World Nutrition, June 2026;17(2): 117-123
DOI: https://doi.org/10.26596/wn.2026172117-123

WORLD NUTRITION
The Official Journal of the World Public Health Nutrition Association
Journal homepage: https://www.worldnutritionjournal.org
ISSN: 2041-9775

Research Article

The development of a nutritionally enhanced composite flour: nutritional, functional, and sensory properties

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OPEN ACCESS

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Article History
Received: March 05, 2026
Reviewed: March 26, 2026
Revised: June 02, 2026
Accepted: June 10, 2026
Published: June 30, 2026

Citation
Poojara R.H., Sreekumar S.P., Somarajan N. & Rose A. (2026). The development of a nutritionally enhanced composite flour: Nutritional, functional, and sensory properties. *World Nutrition*, 17(2), June, 117–123.
https://doi.org/10.26596/wn.2026172117-123

Academic Editor
Ted Greiner, PhD

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Highlights/Key Messages

- Nutrient-rich composite flour was developed from locally available ingredients.
- The T_2 formulation displayed the highest sensory attributes for the three formulated food products.
- Traditional processing improved nutrient bioavailability and functional properties.
- T_2, the optimized flour, enhanced composition with respect to protein, iron, calcium, and dietary fiber.
- Composite flour use can mitigate micronutrient deficiencies and enhance dietary diversity as compared to mono flours.

Background
The development of nutritionally enriched composite flours has gained increasing attention due to the rising prevalence of micronutrient malnutrition and diet-related health disorders. Composite flours prepared from cereals, pulses, and nutrient-rich plant ingredients can enhance the nutritional quality of staple foods while promoting the use of locally available resources.

Objective
The present study aimed to develop and evaluate a nutritionally enhanced composite flour using locally available cereals, pulses and plant-based ingredients, and to assess its functional, nutritional, and sensory characteristics.

Methods
Traditional processing methods, including soaking, sprouting, drying, and milling, were used to improve nutrient bioavailability and functional properties. Three composite flour formulations were prepared using wheat, amaranth seeds, pearl millet, green gram, amaranth leaves, and wheatgrass powder in varying proportions: T_1 (40:20:10:25:4:1), T_2 (40:25:15:15:3:2), and T_3 (40:10:25:20:2:3). Value-added products such as chapati, cookies, and energy balls were developed and evaluated by a semi-trained sensory panel using a 9-point hedonic scale.

Results
Among the formulations, T_2 achieved the highest sensory acceptability across all products. Functional analysis showed water absorption capacity of 77%, oil absorption capacity of 77.9%, swelling capacity of 60%, foam capacity of 30% and bulk density of 0.21 g/mL. Nutritional analysis revealed carbohydrate content of 70 g/100 g, protein 17 g/100 g, crude fiber 5.8 g/100 g, calcium 191 mg/100 g, iron 6.55 mg/100 g and energy value of 319 kcal/100 g, indicating a nutrient-rich formulation.

Conclusion
The developed composite flour demonstrated good functional, nutritional and sensory properties, highlighting its potential as a nutritious and functional ingredient for value-added food products and as a sustainable strategy to address micronutrient deficiencies and malnutrition.

Keywords: Composite flour, Nutritional enhancement, Functional properties, Micronutrient deficiency, Local ingredients

Introduction

Malnutrition in all its forms, including undernutrition, micronutrient deficiencies, and diet-related non-communicable diseases, remains a major global public health concern. Many commonly consumed staple foods, particularly refined cereal-based products, are deficient in essential nutrients. Innovative composite food formulations can help balance nutrition in such products (Banua et al., 2021). Dietary diversification through the use of composite flours has gained considerable attention due to its cost-effectiveness, sustainability, and ability to utilize locally available resources (Olamiti & Ramashia, 2024). Different food sources provide nutrients in varying compositions and bioavailable forms. Cereals are rich in carbohydrates but limited in essential amino acids, whereas legumes provide high-quality protein, and green leafy vegetables contribute vitamins, minerals, and bioactive compounds. Therefore, combining these ingredients into composite flours enables the development of more nutritionally balanced food products with improved functional and health-promoting properties (Mamat et al., 2020; Olamiti & Ramashia, 2024), including dietary fiber, flavonoids, and phenolic acids. These ingredients can provide antioxidant properties, conveying anti-inflammatory and metabolic regulatory effects (Olamiti & Ramashia, 2024). Traditional processing techniques such as sprouting can enhance the bioavailability of iron by activating the enzyme phytase, which breaks down dietary phytates (Elliott et al., 2022; Chandra et al., 2015). Thus achievement of UN Sustainable Development Goal 3-Good Health and Well-being, can also be enhanced with the development and utilization of such flours.

Composite flours are mostly developed from locally available, feasible, and cost-effective ingredients. The selection of ingredients for composite flour formulation is based on their nutritional and functional attributes (Mamat et al., 2020; Olamiti & Ramashia, 2024). Wheat provides gluten for structural integrity and dough formation. Amaranth seeds are rich in high-quality protein, essential amino acids, and minerals such as calcium and iron. Pearl millet contributes dietary fiber and micronutrients, particularly iron, while green gram enhances protein quality and digestibility. Amaranth leaves and wheatgrass powder are rich in chlorophyll, antioxidants, and bioactive compounds.

Composite flours can also improve the sensory qualities of food (Banua et al., 2021). They can be used to create versatile products using both modern and traditional recipes like chapati, porridge, cookies, and energy balls, and thus can be incorporated into daily diets.

Certain composite flour formulations provide cost-effective, sustainable substitutes for traditional flours. Although numerous studies have reported the nutritional and functional benefits of composite flours, limited research has focused on formulations that combine sprouted cereals and legumes with green leafy vegetable powder and on evaluating their nutritional, functional, and sensory properties. The present study aimed to develop and evaluate a nutritionally enhanced composite flour with potential applications in the production of value-added food products, thereby enhancing nutritional intake and improving dietary diversity.

Methods

Source and Preparation of Raw Materials

The composite flour was prepared using a blend of wheat (*Triticum aestivum*), amaranth seeds (*Amaranthus hypochondriacus*), pearl millet (*Pennisetum glaucum*), green gram (*Vigna radiata*), wheatgrass (*Triticum aestivum*), and amaranth leaves (*Amaranthus viridis*), all of which were sourced from local markets in Ernakulam, Kerala, India. Wheat grass was grown separately by sprouting wheat grains under controlled laboratory conditions (Table 1). The processing conditions used in this study were adapted from previously reported methods for sprouting and drying of cereals and legumes (Chandra et al., 2015; Elliott et al., 2022).

Table 1. Preparation of raw materials

Raw materials	Soaking time (h)	Sprouting time (h)	Drying time (h) (60℃)
Wheat	12	24 - 48	6
Amaranth seeds	6	24	6
Green gram	6	24	6
Pearl millet	8	24 - 48	6
Wheatgrass	12	10-12 days	6
Amaranth leaves	-	-	6

Formulation of Composite Flours

The three composite flour formulations that were prepared and designated as T_1 (40:20:10:25:4:1), T_2 (40:25:15:15:3:2), and T_3 (40:10:25:20:2:3), are presented in Table 2.

Table 2. Combinations of the composite flour

Ingredients	T1 (g)	T2 (g)	T3 (g)
Wheat	40	40	40
Amaranth seeds	20	25	10
Green gram	10	15	25
Pearl millet (bajra)	25	15	20
Amaranth leaves	4	3	2
Wheatgrass powder	1	2	3
Total (g)	100	100	100

Organoleptic Evaluation of Composite Flours

These flour blends were then used to formulate three recipes: energy balls, cookies, and chapati. The ingredients used for chapati included composite flour, water, and salt. Cookies were prepared using composite flour, sugar, butter, baking powder, and milk. Energy balls were formulated using

composite flour, dates, jaggery, nuts, and ghee. The formulations were standardized prior to sensory evaluation. Sensory evaluation was conducted using a semi-trained panel of 10 participants selected for their familiarity with sensory analysis techniques. All panelists evaluated all samples under controlled conditions. The composite flour-based products (chapati, cookies, and energy balls) were coded and presented in random order. Each participant evaluated the samples for appearance, color, flavor, texture, taste, and overall acceptability using a 9-point hedonic scale (1 = dislike extremely, 9 = like extremely) using scorecards. Water was provided for palate cleansing between samples. The scores were recorded and used for statistical analysis. The sensory scores obtained were analyzed using descriptive statistics, where the mean ($\bar{X}$) and standard deviation (SD) were calculated for each attribute and formulation.

Analysis of Nutritional Quality and Peroxide Value

The total carbohydrate content was determined using the Anthrone method as described by Wolfrom and Whistler (1962). The protein content of the composite flour formulations was analyzed using the Kjeldahl method, following the procedure described by AOAC (2012) and Offia-Olua (2014). The fat content of the composite flour was estimated using the Soxhlet extraction method, following the AOAC method (AOAC, 2000). The crude fiber content of the composite flour formulations was determined according to the method described by AOAC (2012) and as applied by Offia-Olua (2014). Iron content was determined by atomic absorption spectrophotometry following the method of Page et al. (1992). Calcium was estimated by titration with EDTA, as suggested by Hesse (1971). The peroxide value (PV), an indicator of the oxidative stability of the composite flour, was determined by iodometric titration, as described in AOAC Official Method 965.33 (AOAC, 2000).

Analysis of Functional Properties

Composite flours are primarily evaluated for their functional properties, which include water absorption capacity (WAC), oil absorption capacity (OAC), foaming properties, bulk density, particle size distribution, and pasting characteristics. These functional parameters are essential in determining the flour's applicability in food formulations and its processing behavior.

The moisture content of the composite flour formulations was analyzed using the hot air oven method as per the standard procedure outlined by AOAC (2012). The solubility was determined according to the method described by Oladele and Aina (2007). The swelling index was determined using the method of Onwuka (2005). The water and oil absorption capacity were determined using a method described by Onwuka (2005). The tapped density was determined using the method described by Onwuka (2005). The bulk density was determined according to Onwuka (2005). The foaming capacity was determined using the method described by Onwuka (2005).

Results and Discussion

Formulation and Organoleptic Evaluation of Composite Flour-Based Recipes

In addition to the three composite flour formulations described above, a control formulation, T_0, was prepared using 100% refined wheat flour to represent the original standard recipe. These formulations were incorporated into three commonly consumed recipes: energy balls, cookies, and chapati (Figure 1).

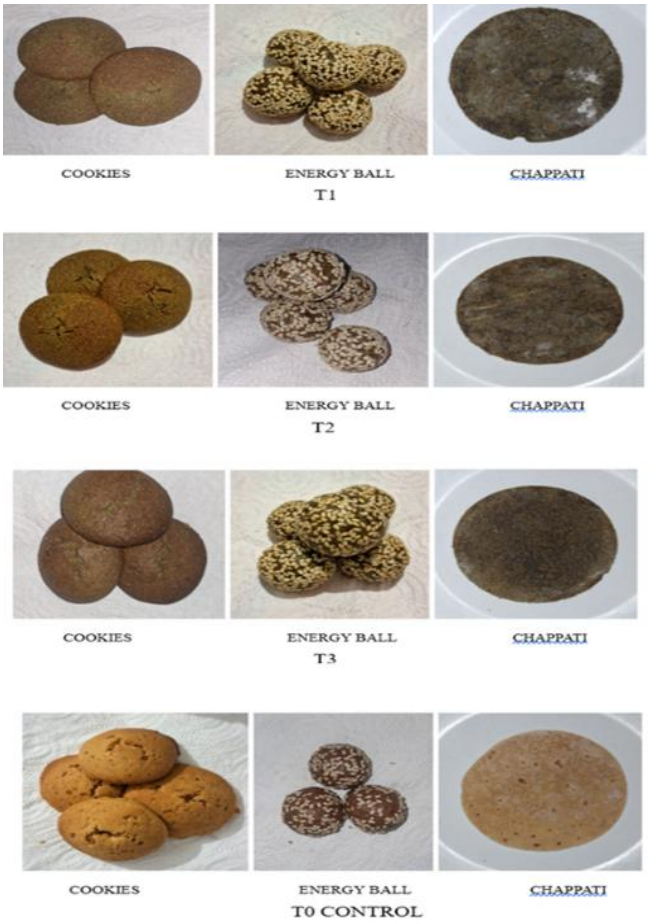


Figure 1. Different combinations of composite flour recipes

As shown in Table 3, for cookies, the highest score of flavor and taste was observed for T_1 (7.8 ± 1.5 and 7.8 ± 1.4), likely due to its balanced composition. The lowest scores across all parameters were observed for the T_3 formulation, attributed to its darker, coarser texture and the earthy taste of green gram and wheatgrass. Moderate acceptability was observed for T_2. McArthur-Floyd and Brako (2024) reported that pumpkin wheat cookies with full wheat (0% pumpkin) had the highest color, aroma, and taste scores; higher substitution levels (⩾50%) resulted in decreased sensory appeal. A study on composite flour extrudates found that inclusion of alternative flours (e.g., sorghum + cowpea) produced cookies with acceptable sensory quality when substitution was optimized (~15-30%) (Mba et al., 2023). Ikade et al. (2024) studied cookies made using composite flours on several millets. Specific formulations were selected

by the sensory panels, particularly those with balanced proportions of various millet flours. This highlights the importance of improving composite flour mixtures to develop baked items with the best possible sensory qualities.

Table 3. Organoleptic evaluation of cookies developed with composite flours

Formulation	Appearance ($\bar{X}$ ± SD)	Flavor ($\bar{X}$ ± SD)	Texture ($\bar{X}$ ± SD)	Taste ($\bar{X}$ ± SD)	Overall acceptability ($\bar{X}$ ± SD)
T_1	7.4 ± 1.6	7.8 ± 1.5	7.4 ± 1.5	7.8 ± 1.4	8.0 ± 1.2
T_2	7.2 ± 1.7	7.2 ± 1.6	7.0 ± 1.7	7.2 ± 1.7	7.4 ± 1.6
T_3	6.8 ± 1.8	6.6 ± 1.7	6.8 ± 1.8	6.8 ± 1.7	6.8 ± 1.6
T_0	8.2 ± 1.2	8.2 ± 1.2	8.2 ± 1.2	8.2 ± 1.2	8.4 ± 1.1

Organoleptic evaluation of the energy ball is reported in Table 4. Acceptance of T_1 and T_2 was highest in terms of appearance (8.2 ± 1.2 and 8.0 ± 1.3), flavor (7.6 ± 1.3 each), texture (7.8 ± 1.2 and 7.8 ± 1.3), and taste (8.0 ± 1.2 and 8.0 ± 1.3), presumably reflecting their balanced composition. Slightly lower ratings for T_3 were still acceptable, while T_0 consistently scored the lowest across all parameters. The highest overall acceptability was observed for T_2 (8.0 ± 1.3), indicating that composite flour blends significantly enhanced both the nutritional and sensory quality of the energy balls compared to the control.

Table 4. Organoleptic evaluation of energy ball developed with composite flours

Formulation	Appearance ($\bar{X}$ ± SD)	Flavor ($\bar{X}$ ± SD)	Texture ($\bar{X}$ ± SD)	Taste ($\bar{X}$ ± SD)	Overall acceptability ($\bar{X}$ ± SD)
T_1	8.2 ± 1.2	7.6 ± 1.3	7.8 ± 1.2	8.0 ± 1.2	7.8 ± 1.2
T_2	8.0 ± 1.3	7.6 ± 1.3	7.8 ± 1.3	8.0 ± 1.3	8.0 ± 1.3
T_3	7.8 ± 1.4	7.4 ± 1.4	7.4 ± 1.4	7.4 ± 1.4	7.4 ± 1.4
T_0	7.0 ± 1.6	6.8 ± 1.6	6.8 ± 1.6	6.8 ± 1.6	6.8 ± 1.6

For the flatbread (chapati), as shown in Table 5, the highest score was observed for the T_0 formulation across all attributes, likely due to familiarity with it when made with refined wheat flour. A favorable rating was observed across all parameters for T_2 (around 7.0 ± 1.5), indicating good consumer acceptance. A moderate acceptance was observed in T_3 (scores ~6.2 ± 1.7), while T_1 had the lowest scores (around 5.8 ± 1.7), likely due to its darker appearance and strong beany flavor. A study on composite flour (wheat + chickpea + finger millet + barley at 70:10:10:10) found that composite chapatis scored ~7.0 on taste, color, puffiness, flavor, and overall acceptability, compared to wheat control (~8.5), suggesting that composite flour chapatis were moderately acceptable (Tangariya et al., 2018).

Table 5. Organoleptic evaluation of chapati developed with composite flours

Formulation	Appearance ($\bar{X}$ ± SD)	Flavor ($\bar{X}$ ± SD)	Texture ($\bar{X}$ ± SD)	Taste ($\bar{X}$ ± SD)	Overall acceptability ($\bar{X}$ ± SD)
T_1	5.6 ± 1.8	5.8 ± 1.7	5.2 ± 1.8	5.8 ± 1.7	5.8 ± 1.7
T_2	7.0 ± 1.5	7.0 ± 1.5	6.8 ± 1.5	7.0 ± 1.5	7.0 ± 1.5
T_3	6.4 ± 1.7	6.2 ± 1.7	6.0 ± 1.8	6.2 ± 1.7	6.2 ± 1.7
T_0	7.4 ± 1.4	7.4 ± 1.4	7.4 ± 1.4	7.4 ± 1.4	7.4 ± 1.4

Among the other formulations, T_2 proved to be the preferred choice because it maintained an ideal combination between various quality aspects, including attributes and general scores. The panel members rated T_2 overall with 7.2-7.4 for cookies (Table 3), 7.0 for chapati (Table 5), and 8.0 for energy ball (Table 4). The panel members positively scored these values, indicating that T_2 delivers an enjoyable sensory experience throughout cookie and savory applications. In addition, it may have had somewhat higher nutritional values. Thus, for further analysis, T_2 (40% wheat, 25% amaranth seeds, 15% green gram, 15% pearl millet (bajra), 3% amaranth leaves, 2% wheatgrass powder) was selected.

Nutritional Analysis of T_2 Composite Flour

Table 6 shows that the T_2 composite flour provides 70 g of carbohydrates and 319 Kcal/100 g. This is lower than the energy content of composite flours reported by Effiong et al. (2018), which ranged from 359 to 365 Kcal/100 g. The carbohydrate content of the developed composite flour depends heavily on wheat, pearl millet, and green gram, which are staple grains, as well as on the legumes used, since they contain starch and other complex carbohydrates.

This composite flour has a high protein content (17 g per 100 g) and would thus be an excellent plant-based protein source. Typically, wheat flour contains only 10.24% protein (Verem et al., 2021). The composite flour had high protein content due to the incorporation of green gram and amaranth seeds; these plant sources also have diverse amino acid profiles. Crude fiber composition was 5.8 g per 100 g, facilitating glycemic control and promoting digestive health. This is also higher than the crude fiber content of most composite flours, which typically range from 4.0% to 7.4% (Dada et al., 2023).

The calcium content was estimated at 191 mg/100 g, indicating a significant contribution to daily intake. In contrast, several composite flour calcium levels have been reported to range between 49 and 106 mg per 100g (Adebayo et al., 2024). The iron content in the flour was 6.55 mg per 100 g. Sprouting likely increased the availability of these minerals. Traditional mono-flours, such as refined wheat flour, contain between 2.51 and 3.35 mg of iron and 38.1 mg of calcium per 100 g serving (Fernández-Canto et al., 2023). Every 100 grams of whole wheat flour contains 2.95 to 4.15 mg of iron and 73.0 mg of calcium (Heshe et al., 2016). The high calcium and iron content in T_2 can be attributed to the incorporation of amaranth leaves and pearl millet. These results indicate that composite flour formulation can be an effective strategy to mitigate micronutrient deficiencies through ingredient diversification (Banua et al., 2021).

Table 6. Macronutrient and mineral composition of T_2* composite flour

Parameters	Composition (Per 100 g)
Carbohydrates (g)	70
Energy (Kcal)	319
Protein (g)	17
Fat (g)	3.5
Crude fiber (g)	5.8
Calcium (mg)	191
Iron (mg)	6.55

*40% wheat, 25% amaranth seeds, 15% green gram, 15% pearl millet (bajra), 3% amaranth leaves, 2% wheatgrass powder

Analysis of Moisture Content and Peroxide Value of T_2 Composite Flour

The quality and shelf-life reliability of composite flours depend heavily on their moisture content and peroxide value (Table 7). The processing, along with storage operations of multiple flour blends, undergo significant changes based on their moisture content according to Carter et al. (2015) and Nainggolan et al. (2023). Assessing moisture content and oxidative stability in composite flours is crucial for maintaining product quality and prolonging shelf life.

The moisture content of the composite flour was about 7.5%, and within the acceptable range for storage. Moisture content below 10% helps to prevent microbial growth and inhibit enzyme reactions. Chandra et al. (2015) indicated that the moisture content in their product ranges considerably from 10.93% to 13.28% and is stable for storage. The peroxide value measurement of 0.21 meq/kg demonstrated minimal oxidation of lipids in the flour. According to Verem et al. (2024), the peroxide value indicates how fresh a fat remains when values stay under 1.0 meq/kg, suggesting stable fat with minimal deterioration. The low peroxide value indicates that fat components found especially in seeds and legumes of the composite flour experience minimal oxidation, resulting in extended shelf life alongside nutritional preservation. Tangariya et al. (2018) found that increased peroxide value after about 60 days of storage resulted in the development of rancidity.

Table 7. Moisture content and peroxide value of t_2* composite flour

Parameters	Composition
Moisture content (%)	7.5
Peroxide value (meq/kg)	0.21

*40% wheat, 25% amaranth seeds, 15% green gram, 15% pearl millet (bajra), 3% amaranth leaves, 2% wheatgrass powder

Functional Analysis of T_2 Composite Flour

Composite flours made from combining wheat flour with different ingredients show multiple functional characteristics, which determine their utility in food product creation. The functional properties of these combinations include the potential for capturing water and oil, as well as foaming abilities and emulsification power, in addition to their minimum gelation threshold and particle size distribution (Mamat et al., 2020). Previous studies have shown that incorporation of non-wheat flours significantly influences functional properties such as water absorption, oil absorption, and dough behavior (Twinomuhwezi et al., 2020). Non-wheat flours create improvements along with drawbacks, which affect functional properties when added to wheat flours. An increasing level of bambara flour in wheat flour led to a reduction in dough consistency measurements and protein weakening, along with starch gelatinization and amylase activity, and retrogradation parameters (Erukainure et al., 2016).

The functional characteristics of the composite flour indicate excellent promise to enrich food applications across health-oriented compositions and baked goods. The developed composite flour demonstrated a water absorption capacity of 77% and an oil absorption capacity of 77.9% when measured. The high water and oil absorption capacities observed in the composite flour can be attributed to the presence of proteins and dietary fiber from green gram and

amaranth, which enhance hydration and lipid-binding properties. These characteristics improve dough handling, texture, and mouthfeel in food products. The increased swelling capacity suggests better starch gelatinization, which contributes to improved product volume and consistency. The composite flour's water absorption capacity (77%) and oil absorption capacity (77.9%) significantly outperform conventional wheat and rice flours, aligning with findings by Twinomuhwezi et al. (2020), who reported increased WAC (5.8-7.2%) and OAC (5.9-7.7%) in rice, soybean, and amaranth blends. The flour demonstrates good flow potential and handling qualities due to its compact density characteristics of 21 g/ml and tapped density level of 0.94 g/ml. The high bulk density measurement may contain a unit error (g/cm^3 or g/ml values remain between 0.5-1.0), yet it represents a denser product which can optimize packing space and boost storage capacity. The flour indicated 60% swelling capacity, which demonstrates its capability to absorb water before expansion. This feature contributes to better dough volume production and product consistency. Baked or steamed products benefit from this flour since its swelling capacity (60%) exceeds that of typical standard wheat flour (20-30%).

The foaming capacity of 30% proves that the flour can excel in foods requiring air incorporation, such as muffins and fritters, and cake batter applications. The protein content in sprouted green gram and amaranth helps create and stabilize foam due to their composition. The solubility index measured 6.93%, suggesting that the flour displays good water-absorption properties yet shows limited solubility (Table 8).

Table 8. Functional properties analysis of T_2* composite flour

Functional property	Proximate value
Water absorption capacity (%)	77
Oil absorption capacity (%)	78
Bulk density (g/ml)	21
Tapped density (g/ml)	0.94
Swelling property (%)	60
Foam capacity (%)	30
Foam stability (%)	66

*40% wheat, 25% amaranth seeds, 15% green gram, 15% pearl millet (bajra), 3% amaranth leaves, 2% wheatgrass powder

Conclusions

The development and evaluation of nutritionally enhanced composite flour demonstrated that blending diverse ingredients can significantly improve the nutritional profile while maintaining adequate functional properties and attaining satisfactory sensory qualities for flour-based products. The present study shows that composite flour has the potential to be developed into a functional food innovation that will improve nutritional well-being and public health. The objectives of this study were to formulate a composite flour from nutrient-rich ingredients, develop and standardize products using the flour, identify the most acceptable formulation through sensory evaluation, and analyze its nutritional and functional quality parameters. The optimized formulation proved to offer a sustainable and cost-effective approach to help mitigate micronutrient deficiencies, enhance dietary diversity, and increase phytochemical intake. The developed flour can be utilized in various food applications and has potential for large-scale production and use among different population groups. Further studies are recommended to evaluate shelf-life, bioavailability of nutrients, and consumer acceptance at a larger scale.

Author Contributions

RHP: Conceptualization, Resources, Project Administration. NS: Methodology, Investigation, Writing-Original Draft Preparation. SPS: Validation, Data Curation, Supervision. AR: Formal Analysis, Visualization, Writing-Review & Editing. All the authors read and approve the final version for publication.

Declaration of Generative AI and AI-Assisted Technologies in Scientific Writing

Nothing to disclose

Acknowledgements

The researchers would like to acknowledge the support received from the DST-SEED(SEED/WS/2023/1019) scheme to St. Teresa's College (Autonomous), Ernakulam. The authors acknowledge the management of St. Teresa's College (Autonomous), Ernakulam, for the infrastructure and technical support.

Institutional Review Board

The study was approved by the Institutional Research Ethics Committee (IREC) of St. Teresa's College (Autonomous), Ernakulam, Kerala, India (Protocol Code: STCAU/115/25).

Data Availability Statement

All data generated or analyzed during this study are included in this published article. Additional details related to the datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

Funding

This work was supported by the Department of Science and Technology, Government of India (Vigyan Dhara-SEED/WS/2023/1019).

Conflict of Interest

The authors declare that they have no conflicts of interest.

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