increasing inclusions of jackfruit flour. Figure 8 (E) illustrates the sensory results obtained for the roti. The statistically analyzed data clearly show that all sensory attributes except appearance are not significant ($p > 0.05$). Mansoor et al. (2019) reported similar observations that the incorporation of non-wheat flour up to 25 % exhibited no significant differnce in sensory attributes including appearance, aroma, flavour and overall acceptability. Hoppers and string hoppers exhibited the highest consumer acceptance, while roti exhibited overall acceptance comparable to 100 % refined wheat roti. .

Nutritional composition of the composite flour

Proximate compositions of the final composite flour formulation (whole wheat flour: rice flour: finger millet flour: cowpea flour: black cumin seed powder: *Sesbania grandiflora* leaves powder at 50:38:5:5:0.75:0.25 ratio) are presented in Table 6. Non-wheat flours have acquired greater consumer interest due to the availability of bioactive compounds, macronutrients and micronutrients in substantial amounts, which contributed to their therapeutic properties (Weerarathna and Wansapala, 2024).

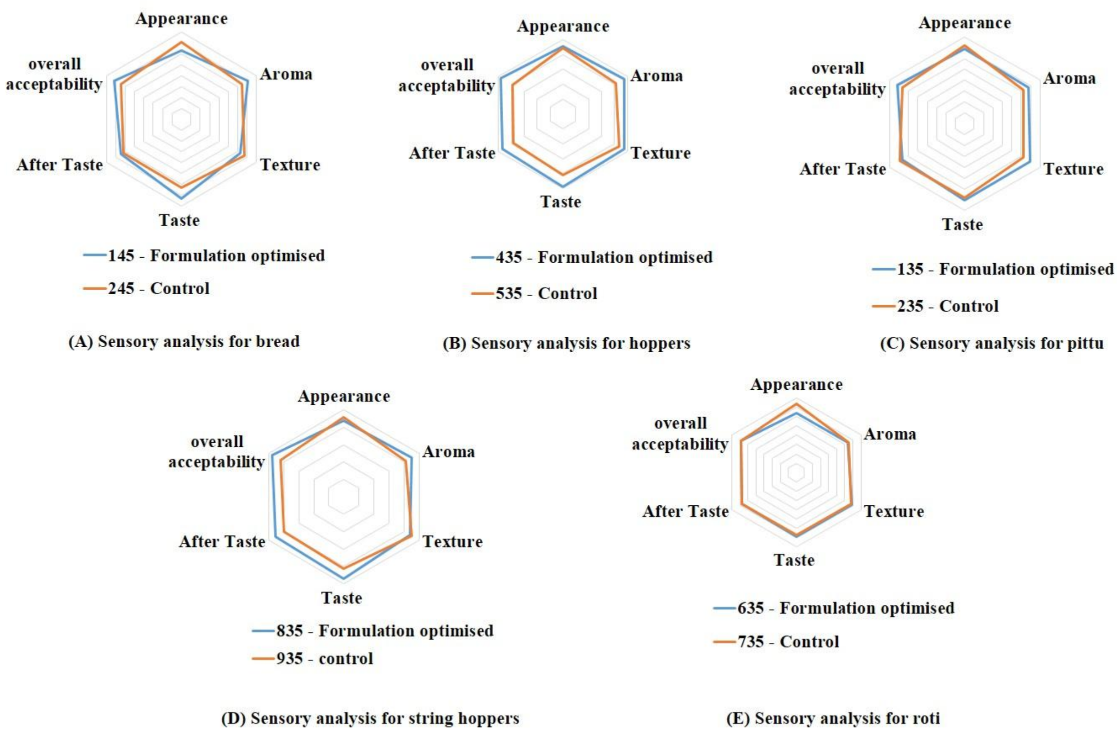

Figure 8. Confirmation of the formula

Table 6. Proximate compositions of the final composite flour (g/100g)

Raw material	Moisture	Ash	Protein	Total fat	Fibre	Free fat	Carbohydrate
Composite flour	8.96 ± 0.11	1.24 ± 0.02	11.16 ± 0.01	2.47 ± 0.13	1.00 ± 0.00	1.45 ± 0.07	75.17 ± 0.17

*db (dry basis) values expressed are average ± SD.

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The moisture content of the composite flour (8.96 %). The inclusion of non wheat flours (i.e. taro root and lotus seed) reduced the moisture content of the whole wheat based composite flour (Antarkar et al., 2019). Lower moisture contents are favourable for long term storage as it augment the storage stability via suppressing the biochemical reactions and mold growth (Akubor et al., 2023).

The ash content of the flour is a potential indicator of its mineral content. Jan et al. (2022) reported results for ash content in coherence with the current study. Amalgamation of the wheat flour (ash content of 0.44%) with rice flour (ash content of 0.32%) at 65:35 ratio reported 0.41 % ash content in the composite flour. Negu et al. (2020) revealed that the inclusion levels of non-wheat flours affected the ash content of the composite flour blends, wherein whole wheat flour substituted with 5 % fenugreek and 10 % oat flour resulted in ash content (1.4 %) similar to whole wheat flour (1.4 %) while 10 % fenugreek and 20 % oat flour inclusion resulted in enhanced ash content (1.8 %).

Wheat germ that is concentrated with fat was removed during the process of wheat milling for refined flour production. Hence, the inclusion of whole wheat flour instead of refined wheat flour, enhanced the fat content of the composite (Miranda-Ramos and Haros, 2020; Man et al., 2021). Jan et al. (2022) reported results for fat content in coherence with the present study, wherein the amalgamation of wheat flour (fat content of 1.21%) with rice flour (fat content of 0.73%) (i.e. according to the 65:35 ratio) reported 1.02 % fat content in the composite flour. Low fat content is favorable for the extended shelf life of the product. Higher fat contents are capable of initiation and acceleration of microbial spoilage. Besides, high fat contents promote the development of off odors and flavors due to rancidity (Olaoye et al., 2008).

The crude fibre content of the composite flour mixture is higher than the refined wheat flour (Man et al., 2021). Offia-Olua et al. (2015) reported higher the inclusion level of cashew apple powder lower the fibre content in the composite flour. Olagunju (2019) revealed reduced crude fibre content in the whole wheat composite bread with greater than 20 % of acha and pigeon pea substitution. Crude fibre content of whole wheat: white bean composite flour exhibited 1.44 % and 1.39 % (i.e. according to 15 % and 20 % supplementation levels of white bean flour) compared to whole wheat flour (1.52 %) (Olaoye et al., 2016).

The findings of Kumar et al. (2021) reported that the protein content of the composite flour had been reduced with the increasing incorporation levels of finger millet flour. Antarkar et al. (2019) reported reduction in the protein content of the whole wheat based composite flour with the inclusion of taro root flour and lotus seed flour. The protein content of the 15 % supplemented composite flour (10 % taro root flour + 5 % lotus seed flour) is 11.32 % compared to the whole wheat flour (14.2 %) while the particular value in 25 % supplementation (15 % taro root flour + 10 % lotus seed flour) is 12.12 %. Olaoye et al. (2019) reported protein contents of 10.13 % and 9.46 % in whole wheat: avocado peels composite flour at 5 % and 10 % inclusion levels of avocado peel flour.

Carbohydrate content of the composite flour is 75.17 %. Antarkar et al. (2019) reported increased carbohydrate content in whole wheat: taro root: lotus seed composite flour with compared to the whole wheat flour. Moreover, the carbohydrate content has been increased with the increasing inclusion levels of non wheat flour. Kokoh et al. (2019) reported improved carbohydrate contents in the whole wheat: yam: moringa leave composite flour at 10 – 40 % inclusion levels of yam flour (78.08 – 78.69 %) compared to whole wheat flour (73.0 %). High carbohydrate contents plays a crucial role in the food formulations as they contribute to the energy content (Agu et al., 2023).

4. Conclusions

The composite flour formulated in the current study using whole wheat flour, rice flour, cowpea flour, finger millet flour, black cumin powder and *Sesbania grandiflora* leaves powder exhibited a notable nutrtitional profile reflecting synergistic effect of alternative plant sources. The formulated flour exhibited acceptable organoleptic properties in both bread and flatbread products. Hoppers and string hoppers exhibited the highest consumer acceptance, while roti exhibited overall acceptance comparable to 100 % refined wheat roti. The findings of this study exhibit the feasibility of using

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locally available alternative plant sources in the development of functional composite flours with acceptable sensory properties and nutritional value, underscoring their potential application as dietary interventions.This formulated composite flour is a promising alternative to conventional refined wheat flour in terms of its nutritive value, therapeutic potential against non-communicable diseases and compatibility with a wide range of functional food products. Further investigations on the therapeutic properties are recommended for the significant health claims.

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