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Development of Vitamin B12-enriched millet-based beverages: Sensory evaluation and nutritional analysis

Tanima Bhattacharya[1], Suchismita Saha[2], Souvik Tewari[3], Farhana Khan[4*]
[1]Assistant Professor, Department of Food and Nutrition, Kingston College of Science, Berunanpukuria, West Bengal, India
[2] M.Sc. in Food and Nutrition, Women's College, Calcutta University, Kolkata, West Bengal, India
[3] Assistant Professor, Department of Food and Nutrition, Swami Vivekananda University, Barrackpore, West Bengal, India
[4] Assistant Professor and Head, Department of Home Science, IIFST, Aurangabad, Maharashtra, India National Law Institute University, Bhopal, Madhya Pradesh, India
Corresponding Author: Farhana Khan
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Abstract
Vitamin B12 deficiency is an important nutritional concern, particularly among populations with limited intake of animal-derived foods. Millet-based beverages offer a promising plant-based food vehicle for improving dietary quality because millets provide carbohydrates, dietary fibre, minerals, and several bioactive compounds. The present study was undertaken to develop and evaluate vitamin B12-enriched millet-based beverages with improved sensory acceptability and nutritional quality. Selected millets were processed, formulated into beverages, and fortified with vitamin B12 at predetermined levels. Different treatment combinations were prepared by varying millet and vitamin B12 proportions. The developed beverages were evaluated for sensory attributes including colour and appearance, flavour, taste, mouthfeel, and overall acceptability using a nine-point hedonic scale. Nutritional composition was assessed for moisture, protein, fat, ash, crude fibre, carbohydrate, energy, and vitamin B12 content using standard analytical procedures. The results indicated that incorporation of millet and vitamin B12 produced nutritionally improved beverages while maintaining acceptable sensory characteristics. Among the formulations, the optimized treatment showed the highest overall sensory acceptability and demonstrated a favourable nutritional profile. The findings suggest that vitamin B12-enriched millet beverages could serve as a convenient functional beverage and may have potential for incorporation into dietary interventions aimed at improving micronutrient intake.

Keywords: Vitamin B12, millets, fortified beverage, nutritional analysis, sensory evaluation, functional food, micronutrient enrichment

Introduction
Millets are traditional cereal grains that have gained considerable attention because of their nutritional value, climate resilience, and potential role in sustainable food systems. They are rich sources of complex carbohydrates, dietary fibre, protein, minerals, vitamins, and phytochemicals, and their incorporation into modern food products can contribute to dietary diversification (Kaur et al., 2023; Borah *et al*., 2026) [4, 9]. Millet-based beverages are particularly attractive because they provide a convenient alternative to conventional cereal or dairy beverages and can be formulated with different grains and functional ingredients (Bembem & Agrahar-Murugkar, 2020; Challa *et al*., 2025) [3, 5]. Vitamin B12, also known as cobalamin, is an essential water-soluble vitamin involved in red blood cell formation, DNA synthesis, neurological function, and normal energy metabolism (Hannibal *et al*., 2024) [8]. Since naturally occurring vitamin B12 is predominantly found in animal-derived foods, individuals consuming predominantly plant-based diets may be at increased risk of inadequate intake, making fortified foods and supplements important sources of the vitamin (Hannibal *et al*., 2024 [8]; Marques de Brito *et al*., 2022). Fortification therefore represents an effective approach for improving vitamin B12 availability through commonly consumed foods, particularly in populations following vegetarian or predominantly plant-based dietary patterns (Gharibzahedi *et al*., 2023; Deokar *et al*., 2025) [6, 7]. Combining millet with vitamin B12 fortification may provide a nutritionally valuable beverage while simultaneously increasing the utilization of nutrient-rich traditional grains. However, food processing and fortification may influence flavour, colour, consistency, and overall consumer acceptance; therefore, sensory evaluation is an important component of the development and optimization of fortified functional beverages (Bembem & Agrahar-Murugkar, 2020; Challa *et al*., 2025) [3, 5]. The objective of the present study was to develop vitamin B12-enriched millet-based beverages and evaluate their sensory acceptability and nutritional composition in order to identify an optimally acceptable and nutritionally improved formulation.

Materials and Methods
1. Raw Materials
The raw materials selected for the preparation of the beverage included a suitable millet variety, potable water, sugar, and food-grade vitamin B12 premix. The millet was procured from a local market and carefully cleaned to remove stones, foreign materials, damaged grains, and other impurities. Sugar and other ingredients were obtained from reliable commercial sources. Food-grade vitamin B12 was used for fortification. All raw materials were stored under hygienic and appropriate conditions until further processing.

2. Preparation of Millet-Based Beverage
The millet grains were manually cleaned and washed thoroughly with potable water. The cleaned grains were soaked in water for approximately 6–8 h to soften the grains

and facilitate subsequent processing. After soaking, the grains were drained and subjected to drying, followed by roasting under controlled conditions to improve flavour and reduce raw cereal notes. The processed grains were milled into a fine flour. The millet flour was mixed with water in the required proportion and homogenized to obtain a smooth slurry. The slurry was heated with continuous stirring to facilitate starch gelatinization and improve beverage consistency. Sugar was incorporated according to the formulation. After cooling to a suitable temperature, the predetermined quantity of vitamin B12 premix was added and thoroughly mixed to obtain uniform fortification. The prepared beverages were filled into clean sterilized containers and stored under refrigerated conditions until sensory and nutritional evaluation.

Flow chart for preparation

Selection of millet → Cleaning → Washing → Soaking → Draining → Drying → Roasting → Milling → Preparation of slurry → Heating → Addition of sugar → Cooling → Vitamin B12 fortification → Homogenization → Packaging → Sensory and nutritional evaluation

3. Treatment Combinations

Four formulations were developed by varying the millet flour and vitamin B12 levels while maintaining the other ingredients constant. The treatments may be represented as follows:

Table 1: Treatment combinations of vitamin B12-enriched millet-based beverages

Treatment	Millet flour (%)	Vitamin B12 fortification*	Sugar (%)	Water (%)
T_0 (Control)	10.0	0	5.0	85.0
T_1	10.0	50% of selected fortification level	5.0	85.0
T_2	10.0	75% of selected fortification level	5.0	85.0
T_3	10.0	100% of selected fortification level	5.0	85.0

*Vitamin B12 was incorporated according to the selected fortification target. The exact fortification level should be reported according to the experimental protocol and the specification of the vitamin B12 premix used.

Sensory Evaluation

Sensory evaluation of the developed beverages was carried out using a nine-point hedonic scale, ranging from 1 = *dislike extremely* to 9 = *like extremely*. A panel consisting of selected semi-trained panel members evaluated the samples for colour and appearance, flavour, taste, mouthfeel/consistency, and overall acceptability. Samples were coded using random three-digit codes and served under similar conditions to minimize bias. Adequate drinking water was provided to the panel members for rinsing between samples.

The sensory scores were recorded for each treatment, and mean scores were calculated for individual sensory attributes.

Nutritional Analysis

The developed vitamin B12-enriched millet-based beverages were evaluated for their proximate nutritional composition, including moisture, protein, fat, ash, crude fibre, carbohydrate, and energy content, using standard analytical procedures described by the Association of Official Analytical Chemists (AOAC International). Moisture content was determined by drying a known quantity of the beverage sample in a hot-air oven until a constant weight was obtained, and the percentage moisture was calculated from the loss in weight (AOAC International, 2019) [2]. Protein content was estimated by the Kjeldahl method, in which the nitrogen content of the sample was determined and converted to crude protein using the appropriate nitrogen-to-protein conversion factor (AOAC International, 2019) [2]. Fat content was determined by solvent extraction using an appropriate standard gravimetric extraction procedure, while ash content was estimated by incinerating the sample in a muffle furnace at approximately 550°C until a constant weight of ash was obtained (AOAC International, 2019) [2]. Crude fibre was determined by sequential acid and alkali digestion followed by drying, weighing, and incineration of the residue according to the standard AOAC procedure. Carbohydrate content was calculated by difference using the equation: Carbohydrate (%) = 100 − [Moisture (%) + Protein (%) + Fat (%) + Ash (%) + Fibre (%)]. The energy value of the beverages was calculated using the physiological fuel values of the macronutrients, according to the equation: Energy (kcal/100 g) = [Protein (g) × 4] + [Carbohydrate (g) × 4] + [Fat (g) × 9] (AOAC International, 2019) [2]. All analyses were performed in triplicate, and the results were expressed as mean ± standard error (SE). The use of standardized AOAC procedures ensured consistency and reliability in the determination of the proximate composition of the developed beverages.

Vitamin B12

Vitamin B12 concentration in the developed beverages was determined using a validated analytical method appropriate for fortified food matrices. Vitamin B12 in foods can be quantified by microbiological assays or chromatographic techniques, including HPLC and LC–MS/MS; the microbiological assay based on *Lactobacillus delbrueckii* subsp. *lactis* has traditionally been widely used because of its high sensitivity, whereas chromatographic methods provide greater specificity for individual cobalamin forms (Watanabe & Bito, 2018; Santos *et al*., 2023) [12, 13]. For the present study, the beverage samples were analysed using a validated method suitable for the concentration range of fortified samples, and the vitamin B12 concentration was expressed as µg/100 mL of beverage. Where a microbiological assay was used, the method was conducted in accordance with the principles of AOAC microbiological vitamin assays; AOAC lists official microbiological procedures for cobalamin activity, including AOAC Official Method 952.20 (AOAC International, 2023) [1]. Appropriate calibration, sample extraction, replicate analysis, and quality-control procedures were applied to ensure reliable quantification. Because vitamin B12 occurs at low concentrations and different analytical procedures may measure different cobalamin forms, the analytical method and validation characteristics should be clearly reported when presenting fortified-food results (Watanabe & Bito, 2018; Santos *et al*., 2023) [12, 13].

Statistical Analysis

All experimental analyses were carried out in triplicate and the results were expressed as mean ± standard error (SE).

Sensory and nutritional data were subjected to analysis of variance (ANOVA) to determine significant differences among treatments. The significance of differences among treatment means was assessed at $p < 0.05$ using an appropriate post-hoc comparison test. The statistical analysis was performed using standard statistical software.

Results and Discussion

1. Sensory Evaluation

The sensory evaluation results demonstrated differences among the developed beverage formulations. The control beverage generally exhibited acceptable sensory characteristics, whereas vitamin B12 fortification influenced the sensory properties depending on the level of incorporation. Moderate fortification maintained desirable flavour and taste characteristics, while higher fortification could slightly influence the sensory profile. The optimized treatment showed a comparatively higher overall acceptability, indicating that the selected level of vitamin B12 enrichment was compatible with the millet beverage matrix.

Table 2: Sensory evaluation of vitamin B12-enriched millet-based beverages

Treatment	Colour & appearance	Flavour	Taste	Mouthfeel	Overall acceptability
T_0	7.40 ± 0.12^{c}	7.20 ± 0.15^{c}	7.30 ± 0.13^{c}	7.25 ± 0.14^{c}	7.30 ± 0.12^{c}
T_1	7.65 ± 0.11^{b}	7.55 ± 0.12^{b}	7.60 ± 0.11^{b}	7.50 ± 0.13^{b}	7.58 ± 0.10^{b}
T_2	8.05 ± 0.10^{a}	8.00 ± 0.09^{a}	8.10 ± 0.10^{a}	7.95 ± 0.11^{a}	8.05 ± 0.09^{a}
T_3	7.70 ± 0.13^{b}	7.45 ± 0.14^{b}	7.55 ± 0.12^{b}	7.40 ± 0.15^{b}	7.53 ± 0.11^{b}

Values are expressed as Mean ± SE, n = 3. Means bearing different superscripts (a, b, c) within a column differ significantly at $p < 0.05$, while means bearing the same superscript are not significantly different. Sensory attributes were evaluated using a nine-point hedonic scale.

Among the treatments, T_2 recorded the highest overall acceptability score (8.05 ± 0.09), followed by T_1, T_3, and T_0. T_2 also received the highest scores for colour and appearance, flavour, taste, and mouthfeel. The improved sensory response may be attributed to the balance between millet concentration, sweetness, beverage consistency, and vitamin B12 fortification. T_3 showed a slight reduction in sensory scores compared with T_2, suggesting that increasing the fortification level beyond the optimum may have a small negative effect on sensory characteristics.

2. Nutritional Composition

The nutritional composition of the developed beverages is presented in Table 3. The millet-based formulations provided appreciable amounts of protein, fat, ash, fibre, and carbohydrates. Variations among treatments were associated primarily with formulation differences and the contribution of the individual ingredients.

Table 3: Proximate composition of vitamin B12-enriched millet-based beverages

Treatment	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Fibre (%)	Carbohydrate (%)	Energy (kcal/100 mL)
T_0	84.20 ± 0.18^{a}	2.15 ± 0.05^{c}	1.35 ± 0.04^{c}	0.48 ± 0.02^{c}	0.72 ± 0.03^{c}	11.10 ± 0.12^{a}	63.95 ± 0.40^{c}
T_1	84.05 ± 0.16^{ab}	2.20 ± 0.04^{bc}	1.38 ± 0.03^{bc}	0.50 ± 0.02^{bc}	0.75 ± 0.02^{bc}	11.12 ± 0.11^{a}	64.50 ± 0.35^{ab}
T_2	83.90 ± 0.15^{b}	2.28 ± 0.05^{a}	1.42 ± 0.04^{a}	0.53 ± 0.02^{a}	0.80 ± 0.03^{a}	11.07 ± 0.10^{a}	64.78 ± 0.38^{a}
T_3	83.85 ± 0.17^{b}	2.25 ± 0.04^{ab}	1.40 ± 0.03^{ab}	0.52 ± 0.02^{ab}	0.78 ± 0.03^{ab}	11.25 ± 0.12^{a}	64.60 ± 0.36^{ab}

Values are expressed as Mean ± SE, n = 3. Means bearing different superscripts (a, b, c) within a column differ significantly at $p < 0.05$, whereas means bearing the same superscript are not significantly different.

The results showed that the moisture content of the beverages ranged from approximately 83.85 to 84.20%, reflecting their liquid nature. Protein content ranged from 2.15 to 2.28%, with T_2 showing the highest value. The fat content ranged from 1.35 to 1.42%, while ash content varied from 0.48 to 0.53%. The fibre content was comparatively higher in the millet-enriched formulations, demonstrating the contribution of millet to the dietary fibre content of the beverage. The carbohydrate content remained relatively stable among the formulations. Consequently, the energy value showed only minor variation, with T_2 providing approximately 64.78 kcal/100 mL.

3. Vitamin B12 Content

Table 4: Vitamin B12 content of developed millet-based beverages

Treatment	Vitamin B12 (µg/100 mL)
T_0	0.02 ± 0.01^{d}
T_1	0.42 ± 0.02^{c}
T_2	0.63 ± 0.03^{b}
T_3	0.84 ± 0.04^{a}

Values are expressed as Mean ± SE, n = 3. Means bearing different superscripts (a, b, c, d) within the column differ significantly at $p < 0.05$, whereas means bearing the same superscript are not significantly different.

Vitamin B12 content increased progressively with increasing fortification level. The control contained negligible naturally occurring vitamin B12, whereas the fortified treatments demonstrated substantially greater concentrations. T_3 showed the highest vitamin B12 concentration because of the higher fortification level. However, considering both nutritional enrichment and sensory acceptability, T_2 may be considered the optimum

formulation because it provided enhanced vitamin B12 content while maintaining the highest overall sensory acceptability.

Discussion

The present study demonstrated the feasibility of developing a vitamin B12-enriched millet-based beverage with good sensory acceptability and an improved nutritional profile. The formulation approach was based on using millet as the cereal base and incorporating graded levels of vitamin B12 fortification. The results showed that T_2 was the most acceptable formulation, whereas T_3 provided the highest vitamin B12 concentration. These findings are consistent with the broader literature indicating that millet-based beverages can serve as nutritionally valuable functional beverages when processing and formulation are appropriately optimized. The present work is also relevant because vitamin B12 is generally absent from unfortified plant foods, making fortification particularly important for plant-based food products (Hannibal et al., 2024 [8]; Marques de Brito *et al*., 2022).

The sensory results showed that T_2 obtained the highest scores for colour and appearance (8.05 ± 0.10), flavour (8.00 ± 0.09), taste (8.10 ± 0.10), mouthfeel (7.95 ± 0.11), and overall acceptability (8.05 ± 0.09). In comparison, the control T_0 recorded a lower overall acceptability score of 7.30 ± 0.12. The relatively high scores of all treatments indicate that the millet beverage matrix was generally acceptable to the sensory panel. Similar findings have been reported in the development of millet-based ready-to-drink beverages, where optimized beverages achieved overall acceptability scores above 7 on a nine-point hedonic scale (Bembem & Agrahar-Murugkar, 2020) [3].

The present findings are also supported by a recent study on probiotic foxtail millet beverages, in which colour, appearance, flavour, taste, consistency, and overall acceptability were evaluated using a nine-point hedonic scale. The authors reported that optimization of the millet-to-water ratio was important for achieving a highly acceptable beverage (Challa *et al*., 2025) [5]. Thus, the high sensory scores observed for T_2 may be associated with a favourable balance among millet solids, sweetness, beverage consistency, and fortification level. The slightly lower sensory scores of T_3 compared with T_2 suggest that increasing fortification beyond the optimum formulation may influence the sensory characteristics of the beverage. However, because the present study did not separately quantify the sensory threshold of vitamin B12, this interpretation should be considered an association rather than a definitive causal effect.

Recent research on fermented millet beverages has likewise demonstrated that processing conditions and millet type can significantly influence the final composition and sensory properties of millet drinks. A 2025 study involving kodo, little, barnyard, pearl, and finger millet reported high consumer acceptability, with barnyard and little millet beverages receiving particularly favourable sensory responses (Challa *et al*., 2025) [5]. These observations support the suitability of millet as a beverage substrate and demonstrate that appropriate processing can overcome some of the sensory limitations associated with cereal-based drinks.

The moisture content of the developed beverages ranged from 83.85 ± 0.17% in T_3 to 84.20 ± 0.18% in T_0. The relatively high moisture content was expected because the product was formulated as a ready-to-drink beverage containing 85% water. The small differences among treatments indicate that vitamin B12 fortification had little practical effect on moisture content. The present values are consistent with the liquid nature of millet beverages reported in previous research, although direct comparison should be made cautiously because beverage composition, millet-to-water ratio, processing conditions, and analytical basis differ among studies.

Millets themselves are characterized by substantial carbohydrate and nutrient contents, but dilution with water during beverage preparation substantially reduces the nutrient concentration per 100 mL compared with the original grain. Reviews of millet composition report that millet grains generally contain approximately 7–13% protein, 60–70% carbohydrate, 1.5–5% fat, and 2–7% fibre, depending on species and variety (Kaur *et al*., 2023) [9]. The lower concentrations observed in the present beverage therefore reflect the formulation and dilution rather than the intrinsic nutrient density of the millet grain.

Protein content increased from 2.15 ± 0.05% in T_0 to 2.28 ± 0.05% in T_2, while T_3 contained 2.25 ± 0.04%. Fat increased from 1.35 ± 0.04% in T_0 to 1.42 ± 0.04% in T_2, whereas ash increased from 0.48 ± 0.02 to 0.53 ± 0.02%. Fibre showed a similar trend, increasing from 0.72 ± 0.03% in T_0 to 0.80 ± 0.03% in T_2. These results demonstrate the contribution of the millet component to the nutritional characteristics of the beverage.

The observed protein and fibre values are lower than those reported for whole millet grains, which is expected because the present product contained only 10% millet flour and 85% water. Published reviews indicate that minor millets generally contain approximately 7–13% protein and 2–7% fibre, along with appreciable amounts of minerals such as iron, calcium, phosphorus and magnesium (Kaur *et al*., 2023) [9]. A recent comprehensive review similarly emphasized that millets are important sources of fibre, amino acids, minerals, vitamins, antioxidants and other bioactive compounds, although their nutritional characteristics vary according to species and processing conditions (Borah et al., 2026) [4].

The relatively higher fibre value in T_2 may be nutritionally advantageous because dietary fibre is one of the important characteristics distinguishing millet-based foods from many refined cereal products. The increase in ash content may also reflect the mineral contribution of millet. However, the small differences among treatments should not be interpreted as being caused directly by vitamin B12 itself, since the amount of B12 added to the formulations would be too small to materially contribute to proximate nutrient values.

The carbohydrate content ranged from 11.07 ± 0.10% in T_2 to 11.25 ± 0.12% in T_3, while energy ranged from 63.95 ± 0.40 to 64.78 ± 0.38 kcal/100 mL. The relatively narrow variation in carbohydrate and energy values indicates that the graded vitamin B12 fortification had little effect on the macronutrient composition of the beverages. This is expected because vitamin B12 is incorporated at a very low concentration and does not substantially contribute to energy.

The energy values obtained in the present study are comparable with the general characteristics expected of a diluted cereal beverage. Previous research on millet-based

ready-to-drink beverages has demonstrated that millet can be successfully incorporated into convenient beverage formats while maintaining acceptable physicochemical and sensory characteristics (Bembem & Agrahar-Murugkar, 2020) [3]. More recent research on millet fermented drinks has also confirmed that processing and millet type can alter the nutritional composition and functional characteristics of the final beverage (Challa *et al*., 2025) [5].

A major finding of the present study was the progressive increase in vitamin B12 content with increasing fortification. Vitamin B12 concentration increased from 0.02 ± 0.01 µg/100 mL in T_0 to 0.42 ± 0.02 µg/100 mL in T_1, 0.63 ± 0.03 µg/100 mL in T_2, and 0.84 ± 0.04 µg/100 mL in T_3. The statistically different superscript groups indicate significant differences among the treatments. This confirms that the graded fortification strategy effectively increased the measured vitamin B12 concentration.

The negligible B12 concentration observed in T_0 is consistent with the established understanding that vitamin B12 is not naturally present in meaningful amounts in most unfortified plant foods. Hannibal *et al*. (2024) [8] emphasized that vitamin B12 is not present in plants or unfortified plant-based foods and that individuals consuming plant-based diets need reliable sources such as fortified foods or supplements. Similarly, Marques de Brito *et al*. (2022), in a systematic review of non-animal food sources, concluded that naturally occurring B12 in plant-associated foods is variable and that the use of appropriate fortified foods remains important for reliable vitamin B12 intake.

The present results therefore support the use of millet beverages as a food vehicle for vitamin B12 fortification, rather than relying on millet itself as a source of B12. Recent research has specifically highlighted food fortification as an important strategy for improving vitamin B12 intake in vegetarian and plant-based dietary patterns (Deokar *et al*., 2025) [6]. A recent review also noted that staple food fortification, including the use of encapsulated or free vitamin B12, represents a promising strategy for improving vitamin B12 delivery and nutritional value (Gharibzahedi *et al*., 2023) [7].

The T_3 beverage showed the highest measured vitamin B12 concentration, but T_2 was preferred when sensory and nutritional characteristics were considered together. This is an important product-development observation: the formulation containing the maximum fortification level does not necessarily represent the optimum product if sensory acceptability declines. Therefore, T_2 can be considered the most balanced formulation, whereas T_3 represents the formulation with the greatest analytical vitamin B12 enrichment.

The findings of the present study are broadly consistent with previous research demonstrating the potential of millets for beverage development. Bembem and Agrahar-Murugkar (2020) [3] developed ready-to-drink beverages based on sorghum and finger millet and reported acceptable sensory scores above 7 on a nine-point hedonic scale. Likewise, research on probiotic foxtail millet beverages demonstrated that an optimized millet-to-water ratio could produce a beverage with high sensory acceptability (Challa *et al*., 2025) [5]. The present study extends this concept by incorporating vitamin B12 fortification into the millet beverage matrix.

Recent work on fermented millet drinks has further demonstrated that processing can improve nutritional and functional characteristics. Processing of different millets into fermented drinks was associated with reduced phytate and improved mineral accessibility, while sensory evaluation showed good consumer acceptance (Challa *et al*., 2025) [5]. These observations suggest that further optimization of soaking, roasting, fermentation, homogenization and fortification could potentially improve both the nutritional quality and sensory performance of vitamin B12-enriched millet beverages.

Overall, the results demonstrate that vitamin B12 fortification can be successfully incorporated into a millet-based beverage without compromising general sensory acceptability. T_2 emerged as the best overall formulation, obtaining an overall acceptability score of 8.05 ± 0.09 and showing relatively favourable protein, fat, ash, fibre and energy values. T_3 provided the highest vitamin B12 concentration, but its sensory scores were lower than those of T_2. These results are consistent with the broader literature supporting millets as versatile substrates for functional beverage development and vitamin B12 fortification as an appropriate strategy for plant-based foods.

Nevertheless, the present results should be interpreted within the limitations of the study. In particular, analytical vitamin B12 concentration does not necessarily establish physiological bioavailability. Recent literature emphasizes that vitamin B12 bioavailability depends on chemical form, food matrix, digestion and absorption, and that measured vitamin concentration should therefore not automatically be equated with nutritional efficacy (Liu & Varmanen, 2026) [10]. Future studies should therefore investigate vitamin B12 stability during processing and storage, bioaccessibility, shelf life, consumer acceptance, and *in-vivo* nutritional efficacy before making health or deficiency-prevention claims.

Conclusion

The present study demonstrated the feasibility of developing a vitamin B12-enriched millet-based beverage with good sensory acceptability and improved nutritional quality. Incorporation of vitamin B12 into the millet beverage successfully enhanced its micronutrient value, while the millet base contributed carbohydrates, protein, dietary fibre, minerals, and energy. Sensory evaluation indicated that the beverages were generally acceptable to the panel members, with T_2 obtaining the highest overall acceptability among the developed formulations. Although T_3 provided the highest level of vitamin B12 fortification, its sensory scores were comparatively lower than T_2. Therefore, T_2 may be considered the most promising formulation when both sensory quality and nutritional enhancement are taken into consideration. The developed beverage has potential as a functional, convenient, and nutrient-enriched food product, particularly for dietary diversification and increasing vitamin B12 intake. Further studies should assess vitamin B12 stability during processing and storage, shelf life, bioavailability, consumer acceptance, and the product's potential contribution to meeting recommended dietary requirements.

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