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Germinated faba bean (*Vicia faba* L.) flour fortification: Impacts on nutritional recovery, hematological parameters and malnutrition amelioration in children

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Abstract

Protein malnutrition among children in India is a major public health concern, and it is expected to worsen as the population grows and protein resources become scarcer. Grain legumes, particularly faba beans, provide a low-cost, plant-based protein alternative due to their high amino acid and nutritional content. This study evaluated the sensory acceptability, nutritional composition, and clinical efficacy of supplementary foods (biscuits and pinni) fortified with germinated faba bean flour. Sensory results indicated that a 30 per cent faba bean biscuit (B3) was highly favored, achieving an "extremely good" rating (8.07 ± 0.29). Nutritionally, fortification significantly increased protein (10.24 ± 0.03 to 17.51 ± 0.02%), fat (19.21 ± 0.02 to 22.67 ± 0.02%), crude fiber (1.28 ± 0.02 to 3.97 ± 0.01%), dietary fibre (2.46 ± 0.02 to 8.61 ± 0.01%), calcium (56.13 ± 0.05 to 86.38 ± 0.06 mg/100 g), zinc (2.67 ± 0.04 to 3.92 ± 0.04 mg/100 g) and lysine (3.18 ± 0.05 to 4.09 ± 0.04 g/100 g). Bioactive components increased, with antioxidant activity improving from 0.19 ± 0.03 to 0.44 ± 0.03% and vitamin C from 0.10 ± 0.03 to 0.30 ± 0.03 mg/100 g, along with enhanced protein digestibility (70%). In a clinical trial of ninety children, faba bean supplementation improved BMI-for-age Z-scores by 83.20 per cent, reduced severe malnutrition from 26.66 to 3.33 per cent, significantly increased serum total protein (7.18 ± 0.38 g/dl), and moderately improved anemia. Overall, germinated faba beans emerge as a cost-effective, nutrient-dense, and protein-rich ingredient with strong potential for inclusion in community-based nutritional rehabilitation programs.

1. Introduction

Malnutrition remains a significant global health challenge, particularly in pediatric populations, where protein-energy and micronutrient deficits hinder growth and development. Malnutrition refers to deviations from optimal nutritional status and includes both undernutrition and overnutrition. It manifests as wasting, stunting, underweight, micronutrient deficiencies, obesity and diet-related non-communicable diseases, often resulting from inadequate nutrition during early childhood feeding periods. Global Hunger Index (2025) data indicate that 12.0 per cent of India's population is undernourished due to insufficient calorie intake, with childhood stunting and wasting rates reaching 32.9 and 18.7 per cent, respectively. Furthermore, NFHS-V (2019-2021) reports a rising prevalence of anaemia, affecting 67.1 per cent of children aged 6-59 months. Such nutritional deficits during early childhood increase the risk of growth failure, cognitive impairment, and vulnerability to infection (Ijarotimi and Keshinro, 2013). In developing regions, commercial weaning foods are often economically inaccessible, necessitating the use of inexpensive, locally available plant protein sources. Supplementing cereal-based diets with legumes is a documented strategy for improving nutritional status (Mahmoud and Anany, 2014). Among these, the faba bean (*Vicia faba* L.) is a multifunctional crop containing 31-34 per cent protein, 44-47 per cent carbohydrates, and 8 per cent dietary fibre (Rahate *et al*., 2021; Khazaei *et al.,* 2019). It is particularly rich in essential amino acids such as arginine, leucine, and lysine, and provides significant levels of minerals, including iron, zinc, calcium, and phosphorus. Beyond macronutrients, faba beans contain bioactive polyphenols, specifically flavonoids and phenolic acids, which offer antioxidant, antinflammatory, and antidiabetic properties (Meng *et al.,* 2021; Valente *et al.,* 2019; Zhang *et al.,* 2019; Karatas *et al.,* 2017; Nosworthy *et al.,* 2018). However, their use is often limited by poor digestibility and sensory barriers. Germination has emerged as a sustainable processing technique for reducing antinutrients, synthesizing bioactive compounds, and improving the protein quality of legumes. This study aimed to develop germinated faba bean-based supplementary foods and assess their impact on the anthropometric and hematological profiles of malnourished children.

2. Materials and Methods

2.1 Raw material procurement and processing

Faba beans (*Vicia faba* L.) were procured from the Department of Plant Breeding and Genetics, Punjab Agricultural University (PAU), Ludhiana. The beans underwent a controlled germination process, *i.e.,* seeds were soaked in water (1:5 w/v) for 12 h at room temperature, drained, and sprouted under moist fine cloth in a dark environment for 48 to 72 h. Germinated seeds were dried at 50°C overnight in a

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drying oven and ground into a fine powder for further analysis and product development.

2.2 Chemical and bioactive analysis

Proximate composition, including moisture, crude protein, ash, crude fat, crude fibre, carbohydrate (by difference) and total dietary fibre, was determined using standard AOAC standard procedures (AOAC, 2010), with moisture by hot air oven drying, protein by the macro-Kjeldahl method (N × 6.25), ash by muffle furnace ashing, fat by soxhlet extraction and crude fibre by acid-alkali digestion; dietary fibre was analyzed by the enzymatic-gravimetric method (AOAC, 991.43). Starch content was estimated by the Clegg (1956) method using acid hydrolysis and anthrone colorimetry.

Sulphur amino acids (methionine, cystine) and tryptophan were quantified after acid hydrolysis using established colorimetric methods. Methionine was estimated using the sodium nitroprusside method (Horn *et al.,* 1946), tryptophan by the colorimetric method of Concon (1975), and cystine by the method of Liddell and Saville (1959). Ascorbic acid was estimated by the 2,6-dichlorophenyl indophenol method (AOAC, 1996). Mineral elements (iron, calcium, zinc, potassium and phosphorus) were determined by atomic absorption spectrophotometry following wet digestion (Lindsey and Norwell, 1969).

Total phenolic and flavonoid contents were estimated by the folin-ciocalteu and aluminum chloride methods (Limmatvapirat *et al.,* 2020; Pavun *et al.,* 2018), respectively, while antioxidant activity was assessed using the DPPH radical scavenging assay (Dehshahri *et al.,* 2012).

In vitro protein digestibility was evaluated by sequential pepsin-pancreatin digestion (Akeson and Stahmann, 1964) and starch digestibility by α-amylase hydrolysis (Bernfeld, 1954), whereas ionizable iron and *in vitro* iron bioavailability were determined using a simulated gastrointestinal digestion model (Rao and Prabhavati, 1978). Protein quality was assessed by calculating the protein digestibility corrected amino acid score (PDCAAS) in accordance with FAO/WHO (1991) guidelines, using preschool child reference amino acid requirements.

2.3 Development and sensory evaluation of supplementary foods

Two supplementary foods, namely biscuits and pinni (Figure 1) were developed by blending whole wheat flour with germinated faba bean flour at 20, 25 and 30 per cent levels in the food laboratory of food and nutrition department, college of community science, PAU, Ludhiana. The developed foods were evaluated organoleptically by a semi-trained panel of 10 judges using a 9-point Hedonic Rating Scale (Rangana, 2002). The recipe with highly acceptable level given below:

2.3.1 Pinni

Pinni was prepared using whole wheat flour (70 g), faba bean flour (30 g), powdered sugar (50 g) and desi ghee (50 g). Whole wheat flour and faba bean flour were roasted separately in a heavy-bottomed iron vessel over a low flame with ghee until a light golden-brown colour and characteristic aroma developed. The roasted flours were then removed from heat, powdered sugar was added and the mixture was thoroughly blended. The warm mixture was finally shaped into round pinni by hand using the palm (Negi and Mann, 2003).

2.3.2 Biscuits

Biscuits were prepared using whole wheat flour (70 g), faba bean flour (30 g), powdered sugar (50 g), butter (50 g), milk (10 ml), baking powder (0.5 g), sodium bicarbonate (0.5 g) and ammonium bicarbonate (0.5 g). Whole wheat flour and faba bean flour were blended thoroughly with powdered sugar, after which butter was rubbed into the mixture to obtain a crumbly texture. The leavening agents, namely baking powder and sodium bicarbonate were then added and mixed uniformly. Milk was gradually incorporated to form a soft and uniform dough. The dough was rolled to approximately one-fourth inch thickness, cut into desired shapes and baked in a preheated oven at 375°F for 10-15 minutes until the biscuits were crisp and lightly browned (Kulshreshta, 2008).

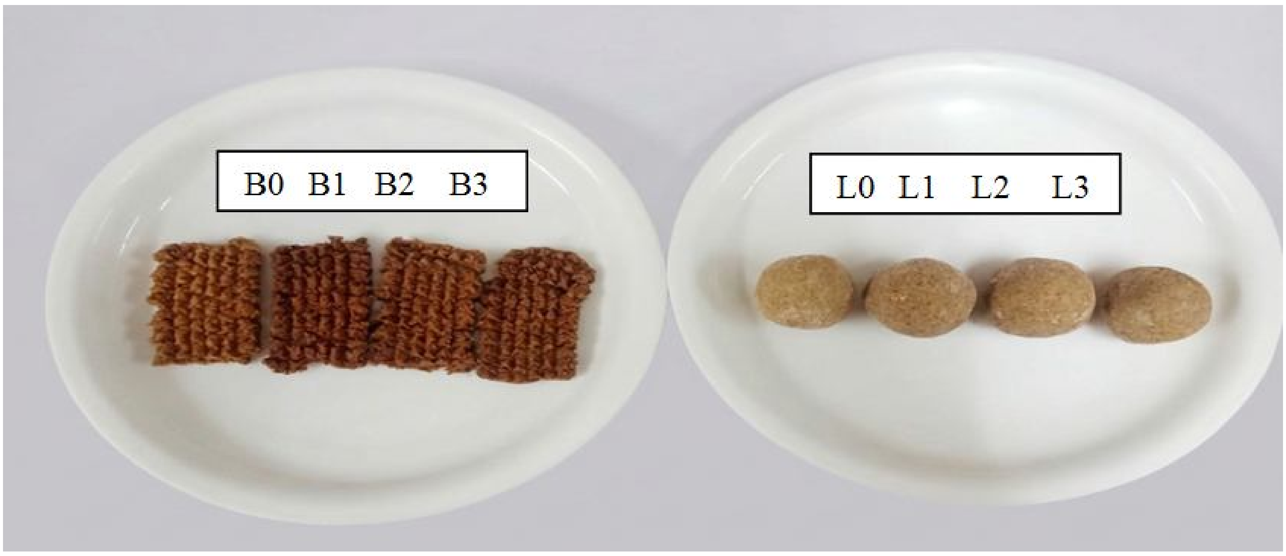

Figure 1: Developed supplementary foods (biscuits and pinni).

2.4 Impact of supplementation

2.4.1 Subject selection

Ninety children (3-5 years) were selected from an urban slum area in Ludhiana, Punjab, schematic representation presented in Figure 2. The study was approved by the institutional ethics committee, PAU, Ludhiana with Endst. No. DR.lll.AU.2023/5339-54 dated on 17.03.2023.

2.4.2 Experimental protocol

The experimental group provided 60 g of 30 per cent germinated faba bean biscuits daily for three months, providing approximately 500 kcal. Nutrition counseling of subjects and their parents was done once during intervention and impact of feeding biscuits was evaluated in terms of improvement in anthropometry and hematological profile of the subjects.

2.4.3 Anthropometric and hematological profile

Weight, height, MUAC and circumferences were measured using Jelliffe (1966) methods. The Z-scores for the different nutritional indices-weight for age (WAZ), height for age (HAZ) and body mass index score (BMI-Z) were calculated by using the "WHO anthro plus software" (v. 1.0.4) (WHO, 2009). Hemoglobin and total protein levels were analyzed before and after the 3-month intervention to assess the prevalence of malnutrition and anaemia by using SD classification (WHO, 2006 a).

2.5 Statistical analysis

The data was analyzed by using appropriate statistical tools such as mean, standard deviation, percentages and paired t-test, to evaluate the effect of intervention before and after supplementation of supplementary foods. Mean values were compared by Tukey HSD test 't' at 5 per cent level of significance (statistical software SPSS 28.0 (IBM, US).

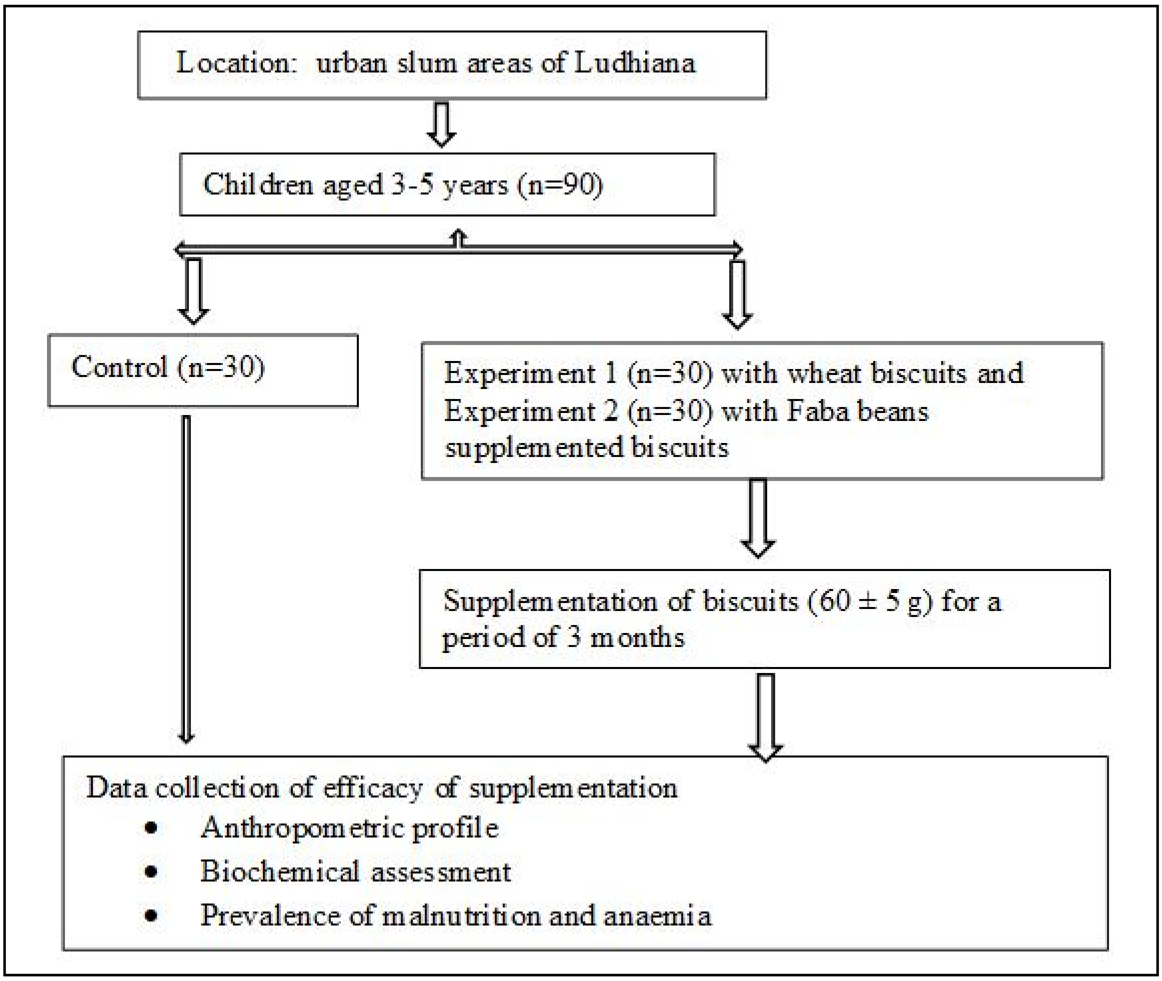

Figure 2: Schematic Presentation of methodology of supplementation.

3. Results

3.1 Organoleptic evaluation and sensory quality

The sensory evaluation of the supplementary foods, as detailed in Figures 3 and 4, demonstrates high acceptability for products fortified with germinated faba bean flour. Biscuits showed no significant differences in appearance, color, texture and flavour across experimental levels (20-30%), though taste scores varied significantly (p=0.00). Notably, the 30 per cent faba bean biscuit (B3) achieved the highest overall acceptability score (8.07 ± 0.29), categorized as "extremely good". Similarly, pinni formulations exhibited high acceptability, with significant improvements in appearance (p=0.01) as bean flour concentration increased. This indicates that germinated faba bean flour can be effectively integrated into supplementary foods without compromising sensory quality. Similarly, Anushree *et al.* (2024) reported that five noodle formulations containing 0-40% lentil flour were evaluated using the hedonic scale and the highest acceptability was observed for T3 (70% wheat + 30% lentils) and the control (100% wheat).

3.2 Nutritional and bioactive profile of supplementary foods

The nutritional profile of supplementary foods (biscuits and pinni) was significantly influenced by the incorporation of germinated faba bean flour (Table 1). The comparative analysis between control and experimental groups is detailed below:

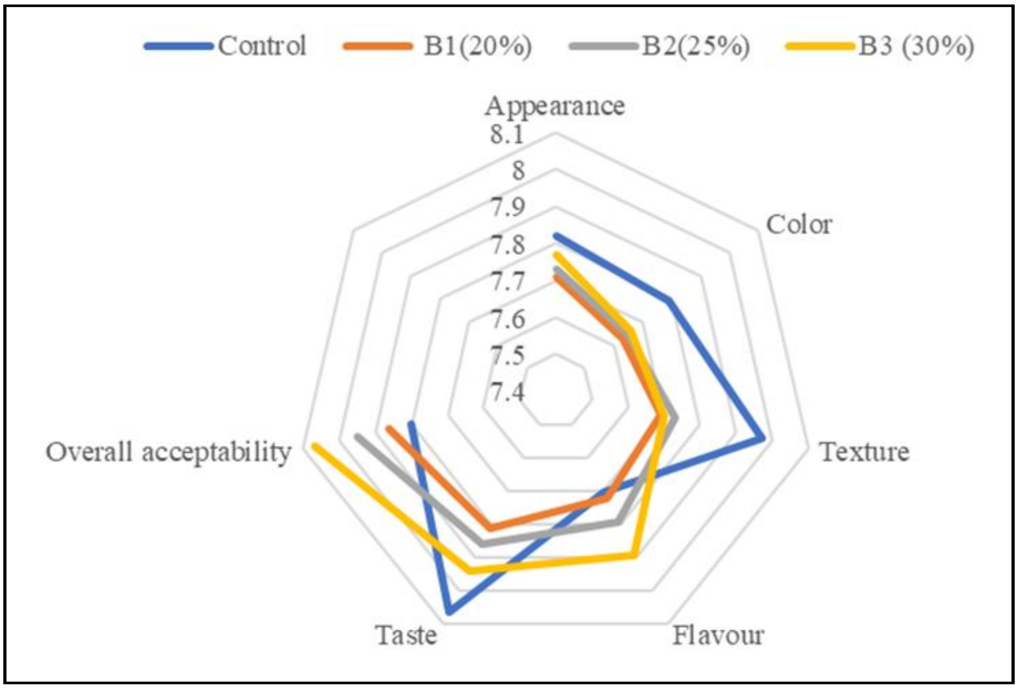

Figure 3: Organoleptic score of biscuits.

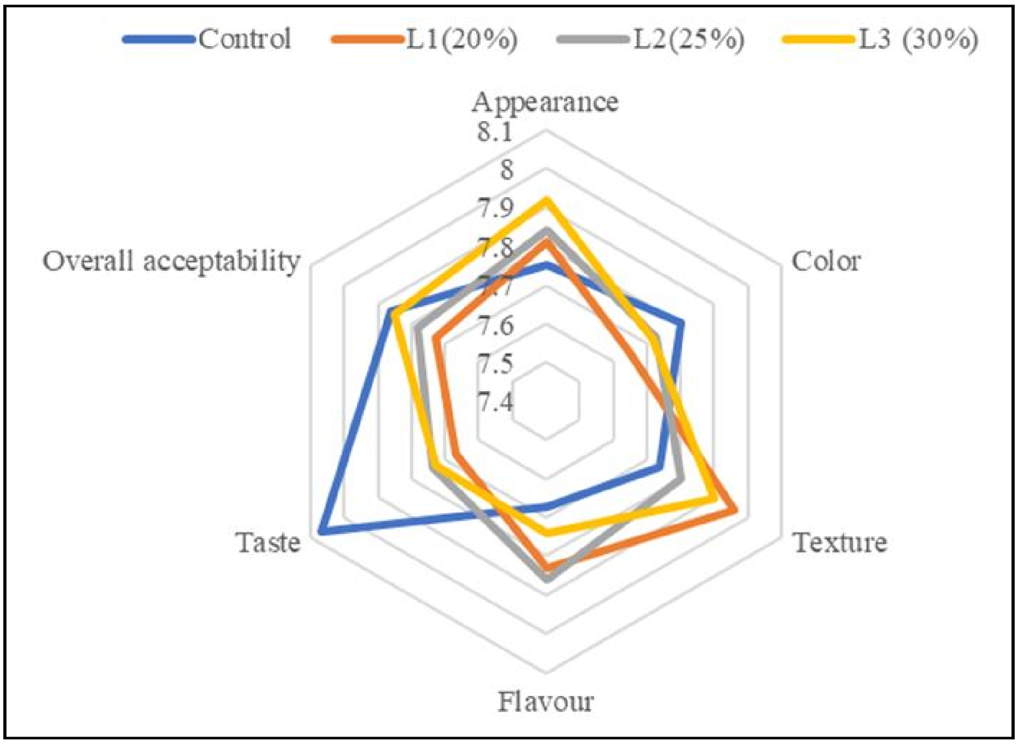

Figure 4: Organoleptic score of pinni.

3.2.1 Proximate composition

The proximate composition of biscuits and pinni developed with germinated faba bean flour showed significant improvement compared to their respective controls. In both products, experimental formulations exhibited significantly higher moisture, protein, fat, ash, crude fibre, starch and dietary fibre contents, while carbohydrate content decreased significantly. In biscuits, protein increased from 10.24 to 17.51 per cent, fat from 19.21 to 22.67 per cent, crude fibre from 1.28 to 3.97 per cent, starch from 25.60 to 28.93 per cent and dietary fibre from 2.46 to 8.61 per cent, whereas carbohydrates reduced from 64.57 to 59.27 per cent. A similar trend was observed in pinni. Overall, incorporation of germinated faba bean flour significantly enhanced the nutritional quality of both biscuits and pinni, particularly improving protein and fibre content.

3.2.2 Mineral content

The mineral composition of biscuits and pinni supplemented with germinated faba bean flour showed a consistent and significant improvement in most minerals compared to their respective controls. In biscuits, calcium (56.13 to 86.38 mg/100 g), phosphorus (208.17 to 278.01 mg/100 g), potassium (450.33 to 495.07 mg/100 g) and zinc (2.67 to 3.92 mg/100 g) increased significantly, while iron remained unchanged (4.80 to 4.82 mg/100 g). A similar trend was observed in pinni.

3.2.3 Amino acid profile

The amino acid composition of supplementary foods prepared with germinated faba bean flour showed significant improvement in lysine content in both biscuits and pinni. Lysine increased significantly (p<0.01) from 3.18 to 4.09 g/100 g in biscuits and from 3.16 to 4.02 g/100 g in pinni. In biscuits, methionine and cystine contents decreased significantly in experimental products, whereas tryptophan remained unchanged. In pinni, methionine, cystine and tryptophan contents showed no significant differences between control and experimental products.

3.2.4 Digestibility and protein quality

The digestibility, bioavailability and protein quality of biscuits and pinni developed using germinated faba bean flour showed overall improvement compared to their respective controls (Figure 5). In biscuits, *in vitro* protein digestibility (IVPD) increased from 62.31 to 70.34 per cent, while in vitro starch digestibility (IVSD) showed a marked rise from 45.76 to 61.25 per cent. In vitro iron availability (IVID) also increased significantly from 2.51 to 2.77 per cent (p<0.05), whereas PDCAAS improved slightly from 55.89 to 60.09 per cent but remained non-significant. Similarly, in pinni, all parameters showed significant improvement (p<0.01).

3.2.5 Bioactive compounds and antioxidant activity

The bioactive components and antioxidant properties of biscuits and pinni developed using germinated faba bean flour showed significant improvement compared to their respective controls (Figure 6). In both products, vitamin C content increased markedly. In biscuits, vitamin C increased from 0.10 to 0.30 mg/100 g, while in pinni the corresponding increases were from 0.09 to 0.29 mg/100 g (p<0.01). Antioxidant activity also improved significantly in biscuits (0.19 to 0.44%) and pinni (0.18 to 0.42%). Similarly, total phenols increased from 0.33 to 0.55 mg GAE/g in biscuits and from 0.10 to 0.31 mg GAE/g in pinni, while flavonoid content rose from 0.17 to 0.42 mg QE/g and from 0.15 to 0.40 mg QE/g, respectively.

Table 1: Proximate composition, minerals and amino acids content of supplementary foods developed using germinated faba beans flour

Treatment	Supplementary foods					
	Biscuits			Pinni		
	Control	Experimental	t-value (p-value)	Control	Experimental	t-value (p-value)
Proximate composition (%)						
Moisture	001.86 ± 0.05	002.96 ± 0.02	022.44 (0.03)	001.55 ± 0.04	002.32 ± 0.04	0014.39 (0.00)
Crude protein	010.24 ± 0.03	017.51 ± 0.02	108.14 (0.00)	010.12 ± 0.04	017.04 ± 0.04	0246.07 (0.00)
Crude fat	019.21 ± 0.02	022.67 ± 0.02	048.68 (0.00)	017.81 ± 0.05	020.82 ± 0.05	0038.69 (0.00)
Ash	000.75 ± 0.02	001.54 ± 0.03	011.92 (0.05)	000.71 ± 0.05	001.23 ± 0.04	0016.39 (0.00)
Crude fibre	001.28 ± 0.02	003.97 ± 0.01	023.11 (0.00)	001.21 ± 0.05	003.90 ± 0.04	0021.02 (0.00)
Carbohydrates	064.57 ± 0.05	059.27 ± 0.03	067.15 (0.00)	069.07 ± 0.05	060.17 ± 0.05	0158.76 (0.00)
Starch	025.60 ± 0.05	028.93 ± 0.05	061.24 (0.00)	024.92 ± 0.05	027.46 ± 0.04	0103.00 (0.00)
Dietary fibre	002.46 ± 0.02	008.61 ± 0.01	079.07 (0.00)	001.99 ± 0.05	007.16 ± 0.04	0208.20 (0.00)
Minerals (mg/100 g)						
Calcium (Ca)	056.13 ± 0.05	086.38 ± 0.06	945.32 (0.00)	055.62 ± 0.05	086.10 ± 0.06	0862.11 (0.00)
Iron (Fe)	004.80 ± 0.10	004.82 ± 0.10	049.00 (0.71)	004.71 ± 0.03	004.73 ± 0.04	0000.60 (0.61)
Potassium (K)	450.33 ± 5.51	495.07 ± 4.00	012.42 (0.00)	439.17 ± 4.44	476.34 ± 3.30	0011.51 (0.00)
Phosphorus (P)	208.17 ± 3.01	278.01 ± 3.00	036.02 (0.00)	196.76 ± 0.06	271.11 ± 0.06	1902.50 (0.00
Zinc (Zn)	002.67 ± 0.04	003.92 ± 0.04	058.92 (0.00)	002.31 ± 0.06	003.62 ± 0.05	0037.72(0.00)

Amino acids (g/100 g protein)						
Methionine	001.61 ± 0.03	001.17 ± 0.02	005.77 (0.03)	000.98 ± 0.03	001.01 ± 0.03	0000.64 (0.58)
Cystine	001.87 ± 0.02	001.43 ± 0.02	007.37 (0.02)	000.98 ± 0.04	000.99 ± 0.04	0000.35 (0.76)
Tryptophan	001.12 ± 0.04	001.12 ± 0.04	000.47 (0.68)	000.97 ± 0.02	000.98 ± 0.03	0000.83 (0.49)
Lysine	003.18 ± 0.05	004.09 ± 0.04	024.62 (0.00)	003.16 ± 0.04	004.02 ± 0.03	0029.79 (0.00)

Values are expressed as mean ± SD and at $p<0.05$ is significant.

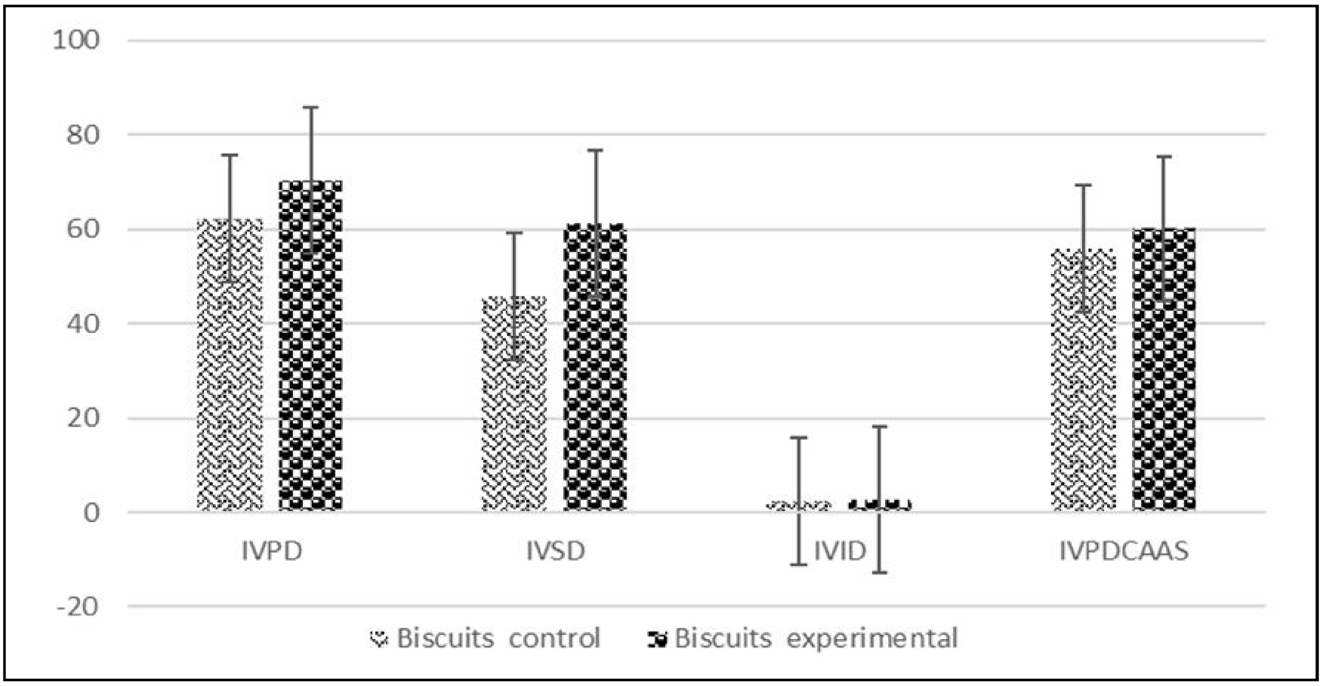

Figure 5: Digestibility and protein quality of supplementary foods.

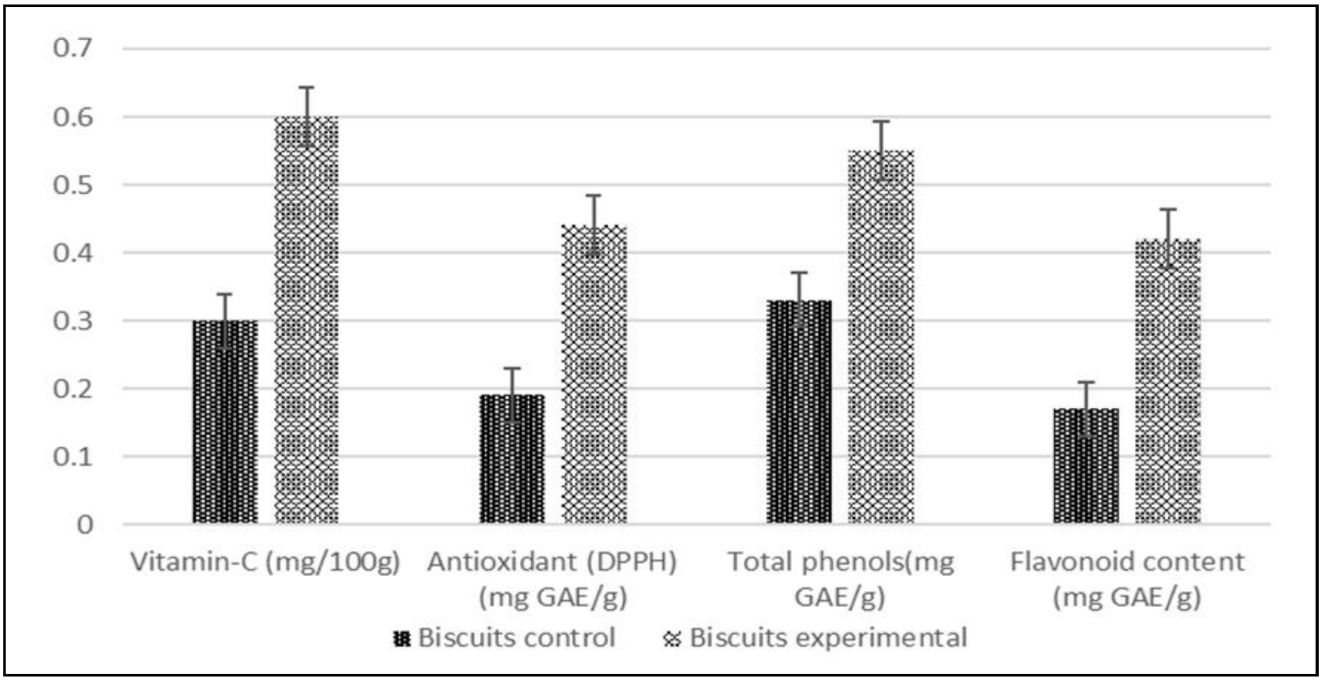

Figure 6: Bioactive compounds and antioxidant activity of supplementary foods.

3.3 Efficacy of supplementation on the anthropometric, hematological profile and mean Z-scores of selected children

The efficacy of nutritional supplementation was evaluated across three groups, a control group, an experimental group receiving wheat-based supplementation and an experimental group receiving faba bean-based supplementation (n=30 per group) (Table 2).

3.3.1 Anthropometric profile

The anthropometric profile of children in the control, experiment 1 and experiment 2 groups showed overall improvement after supplementation. In the control group, mean height increased significantly from 94.00 ± 6.39 cm to 95.20 ± 6.70 cm (p=0.03), while weight increased significantly from 12.21 ± 1.76 kg to 13.32 ± 1.75 kg (p<0.01). MUAC showed a non-significant change (16.30 ± 1.34 to 16.18 ± 1.34 cm), whereas head circumference (49.10 ± 2.08 to 49.66 ± 1.73 cm, p=0.07) and chest circumference (49.86 ± 1.65 to 49.66 ± 1.95 cm, p=0.23) remained unchanged. In experiment 1, height increased significantly from 94.47 ± 3.95 cm to 95.05 ± 3.96 cm (p<0.01), and weight showed a significant rise from 11.99 ± 1.33 kg to 13.29 ± 1.48 kg (p<0.01). Chest circumference also increased significantly from 50.37 ± 2.47 cm to 50.90 ± 2.29 cm (p=0.03), while MUAC (16.03 ± 1.00 to 16.15 ± 0.88 cm) and head circumference (49.22 ± 1.76 to 49.37 ± 1.75 cm) showed non-significant changes. In experiment 2, a significant improvement was observed only in weight, increasing from 12.95 ± 1.82 kg to 14.27 ± 1.84 kg (p<0.01), whereas height (96.85 ± 5.30 to 97.19 ± 5.75 cm), MUAC (16.48 ± 1.30 to 16.70 ± 1.12 cm), head circumference (49.50 ± 2.44 to 49.63 ± 2.41 cm) and chest circumference (50.83 ± 2.51 to 51.33 ± 2.34 cm) showed non-significant changes.

3.3.2 Hematological profile

The hematological profile of children receiving biscuit supplementation showed slight improvements across all groups, with hemoglobin levels remaining below the normal cut-off (<11.5 g/dl) at baseline and increasing marginally post-intervention in the control group (10.85 to 11.05 g/dl), wheat experimental group (10.86 to 11.16 g/dl) and faba bean experimental group (11.05 to 11.27 g/dl), although these changes were not statistically significant (p>0.05). In contrast, total protein showed a significant improvement in both experimental groups, increasing from 6.48 ± 0.60 to 7.05 ± 0.57 g/dl in the wheat group and from 6.55 ± 0.36 to 7.18 ± 0.38 g/dl in the faba bean group, while the control group remained nearly unchanged (6.52 to 6.55 g/dl). Serum albumin also showed slight, non-significant increases in all groups.

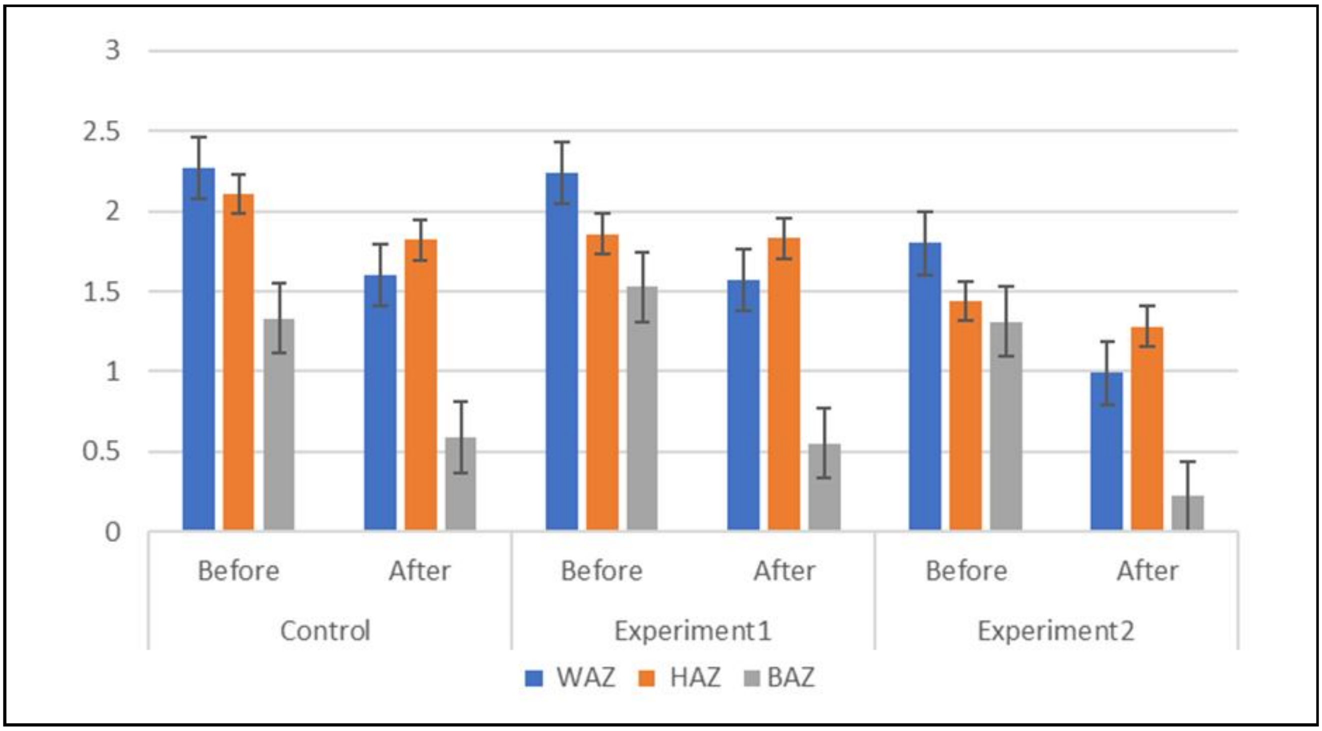

Figure 7: Efficacy of supplementation on mean Z-scores of selected children.
Experiment 1- wheat biscuits supplement, experiment 2- faba beans supplemented, WAZ- weight-for-age, HAZ, height-for -age, BAZ-BMI-for-age.

3.3.3 Mean Z-scores

The mean Z-scores of Weight-for-Age (WAZ), Height-for-Age (HAZ) and BMI-for-Age (BAZ) showed variable improvements after supplementation across control, experiment 1 and experiment 2 groups (Figure 7). For WAZ, a significant reduction was observed in all groups, with values decreasing from 2.27 ± 1.11 to 1.60 ± 1.01 in the control group (p=0.05), from 2.24 ± 0.88 to 1.57 ± 0.89 in experiment 1 (p<0.01), and from 1.80 ± 1.20 to 0.99 ± 1.10 in experiment 2 (p<0.01), indicating improvement in underweight status. In contrast, HAZ showed only marginal, non-significant changes across all groups, decreasing from 2.11 ± 1.44 to 1.82 ± 1.60 in control, 1.86 ± 1.14 to 1.83 ± 1.12 in experiment 1, and 1.44 ± 1.32 to 1.28 ± 1.48 in experiment 2 (p>0.05), suggesting limited impact on linear growth. Similarly, BAZ showed a significant improvement in all groups, decreasing from 1.33 ± 1.53 to 0.59 ± 0.68 in control (p=0.03), from 1.53 ± 0.91 to 0.55 ± 1.03 in experiment 1 (p<0.01), and from 1.31 ± 0.78 to 0.22 ± 0.99 in experiment 2 (p<0.01), indicating better improvement in BMI-for-age status, particularly in the experimental groups.

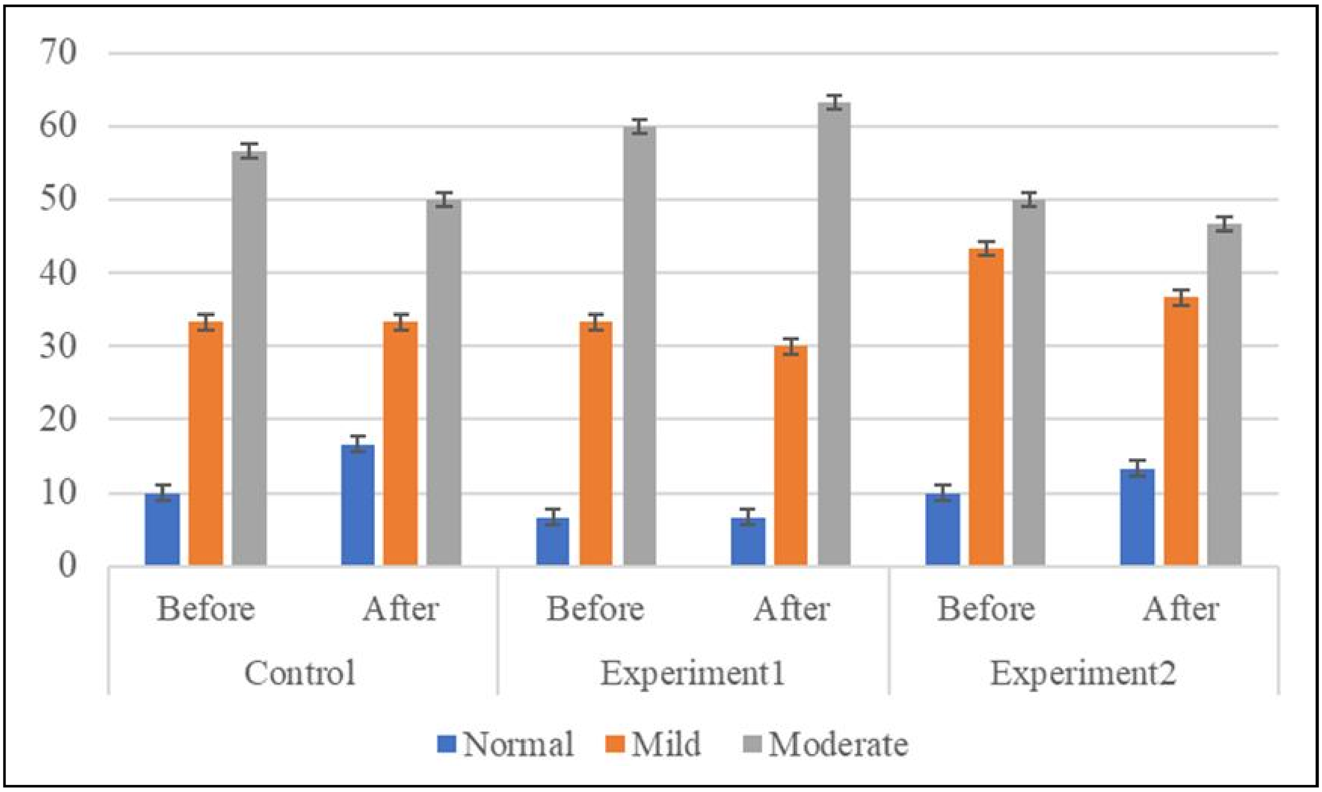

Figure 8: Efficacy of supplementation on the prevalence of anaemia.
Experiment 1- wheat biscuits supplemented, experiment 2- faba beans supplemented.

Table 2: Efficacy of supplementation on the anthropometric, hematological profile and mean Z-scores of selected children

Parameters	Control (n=30)			Experiment 1 (n=30)			Experiment 2 (n=30)		
	Before	After	Paired t (p-value)	Before	After	Paired t (p-value)	Before	After	Paired t (p-value)
Anthropometric profile									
Height (cm)	94.00 ± 6.39	95.20 ± 6.70	2.34 (0.03)	94.47 ± 3.95	95.05 ± 3.96	5.19 (0.00)	96.85 ± 5.30	97.19 ± 5.75	1.69 (0.10)
Weight (kg)	12.21 ± 1.76	13.32 ± 1.75	9.49 (0.00)	11.99 ± 1.33	13.29 ± 1.48	9.25 (0.00)	12.95 ± 1.82	14.27 ± 1.84	7.42 (0.00)
MUAC (cm)	16.30 ± 1.34	16.18 ± 1.34	0.96 (0.34)	16.03 ± 1.00	16.15 ± 0.88	0.81 (0.42)	16.48 ± 1.30	16.70 ± 1.12	1.53 (0.14)
Head circumference (cm)	49.10 ± 2.08	49.66 ± 1.73	1.90 (0.07)	49.22 ± 1.76	49.37 ± 1.75	1.09 (0.28)	49.50 ± 2.44	49.63 ± 2.41	0.90 (0.37)
Chest circumference (cm)	49.86 ± 1.65	49.66 ± 1.95	1.22 (0.23)	50.37 ± 2.47	50.90 ± 2.29	2.25 (0.03)	50.83 ± 2.51	51.33 ± 2.34	1.55 (0.13)
Hematological profile									
Hemoglobin (g/dl)	10.85 ± 0.67	11.05 ± 0.71	1.12 (0.27)	10.86 ± 0.59	11.16 ± 0.63	1.90 (0.06)	11.05 ± 0.64	11.27 ± 0.63	1.34 (0.18)
Total protein (g/dl)	06.52 ± 0.56	06.55 ± 0.51	0.22 (0.83)	06.48 ± 0.60	07.05 ± 0.57	3.77 (0.00)	06.55 ± 0.36	07.18 ± 0.38	6.59 (0.00)
Serum albumin (g/dl)	02.92 ± 0.54	03.02 ± 0.49	0.75 (0.46)	02.83 ± 0.63	03.08 ± 0.61	1.56 (0.12)	03.03 ± 0.56	03.23 ± 0.52	1.43 (0.16)
Mean Z-scores of WAZ, HAZ and BAZ*									
Weight-for-age (WAZ)	02.27 ± 1.11	01.60 ± 1.01	2.06(0.05)	02.24 ± 0.88	01.57 ± 0.89	6.97 (0.00)	01.80 ± 1.20	00.99 ± 1.10	4.20 (0.00)
Height-for-age (HAZ)	02.11 ± 1.44	01.82 ± 1.60	0.59 (0.56)	01.86 ± 1.14	01.83 ± 1.12	0.49 (0.63)	01.44 ± 1.32	01.28 ± 1.48	0.72 (0.48)
BMI-for -age (BAZ)	01.33 ± 1.53	00.59 ± 0.68	2.31 (0.03)	01.53 ± 0.91	00.55 ± 1.03	6.92 (0.00)	01.31 ± 0.78	00.22 ± 0.99	6.22 (0.00)

Values are expressed as mean ± SD, at p<0.05 is significant., Cut off value: Hemoglobin(g/dl)-11.5 (WHO 2001), Total protein (g/dl)- 6.6, albumin (g/dl)-4.35 (Murray 1998), *WHO (2006).

3.4 Efficacy of supplementation on the prevalence of malnutrition and anaemia among selected children

The distribution of nutritional status based on Z-scores (WAZ, HAZ and BAZ) indicated overall improvement in all groups after supplementation, with more pronounced effects in the experimental groups, particularly the faba bean group (Table 3). For WAZ, the proportion of children in the severe underweight category (<3 SD) reduced in all groups, with complete elimination in the wheat group and a marked reduction in the faba bean group (from 26.66% to 3.33%), along with an increase in children shifting to the 1 SD to median category. A similar improving trend was observed for HAZ, where the faba bean and wheat groups showed a shift from lower categories to higher nutritional status groups, with severe stunting cases reduced to 3.33 per cent and eliminated respectively in the wheat group. For BAZ, both experimental groups showed clear reductions in severe thinness and movement towards better nutritional categories, with no severe cases remaining in the wheat and faba bean groups after intervention.

The prevalence of anaemia among selected children showed only marginal changes after supplementation across all groups (Figure 8). In the control group, the proportion of children with normal hemoglobin (<11.5 g/dl) increased slightly from 10 to 16.66 per cent, while mild anaemia remained unchanged (33.33%), and moderate anaemia decreased from 56.66 to 50 per cent, with no severe cases reported. In the wheat-experimental group, normal hemoglobin remained constant at 6.66 per cent, mild anaemia decreased slightly from 33.33 to 30 per cent, and moderate anaemia showed a minor increase from 60 to 63.33 per cent. In the faba bean-experimental group, normal hemoglobin increased from 10 to 13.33 per cent, mild anaemia decreased from 43.33 to 36.66 per cent and moderate anaemia remained relatively stable (46.66% to 50%).

Table 3: Efficacy of supplementation on the prevalence of malnutrition and anaemia among selected children

Indices*	Control (n = 30)		Experiment 1 (n = 30)		Experiment 2 (n = 30)	
	Before	After	Before	After	Before	After
			Malnutrition			
Weight-for-age (WAZ)						
Median to +1 SD	-	-	-	-	-	-
-1 SD to Median	03 (10.00)	08 (26.66)	04 (13.33)	09.00 (30.00)	04 (13.33)	09(30.00)
-2 SD to -1 SD	24 (80.00)	02 (73.33)	21 (70.00)	21.00 (70.00)	18 (60.00)	20(66.66)
≥3 SD	03 (10.00)	-	05 (16.66)	-	08 (26.66)	01(03.33)
Height-for-age (HAZ)						
Median to +1 SD	02 (6.66)	04 (13.33)	04 (13.33)	06.00 (20.00)	05 (16.66)	06 (20.00)
-1 SD to Median	06 (20.00)	12 (40.00)	12 (40.00)	09.00 (30.00)	11 (36.66)	12 (40.00)
-2 SD to -1 SD	12 (40.00)	11 (36.66)	12 (40.00)	15.00 (50.00)	10 (33.33)	11 (36.66)
≥3 SD	10 (33.33)	03 (10.00)	02 (06.66)	-	04 (13.33)	01 (3.33)
BMI-for-age (BAZ)						
Median to +1 SD	-	02 (06.66)	01 (03.33)	04 (13.33)	03 (10.00)	04 (13.33)
-1 SD to Median	04 (13.33)	08 (26.66)	09 (30.00)	10 (33.33)	08 (26.66)	09 (30.00)
-2 SD to -1 SD	20 (66.66)	19 (63.33)	18 (60.00)	21 (70.00)	17 (56.66)	17(56.66)
≥ 3SD	06 (20.00)	01 (03.33)	02 (06.66)	-	02 (06.66)	-
			Anaemia			
Suggestedvalue (g/dl)**						
Normal ≥11.5	03 (10.00)	05 (16.66)	02 (06.66)	02 (06.66)	03(10.00)	04 (13.33)
Mild 11-11.4	10 (33.33)	10 (33.33)	10 (33.33)	09 (30.00)	13(43.33)	11 (36.66)
Moderate 8-10.9	17 (56.66)	15 (50.00)	18 (60.00)	19 (63.33)	14(46.66)	15 (50.00)

*Nahar *et al.* (2008), **WHO (2006a), Values in parenthesis represent the per cent.

4. Discussion

4.1 Proximate composition

The incorporation of germinated faba bean flour significantly altered the proximate profile of the biscuits and pinni (p<0.05) (Table 1). The experimental biscuits showed a protein increase from 10.24 to 17.51 per cent. This enhancement is consistent with the findings of Singh *et al.* (2023), who noted that legume fortification significantly boosts the amino acid content of cereal-based snacks. The significant rise in dietary fiber (from 2.46 to 8.61% in biscuits) is attributed to the structural components of the faba bean cotyledon. According to Vara and Gupta (2024), germination further modifies these fiber fractions, potentially improving their prebiotic properties. The increase in dietary fiber content during germination may be attributed to the structural disruption of polysaccharides in the grain's cell wall. While crude fat increased slightly, total carbohydrates decreased in the experimental samples. This inverse relationship is common when replacing cereal-based flours with high-protein legume flours.

4.2 Mineral content

Mineral content showed a positive trend, particularly for calcium and zinc. Calcium and phosphorus, both minerals saw significant elevations. Calcium levels in biscuits increased from 56.13 mg/100 g to 86.38 mg/100 g. Zinc levels improved significantly (p=0.00) in both products. This increase is likely due to the reduction of phytates during the germination process, which acts as a natural de-branning mechanism to release bound minerals (FAO/WHO, 2022). However, iron (Fe) levels showed a non-significant change (p=0.71 for biscuits). This suggests that while faba beans are nutrient-dense, the specific variety or the germination duration used may not have been sufficient to significantly alter the iron baseline compared to the control (Table 1).

4.3 Amino acid profile

The amino acid composition reflected the characteristic profile of legumes. There was a significant increase in lysine (from 3.18 to 4.09 g/100 g protein in biscuits). Since cereal flours are typically deficient in lysine, the germinated faba bean acts as an excellent complementary protein source. Conversely, the reduction in methionine (from 1.61 to 1.17 g/100 g protein) reflects the inherent amino acid profile of pulses. As discussed by Singh *et al.* (2023), legumes are typically limiting in sulfur-containing amino acids; therefore, the decrease in the experimental group is a rational result of substituting cereal protein with legume protein (Table 1).

4.4 Digestibility and protein quality

The biochemical analysis of the developed supplementary foods revealed that the experimental formulations significantly enhanced nutrient bioavailability compared to the control groups (Figure 5). Specifically, the *in vitro* protein digestibility (IVPD) for the experimental pinni increased to 70.57 ± 0.06 per cent (p=0.00) and the biscuits improved to 70.34 ± 4.87 per cent. This enhancement is largely attributed to the germination of faba beans, a process known to reduce protease inhibitors and break down complex storage proteins into more digestible peptides. The protein digestibility corrected amino acid score (IVPDCAAS) also showed a significant rise in the pinni formulation to 59.12 ± 0.03 per cent (p=0.00). According to Sarwar (1997), improving the digestibility of plant-based proteins is crucial in pediatric diets to ensure that the limiting amino acids are sufficiently absorbed to support muscle synthesis and metabolic recovery. However, the simultaneous increase in *in vitro* starch digestibility (IVSD) to over 60 per cent in both products showed that the energy from carbohydrates remains highly accessible. As studied by Jenkins *et al.* (2001), the structural changes in starch during germination specifically the activation of amylases facilitate a higher glycemic response which is beneficial for rapid energy replenishment in children suffering from wasting.

4.5 Bioactive compounds and antioxidant activity

The incorporation of germinated faba bean flour led to a significant increase in health-promoting bioactive compounds (Figure 6). Vitamin C levels tripled in both the biscuits (0.30 ± 0.03 mg/100 g) and pinni (0.29 ± 0.02 mg/100 g) compared to their respective controls (p=0.00). This increase is consistent with the findings of Oghbaei and Prakash (2016), who noted that germination triggers the de novo synthesis of ascorbic acid in legumes. Furthermore, total phenols and flavonoids saw significant elevations in both experimental products (p<0.05). These phytochemicals contributed to a marked increase in antioxidant DPPH activity, which reached 0.44 ± 0.03 per cent in biscuits and 0.42 ± 0.03 per cent in pinni. Such increases in antioxidant capacity are vital for undernourished children, as they help mitigate the oxidative stress associated with malnutrition and chronic infection (Sies, 2015).

4.6 Anthropometric profile

The anthropometric data revealed significant improvements in weight for all groups (Table 2). The wheat-supplemented group showed a significant increase in weight from 11.9 ±1.33 kg to 13.29 ± 1.48 kg (p<0.01), while the faba bean group increased from 12.95 ±1.82 kg to 14.27 ±1.84 kg (p<0.01). The significant increase in body weight across both experimental groups suggests that the caloric and protein content of the supplements was sufficient to support growth. Height improvements were statistically significant in the wheat group (p=0.00) but did not reach significance in the faba bean group (p=0.10). Other parameters, such as mid-upper arm circumference (MUAC) and head circumference, showed marginal changes across all groups without reaching statistical significance (p>0.05). The control group also showed improvement in anthropometric parameters, possibly due to normal growth, improved feeding practices, regular health monitoring and better overall care during the study period. However, the supplemented groups demonstrated comparatively greater improvement, indicating the additional beneficial effect of faba bean supplementation on nutritional status.

4.7 Hematological profile

Baseline hemoglobin levels in all groups were below the WHO (2001) cut-off of 11.5 g/dl. Post-intervention, the wheat group showed a near-significant trend in hemoglobin improvement (p=0.06). Notably, total protein levels increased significantly in both experimental groups: the wheat group rose from 6.48 ± 0.60 g/dl to 7.05 ± 0.57g/dl (p<0.01) and the faba bean group increased from 6.55 ± 0.36g/dl to 7.18 ± 0.38 g/dl (p<0.01), effectively surpassing the reference cut-off of 6.6 g/dl (Murray, 1998). Serum albumin levels remained below the reference value of 4.35 g/dl in all groups, despite minor increases. The significant rise in total protein post-supplementation suggests that the quality of protein provided, particularly in the faba bean group, was effectively utilized for systemic protein synthesis. However, the lack of significant improvement in hemoglobin levels (p>0.05*)* suggests that while protein-energy malnutrition was being addressed, micronutrient deficiencies, such as iron deficiency, may require more targeted fortification or longer-term intervention as per WHO (2001) guidelines (Table 2).

4.8 Mean Z-scores

The nutritional status as measured by Z-scores showed substantial shifts (Figure 7). Both experimental groups demonstrated highly significant reductions in weight-for-age (WAZ) and BMI-for-age (BAZ) Z-scores (p<0.01). Specifically, the BAZ in the wheat group improved from 1.53 ± 0.91 to 0.55 ± 1.03, and in the faba bean group from 1.31 ± 0.78 to 0.22 ± 0.99, indicating a move toward the WHO (2006) standard mean. Height-for-age (HAZ) scores did not show significant changes during the study period. The marked reduction in

BAZ and WAZ scores toward the median indicates a reduction in the prevalence of malnutrition within the children (WHO, 2006). The stability of the HAZ scores across all groups, including the control, reinforces the understanding that stunting is a chronic condition that is less responsive to short-term dietary changes compared to wasting or underweight status.

4.9 Prevalence of malnutrition and anaemia

The nutritional intervention demonstrated a significant shift in the prevalence of malnutrition among the participants (Table 3).

Analysis of Weight-for-age (WAZ) indices revealed a significant reduction in severe malnutrition (e"3 SD). Specifically, the faba bean group showed the most substantial recovery, with the percentage of children in the >3 SD category decreasing from 26.66 to 3.33 per cent post-intervention, while the wheat group eliminated all cases in this severe category. This transition from severe to moderate or mild malnutrition categories suggests that the energy-dense nature of the supplements provided sufficient substrate for rapid weight-for-age improvement, aligning with the standards for recovery defined by Nahar *et al.* (2008).

Linear growth, assessed *via* Height-for-age (HAZ), showed a positive trend in the "Median to + 1 SD" category, which increased from 13.33 to 20 per cent in the wheat group and 16.66 to 20 per cent in the faba bean group. Despite this shift, a high prevalence of children remained in the stunted or at-risk categories (-2 SD to -1 SD). This observation supports the "stunting lag" theory, which suggests that linear growth requires a more prolonged period of nutritional stability compared to weight-based indices (WHO, 2006a; Black *et al.,* 2013).

The body mass index-for-age (BAZ) data further confirmed the intervention's success in improving body composition. The wheat group successfully shifted all children out of the >3 SD category (from 6.66 to 0%), while the faba bean group showed an increase in children achieving the "Median to +1 SD" range. These shifts toward the median reflect a normalization of body mass relative to height, a critical indicator of reduced wasting as categorized by Nahar *et al.* (2008).

Conversely, the prevalence of anemia remained a persistent challenge (Figure 8). Adhering to the WHO (2006 a) threshold of >11.5 g/dl for normal hemoglobin levels, only a marginal improvement was noted. In the faba bean group, the percentage of "normal" children rose slightly from 10 to 13.33 per cent, while the wheat group remained stagnant at 6.66 per cent. The majority of children remained in the "moderate" anemia category (8.0-10.9 g/dl). The inability to significantly shift children from moderate to normal status suggests that while the protein and caloric needs were met, the bioavailable iron content of the faba bean and wheat supplements was insufficient to overcome systemic iron deficiency, a common finding in plant-based interventions (Gibson *et al.,* 2010).

5. Conclusion

The present study concludes that germinated faba bean–based supplementary foods serve as a high-impact, culturally congruent intervention for rehabilitating malnourished children. By utilizing germination as a strategic bioprocessing tool, the nutritional profile of the formulations was significantly enhanced, achieving a superior protein concentration of 17.51% and a vital lysine content of 4.09 g/ 100 g. The intervention successfully optimized micronutrient density, specifically increasing calcium and zinc levels, while simultaneously improving protein digestibility to 70%. Clinical outcomes provided definitive evidence of bio-efficacy, with subjects exhibiting a marked increase in serum protein and a decisive decline in the prevalence of stunting, wasting, and severe underweight status. Furthermore, the modest improvements in hemoglobin levels and the reversal of mild anemia underscore the systemic benefits of this legume-based fortification. Given the high acceptability scores and cost-effectiveness of the formulations, this research concludes that faba beans are a viable cornerstone for large-scale community feeding programs. Ultimately, these findings offer a scalable and sustainable framework for utilizing underutilized legumes to combat protein-energy malnutrition and hidden hunger in vulnerable pediatric populations.

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Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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