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Formulation and Nutritional Evaluation of Extruded Vermicelli from Browntop Millet

Raju, C. A. [a*], **Shamshad Begum, S.** [a], **Nagraja, T. E.** [b], **Suresha, K. B.** [c], **Bhavani, P.** [d] **and K. G. Vijayalaxmi** [a]

[a] *Department of Food Science and Nutrition, University of Agricultural Sciences, GKVK, Bengaluru – 560065, India.*
[b] *ICAR-AICRP on Small Millets, ZARS, University of Agricultural Sciences, GKVK, Bengaluru – 560 065, India.*
[c] *Dairy Technology, College of Sericulture, University of Agricultural Sciences, GKVK, Bengaluru – 560065, India.*
[d] *Department of Plant Biotechnology, University of Agricultural Sciences, GKVK, Bengaluru – 560065, India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The rising awareness of health benefits associated with millets has led to the increased interest in utilizing them for value-added food products. Browntop millet (*Brachiaria ramosa*), a highly nutritious, drought-tolerant grain, is one such millet that is rich in fiber, protein and essential

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**Corresponding author: Email: rajuca80@gmail.com;*

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micronutrients like iron and zinc. This study focuses on the development of extruded vermicelli from browntop millet to create a convenient, nutrient-dense alternative to traditional refined wheat products. Blends of browntop millet flour with whole wheat flour were developed that indicated the vermicelli with 50 per cent browntop millet (T_2) demonstrated enhanced nutritional properties, including a significant increase in fiber (4.45 g), protein (14.48 g), fat (1.48 g) and essential minerals such as iron (4.51 mg), zinc (4.44 mg) and copper (0.58 mg) when compared to the conventional counterpart. Despite the improved nutritional profile, the browntop millet vermicelli also exhibited higher levels of antinutritional factors, such as phytic acid (1039.78 mg/100 g) and polyphenols (186.05 mg/100 g). The product displayed favourable cooking qualities, with a cooking time of 7.15 minutes and a cooking loss of 12.24 per cent. Consumer acceptability revealed acceptance in key attributes, including flavour, consistency and appearance. Over a 90-day storage period, the millet-based vermicelli exhibited lower bacterial counts (2.58×10^4 CFU/g) compared to the control sample (3.08×10^4 CFU/g), while yeast and mold levels remained within acceptable limits. Although there was gradual increase in moisture, free fatty acids and peroxide values during storage, these remained within permissible limits, indicating good storage stability. The development of browntop millet-based extruded vermicelli offers a promising, health-oriented option for consumers, catering to the increasing demand for convenience foods that support both nutrition and convenience.

Keywords: Antinutrients; browntop millet; cooking quality; extruded product; minerals; sensory attributes; storage.

1. INTRODUCTION

Millets, small-seeded annual grasses from the Poaceae family, thrive in dry, marginal lands across temperate, subtropical and tropical regions. These resilient crops offer high yields even under harsh conditions (Gomashe 2017). Rich in fiber, polyphenols and bioactive compounds, millets are known to lower fat absorption, slow sugar release (low glycemic index) and reduce the risk of heart disease, diabetes and hypertension (Kumar et al. 2018). Among them, browntop millet has gained attention for its ability to ensure economic and nutritional security in resource-poor conditions, making it crucial for sustainable smallholder farming (Maitra 2020).

Browntop millet (*Brachiaria ramosa*), an ancient grain traditionally cultivated in semi-arid regions of India, is gaining recognition for its adaptability to poor soils and harsh climates, as well as its rich nutritional profile. Browntop millet is a nutrient-dense, energy-rich grain, offering 338 Kcal of energy along with 71.32 g of carbohydrates, 8.98 g of protein and 1.89 g of fat per 100 g (Roopa 2015). It is a rich source of natural fiber *i.e.,* 8.5 per cent and also rich in minerals like iron (7.72 mg), zinc (2.5 mg), calcium (28 mg), magnesium (94.5 mg) and gluten-free, this millet is ideal for individuals with gluten sensitivities or those seeking healthier alternatives to refined grains (Kishore et al. 2021). With global awareness of nutrition increasing, traditional grains like browntop millet are being reconsidered as vital components of modern diets.

Historically considered a "poor man's crop," millets are now seen as essential for sustainable agriculture and food security (Singh et al. 2022). Browntop millet offers opportunities for value addition, with products like extruded vermicelli providing the nutritional benefits of millet in a convenient form. Its high fiber content aids digestion and helps regulate blood sugar, making it ideal for people with diabetes or those seeking weight management. Moreover, its antioxidants help lower the risk of chronic diseases (Dayakar et al. 2017). Extruded browntop millet products thus align with the growing market demand for nutritious, convenient and health-promoting foods.

Vermicelli, derived from the Italian word meaning "little worms," is a type of extruded product that is round in shape and thinner than spaghetti. As a widely consumed extruded food product, vermicelli is traditionally made from wheat flour and is a staple in various cuisines. Extruded product such as vermicelli is not only a versatile food item but also an effective means of fulfilling nutritional requirements while promoting health. One of the key attributes of vermicelli is its high protein content, making it a nutritious snack food suitable for individuals across all age groups. Its popularity as an instant food product has surged due to its ease of preparation and compatibility with fast-paced, modern lifestyles (Lande et al. 2017). As consumer awareness of health and nutrition continues to grow, vermicelli has emerged as a convenient and appealing choice in the expanding market for quick meals. In response to the rising demand for ready-to-cook products, this study aimed to develop value-added vermicelli using a nutritious blend of browntop millet flour and whole wheat flour. Therefore, the main objective of this study was to develop and evaluate the sensory quality, nutritional, cooking and shelf life of browntop millet-based vermicelli as a value-added novel product.

2. MATERIALS AND METHODS

2.1 Procurement of Raw Materials

The study was conducted in the Department of Food Science and Nutrition at the University of Agricultural Sciences, Bangalore. The popular browntop millet variety (GPUBT2), was selected for this study and sourced from the All India Coordinated Research Project on Small Millets at the Zonal Agricultural Research Station, University of Agricultural Sciences, Bangalore. Whole wheat flour was procured from a local market in Bangalore. The browntop millet underwent thorough cleaning before being ground into fine flour using a pulverizer. The resulting flour was passed through a sieve to ensure uniformity and then stored in a cool, dry environment for further experimentation.

2.2 Single Screw Extruder

The experiment employed a laboratory single-screw extruder equipped with an automatic facility for mixing, kneading and extruding in a single operation. The extruder consists of several key components: a main unit, a mixing chamber, a mixer, a container lid and a front panel with a knob for control. Specially designed dies allowed the creation of various noodle and pasta shapes, including macaroni, linguine and tagliatelle. The extruder was also designed for easy disassembly, facilitating efficient cleaning. The entire extrusion process takes approximately 10-15 minutes to extrude the product.

2.3 Formulation and Preparation of Browntop Millet Vermicelli

Four distinct formulations of vermicelli were developed to evaluate the impact of browntop millet on nutritional quality. The first formulation served as a control, consisting entirely of wheat flour. The remaining three variations incorporated browntop millet at different substitution levels *viz.,* T_1 which contained 25 per cent millet flour and 75 per cent wheat flour, T_2 composed of 50 per cent millet flour and 50 per cent wheat flour and T_3 consisting of 75 per cent millet flour and 25 per cent wheat flour. The details of these formulations are summarized in Table 1.

The browntop millet-based cold extruded vermicelli products were developed using a systematic procedure recommended by the manufacturer of the pasta and noodles machine. Initially, the sieved flours of millet and wheat were blended and kneaded within the machine for 15 minutes, during which an optimum quantity of water was added based on the manufacturer's specifications. Once the dough reached its desired consistency, it was extruded through appropriately selected dies. The cutter speed was adjusted to an optimal level, depending on the shape of the final product. Following extrusion, the vermicelli was collected in trays and subsequently dried in a convective hot air oven at 50 °C for approximately three hours to achieve the desired texture. Upon completion of the drying process, the products were packaged in metalized polyester material, thermally sealed and stored under ambient conditions. A comprehensive flow chart detailing the production process of the browntop milled-based cold extruded ready-to-cook vermicelli was prepared (Fig. 1).

2.4 Organoleptic Evaluation

The developed vermicelli was evaluated for its sensory qualities by a panel of semi-trained individuals. The panelists assessed vermicelli *kheer* made from browntop millet, scoring it based on several criteria, including appearance, color, consistency, taste, flavor and overall acceptability. Using a nine-point Hedonic rating scale (Nicolas et al. 2010), the panelists rated their preferences, where a score of 9 indicated "like extremely" and a score of 1 indicated "dislike extremely."

2.5 Proximate Composition

The best vermicelli formulated from browntop millet, alongside a control sample made from whole wheat flour, was analyzed for its micronutrient and macronutrient content (AOAC 2005). The determination of moisture and ash content was conducted gravimetrically; moisture levels were measured post-oven drying, while ash content was quantified by the reduction method in a muffle furnace. Total fat was extracted utilizing a SoxPlus apparatus, and protein content was calculated from nitrogen levels through Kjeldahl titration, employing a conversion factor of 6.25. The carbohydrate content and energy values were ascertained using the difference method, resulting in a comprehensive nutritional profile for both vermicelli formulations.

2.6 Estimation of Minerals

The mineral analysis of browntop millet-based vermicelli, alongside a control group of whole wheat vermicelli was conducted. Samples were homogenized into a fine powder and one gram of each was digested with a di-acid mixture of 9 parts nitric acid (HNO_3) and 4 parts perchloric acid ($HClO_4$) on a hot plate until a snow-white residue formed. After cooling, the solution was diluted and filtered. Mineral content was estimated using atomic absorption photometry for copper, manganese, iron and zinc. Calcium and magnesium were assessed by titration, while potassium and sodium were measured *via* flame photometry and phosphorus was analyzed using spectrophotometry (AOAC 2005).

Table 1. Formulation of browntop millet-based vermicelli

Treatments	Millet flour (%)	Whole wheat flour (%)	Water (ml/kg)
Control	0	100	450
T_1	25	75	
T_2	50	50	
T_3	75	25	

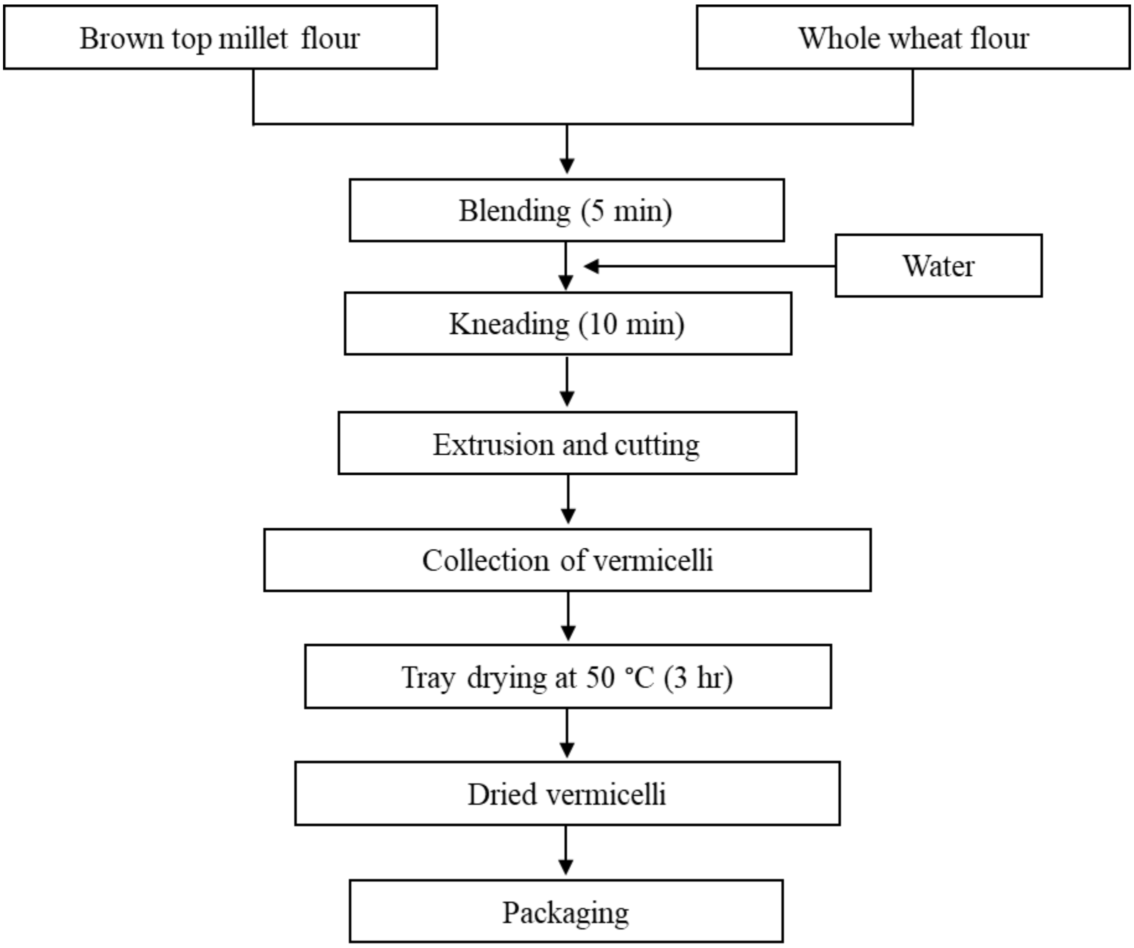

Fig. 1. Process for production of browntop millet-based vermicelli

2.7 Determination of Anti-nutrients

The anti-nutritional components, including total polyphenols, tannins and phytates were assessed in both the control vermicelli and the optimized browntop millet vermicelli. The analysis of these anti-nutrients was conducted using established methods.

2.8 Estimation of Phytic Acid

A 50 mg sample was accurately weighed and placed in a microfuge tube, followed by the addition of 1 ml of 2.4% HCl. The mixture was shaken on a mechanical shaker at room temperature for 16 hours at 220 rpm. After centrifugation at 1000 g for 20 minutes at 10 °C, the supernatant was collected using fresh tubes containing 25 mg of NaCl. This was shaken for 20 minutes at 350 rpm and allowed to settle at 4°C for 60 minutes. The clear supernatant was diluted 25 times, mixed with modified Wade reagent (3:1), vortexed and centrifuged, with absorbance measured at 500 nm (Gao et al. 2007).

> Calculation PA-P (mg/g) = (X value × Vol. taken for extraction (ml) × Dilution factor) / (Weight of sample (mg) × 1000)

2.9 Estimation of Tannins

One ml of sample extract was placed in a 100 ml volumetric flask, followed by the addition of 5 ml of Folin-Denis reagent and 10 ml of sodium carbonate solution. The mixture was diluted to 100 ml with distilled water and allowed to stand for 30 minutes. Absorbance was measured at 760 nm and tannin content was calculated as tannic acid equivalents using a standard graph (AOAC 2005).

> Tannins % = (Tannic acid (mg) x Dilution x100) / (Sample taken for colour development (ml) x Weight of sample (g)) X 100

2.10 Estimation of Total Polyphenols

Take known aliquot of sample and make volume up to 1.5 ml with distilled water. To this add 0.5 ml of Folin-ciocalteu reagent. Add 10 ml of 7.5 per cent Na_2Co_3 and incubate at 37°C for 60 minutes. Read the resulting blue colour complex at 765 nm (AOAC 2005).

> Total polyphenols = ((Conc. of polyphenol mg/100 g sample from graph) / Aliquot taken for estimation) × 5 × (100 / Wt. of sample) × (1 / 100)

2.11 Cooking Quality

The cooking characteristics of experimental vermicelli sample was determined by following the established cooking procedures.

2.12 Optimum Cooking Time

The control vermicelli and browntop millet-based vermicelli products (10 g) were cooked in 100 ml of boiling water over a gas stove. The optimum cooking time was assessed subjectively by pressing the products at 1-minute intervals, with the time noted once they became completely soft (Gull et al. 2015).

2.13 Percent Solids Dispersion

The Percent Solids dispersion in the vermicelli samples was determined by boiling them in water for 20 minutes. After cooking, the samples were strained, and the filtrate was quantitatively transferred to a pre-weighed petri dish. The water was evaporated using a water bath, followed by drying the dish in a hot air oven at 105 ± 2 °C for 1 hour. The final weight of the dried solids was recorded for calculation of solids loss (Gull et al. 2015).

> Percent Solids dispersion (%) = (W2 - W1) / W × 100

Where,

> W - Initial weight of vermicelli taken for cooking
> W1 - Weight of empty petri dish
> W2 - Weight of petri dish with dried solids after evaporation

2.14 Swelling Power

The swelling power of vermicelli products was determined using the method (Schoch 1964). A known weight of 10 g of vermicelli was cooked in 200 ml of boiling water (20 times its weight) for 20 minutes in a water bath maintained at 100 ºC. After cooking, the water was drained, and the cooked vermicelli was dried with filter paper before being weighed. The swelling power was then calculated from the initial and final weights.

Swelling power (g/g) = (W2 - W1) / W1

Where,

W1 = Sample weight before cooking (g)
W2 = Sample weight after cooking (g)

2.15 Storage Studies

The best-accepted vermicelli, along with the control vermicelli was selected for a shelf-life study. The vermicelli was developed and packaged in metalized polyester material, then stored at ambient temperature (28 ± 2 °C). Samples were drawn from the storage conditions on the 0th, 30th, 60th and 90th day and were analyzed for various parameters such as sensory evaluation, moisture content, microbial load, peroxide value and free fatty acid levels.

2.16 Microbial Load of Developed Food Product

Microbial analysis of the developed products was conducted using the standard plate count method (Tate 1995). Nutrient Agar (NA) assessed bacterial populations, while Martins Rose Bengal Agar (MRBA) targeted fungi and Eosin-Methylene Blue (EMB) for *E. coli.* After solidifying the media, plates were incubated inverted at 28 ± 2 ºC for two days (bacteria) and four days (fungi and *E. coli*) before colony enumeration.

2.17 Free Fatty Acid

The free fatty acid content was determined by titrating with 0.1N KOH and phenolphthalein indicator, continuing until the pink color persisted for 15 seconds. The percentage of free fatty acids was calculated using oleic acid as the reference factor (Nithyashree, 2022).

Acid value (mg KOH/g of oil) = (a x 0.00561 x 1000) / Weight of the sample (g)

Percent free fatty acid = Acid value / 1.99

2.18 Peroxide Value

Ten grams of the sample were weighed for fat extraction. Between 0.5 ml and 1 ml of the extracted fat was placed in a flask, followed by the addition of 20 ml of acetic acid and 10 ml of chloroform to dissolve the fat. After adding 1 ml of potassium iodide and allowing it to stand for 5 minutes, precipitation occurred upon adding 30 ml of distilled water and starch was introduced as an indicator. The mixture was titrated with sodium thiosulfate until the violet-blue colour disappeared (Raguramulu et al. 2003).

Peroxide value of oil (meq/kg of sample) = ((Titre-blank) ×N×1000) / Weight of the oil (g)

2.19 Water Activity

The water activity of vermicelli was assessed at an ambient temperature of 28 ± 2 °C using a RotronicHygro Lab water activity meter (Abbey et al. 2017). A two-gram powdered sample was placed in the chamber and after positioning the measuring head, the instrument was activated, yielding a stable reading that was recorded.

2.20 Statistical Analysis

Data were analyzed using a completely randomized design in SPSS software *i.e.,* software Statistical Package for Social Sciences (SPSS) version 12.0 (Sabine and Brian 2004) Means and standard deviations for various parameters were computed. One-way ANOVA assessed the sensory and nutritional attributes of the developed products, while Duncan's multiple range test identified significant differences among the vermicelli samples.

3. RESULTS AND DISCUSSION

3.1 Mean Sensory Scores of Browntop Millet-based Vermicelli *Kheer*

The sensory evaluation of vermicelli developed by incorporating browntop millet (GPUBT2) at 25 percent (T_1), 50 percent (T_2) and 75 percent (T_3) levels, alongside a control vermicelli made with 100 percent whole wheat flour, was presented in Table 2 and Fig. 2. The control vermicelli *kheer* exhibited higher mean sensory scores, 7.95 for appearance, 7.80 for colour, 8.00 for consistency, 7.85 for aroma, 7.90 for taste and 8.09 for overall acceptability. In contrast, vermicelli *kheer* with browntop millet incorporation showed a decline in sensory scores across all attributes. The incorporation of 25 per cent browntop millet (T_1) resulted in mean scores of 7.47 for appearance, 7.30 for colour, 6.23 for consistency, 7.23 for aroma, 7.28 for taste and 7.40 for overall acceptability. At the 50 percent level of incorporation (T_2), the vermicelli *kheer* exhibited intermediate sensory scores with 7.28 for appearance, 6.80 for colour, 7.07 for consistency, 6.73 for aroma, 6.80 for taste and

7.04 for overall acceptability. However, the 75 percent incorporation (T_3) scored the lowest scores with 6.61 for appearance, 6.00 for colour, 6.14 for consistency, 6.02 for aroma, 6.07 for taste and 6.02 for overall acceptability. As the level of browntop millet incorporation increased, the sensory scores consistently decreased. The difference in mean sensory scores between the control and millet-incorporated vermicelli was statistically significant across all sensory parameters at the 5 percent level. Similarly, browntop millet biscuits were prepared using varying levels of millet flour and refined flour (maida) across 11 treatments. Biscuits containing a 50 percent blend of browntop millet flour and maida achieved higher sensory scores, with 8.47 for colour and appearance, 8.40 for flavour, 8.41 for texture, 8.49 for taste and 8.44 for overall acceptability (Titkare et al. 2021). As observed with the vermicelli, increasing the proportion of millet flour in the biscuits also led to a decline in sensory scores.

3.2 Proximate Composition of Browntop Millet-based Vermicelli

The proximate composition of vermicelli incorporated with 50 per cent browntop millet and the control (wheat flour vermicelli) is presented in Table 3. It was observed that the moisture content was lower in control vermicelli (8.17%) compared to the browntop millet vermicelli (8.50%). Protein levels were comparable between the two, with browntop millet vermicelli containing 14.48 g/100 g and control vermicelli containing 13.94 g/100 g. Additionally, the browntop millet vermicelli exhibited a higher fat content (1.48 g/100 g) and crude fiber (4.45 g/100 g), while the control vermicelli had lower values for fat (0.87 g/100 g) and crude fiber (1.48 g/100 g). Carbohydrates and energy values were slightly lower in browntop millet vermicelli, with 69.46 g/100 g of carbohydrates and 349 Kcal, compared to 73.99 g/100 g of carbohydrates and 359 Kcal in the control vermicelli. The incorporation of 50 per cent browntop millet resulted in higher crude fiber and fat content compared to the control, which may be attributed to the naturally high fiber content in millets. A statistically significant difference at the 5 per cent level was observed for fat and crude fiber content, whereas no significant differences were found for moisture, protein, ash, carbohydrates or energy values. In comparison (Chandraprabha 2017), lower values for moisture (7.70 %), carbohydrates (50 - 53 g/100 g), protein (7.96 - 9.34 g/100 g) and energy (257 - 272 kcal/100 g) and higher crude fiber and fat content compared to the current study. The results of the present study aligned more closely with the findings (Mogra and Midha 2013), particularly for moisture, protein and carbohydrate levels, although slightly lower values for fat and crude fiber were noted.

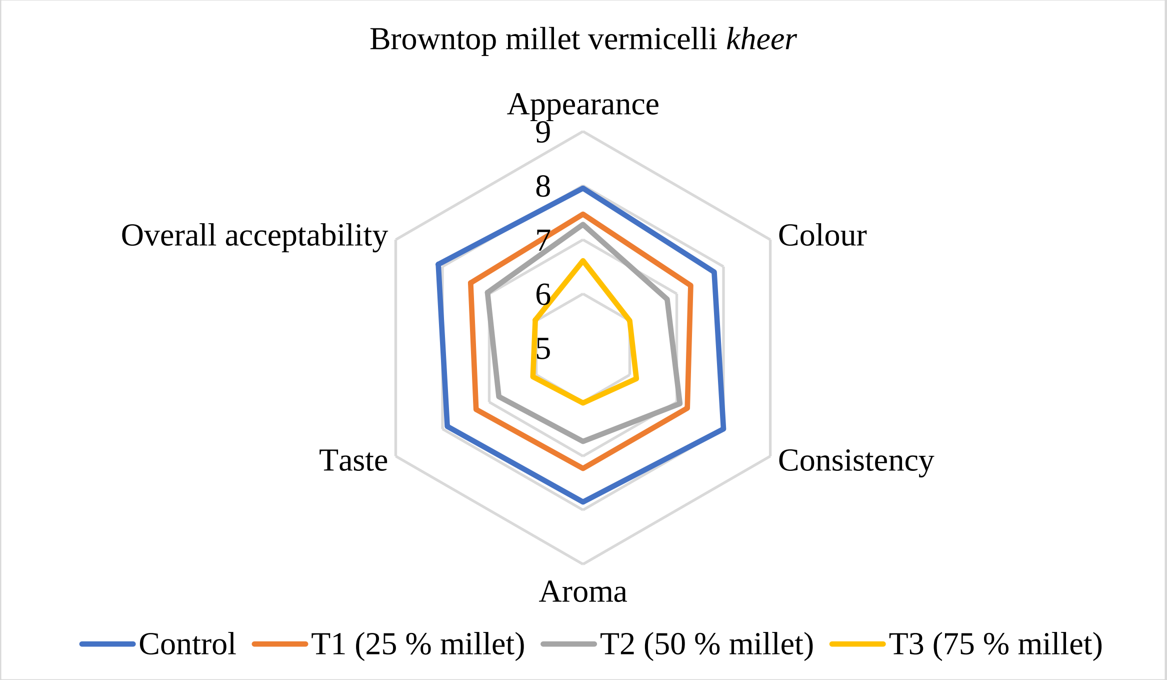

Fig. 2. Mean sensory scores browntop millet vermicelli *kheer*

Table 2. Sensory evaluation of browntop millet vermicelli *kheer*

Product's	Appearance	Colour	Consistency	Aroma	Taste	Overall acceptability
Control	7.95 ± 0.72^{a}	7.80 ± 0.66^{a}	8.00 ± 0.81^{a}	7.85 ± 0.98^{a}	7.90 ± 0.97^{a}	8.09 ± 0.81^{a}
T_1	7.47 ± 0.49^{ab}	7.30 ± 0.73^{ab}	7.23 ± 0.74^{b}	7.23 ± 0.81^{b}	7.28 ± 0.98^{b}	7.40 ± 0.71^{b}
T_2	7.28 ± 0.62^{b}	6.80 ± 0.99^{b}	7.07 ± 0.79^{b}	6.73 ± 1.15^{b}	6.80 ± 1.08^{b}	7.04 ± 0.77^{b}
T_3	6.61 ± 1.04^{c}	6.00 ± 0.97^{c}	6.14 ± 1.08^{c}	6.02 ± 1.13^{c}	6.07 ± 1.11^{c}	6.02 ± 1.05^{c}

Note: Rows differ significantly ($p \le 0.05$) based on Duncan's test, T_1 – 25 % millet flour, T_2 – 50 % millet flour and T_3 – 75 % millet flour

Table 3. Proximate composition of browntop millet-based vermicelli

Proximates	Vermicelli		t - test
	Control (Wheat flour)	**Browntop millet**	
Moisture (%)	8.17 ± 0.01	8.50 ± 0.02	1.83^{NS}
Protein (g)	13.94 ± 0.28	14.48 ± 0.75	1.75^{NS}
Ash (g)	1.53 ± 0.13	1.61 ± 0.10	1.00^{NS}
Fat (g)	0.87 ± 0.05	1.48 ± 0.02	13.45*
Crude Fibre (g)	1.47 ± 0.02	4.45 ± 0.16	63.61*
Carbohydrate (g)*	73.99 ± 0.45	69.46 ± 0.64	1.69^{NS}
Energy (Kcal)*	359 ± 0.18	349 ± 0.20	0.62^{NS}

*Note: Values are expressed as mean ± standard deviation of three determinants, Carbohydrate – by difference method, Energy – by calculation method, *Significant at ($p \le 0.05$) and NS - Non-significant*

3.3 Mineral Composition of Browntop Millet Vermicelli

The mineral content of control and browntop millet vermicelli is presented in Table 4. It was observed that control vermicelli made from whole wheat flour contained 31.20 mg of calcium, 3.22 mg of sodium, 307.91 mg of potassium, 3.82 mg of iron, 0.40 mg of copper, 113.60 mg of magnesium, 2.81 mg of zinc, 303.53 mg of phosphorus and 2.48 mg of manganese. In contrast, vermicelli incorporating 50 per cent browntop millet exhibited 28.53 mg of calcium, 7.93 mg of sodium, 296.60 mg of potassium, 4.51 mg of iron, 0.58 mg of copper, 94.40 mg of magnesium, 4.44 mg of zinc, 276.86 mg of phosphorus and 2.42 mg of manganese per 100 g. Incorporation of browntop millet significantly increased the micro-mineral content, as millet is known to be rich in minerals that meet daily nutritional requirements. Statistical analysis revealed that the mineral composition of both control and millet-incorporated vermicelli samples showed significant variability at the 5 per cent level except for manganese and potassium. A study reported (Lande et al. 2017) significantly lower calcium (18.56 mg), iron (2.13 mg) and phosphorus (107.67 mg) in finger millet vermicelli compared to the present study. Similarly, the findings differed in mineral composition in whole wheat flour vermicelli (Mogra and Midha 2013). Sodium (38.2 mg), iron (6 mg), copper (1.93 mg), potassium (375 mg) were considerably higher, while calcium (25 mg) and phosphorus (217 mg) was lower compared to the present study. These discrepancies in mineral concentrations may be due to differences in millet varieties, formulations, processing techniques or analytical methods employed.

3.4 Antinutrient Composition of Browntop Millet Vermicelli

The antinutrient content of control and browntop millet vermicelli was presented in Table 5. A significant variation in antinutrient levels was observed between control vermicelli and vermicelli with 50 percent millet incorporation. Browntop millet vermicelli demonstrated notably higher levels of phytic acid (1039.78 mg/100 g) and polyphenols (186.05 mg/100 g) compared to the wheat-based control vermicelli, which contained 505.31 mg/100 g of phytic acid and 118.10 mg/100 g of polyphenols. However, the tannin content remained consistent between both types of vermicelli, with browntop millet vermicelli showing 203.01 mg/100 g and control vermicelli showing 203.33 mg/100 g. These findings suggested that browntop millet vermicelli contained significantly higher levels of certain antinutritional factors, particularly phytic acid and polyphenols.

Table 4. Mineral composition of millet-based vermicelli

Minerals	Vermicelli		t - test
	Control (Wheat flour)	Browntop millet	
Calcium	31.20 ± 3.26	28.53 ± 2.09	4.13*
Sodium	3.22 ± 0.17	7.93 ± 0.80	45.54*
Potassium	307.91 ± 11.98	296.60 ± 10.63	0.73^{NS}
Iron	3.82 ± 0.11	4.51 ± 0.03	4.41*
Copper	0.40 ± 0.02	0.58 ± 0.01	25.54*
Magnesium	113.60 ± 11.59	94.40 ± 5.98	8.51*
Zinc	2.81 ± 0.10	4.44 ± 0.08	9.65*
Phosphorus	303.53 ± 11.73	276.86 ± 14.87	3.11*
Manganese	2.48 ± 0.22	2.42 ± 0.08	0.68^{NS}

*Note: Values are expressed as mean ± standard deviation of three determinants. *Significant at ($p \leq 0.05$) and NS - Non-significant*

Table 5. Antinutrient composition of browntop millet-based vermicelli

Parameters (mg/ 100 g)	Vermicelli		t - test
	Control (Wheat flour)	Browntop millet	
Phytic acid	505.31 ± 18.15	1039.78 ± 26.79	30.25*
Tannins	203.33 ± 10.03	203.01 ± 3.42	0.07^{NS}
Polyphenols	118.10 ± 8.62	186.05± 4.22	8.55*

*Note: Values are expressed as mean ± standard deviation of three determinants, *Significant at ($p \leq 0.05$) and NS - Non-significant*

3.5 Cooking Quality of Browntop Millet-based Vermicelli

The cooking characteristics of the optimized vermicelli products, including cooking time, swelling power, solids loss and cooking weight were assessed and are presented in Table 6. The evaluation of these parameters revealed that the vermicelli made exclusively from browntop millet flour did not retain their shape during cooking. Consequently, whole wheat flour was incorporated at varying levels as a binding agent to improve texture and maintain the product's shape during cooking. The cooking properties of the control wheat flour vermicelli and the browntop millet vermicelli displayed notable differences. The browntop millet vermicelli exhibited a shorter cooking time of 7.15 minutes compared to the 8.10 minutes required for the wheat-based vermicelli. The swelling power was slightly lower for the browntop millet vermicelli (2.81 ml) compared to the control (3.13 ml). However, the browntop millet vermicelli experienced significantly higher solids loss (12.24%) than the wheat flour vermicelli (6.84%), indicating a greater loss of nutrients during the cooking process. Furthermore, the cooking weight of the wheat flour vermicelli (41.36 g) exceeded that of the browntop millet vermicelli (38.18 g). The findings recorded a higher cooking loss (34.37 g/100 g) compared to the present findings (Pandey et al. 2017). Additionally, lower gruel loss (8.6%) in vermicelli prepared from finger millet incorporated into semolina (Sudha et al. 1998). These differences in solid loss were attributed to the variation in ingredients used during preparation, as well as differences in gluten content.

3.6 Storage Studies of Browntop Millet-based Vermicelli

The results of a storage study conducted on browntop millet-based vermicelli (formulated with 50% millet flour and 50% wheat flour) and control vermicelli were assessed after being stored under ambient conditions (28 ± 2°C) for a duration of three months. Both variants were packaged in metalized polyester material to ensure optimal preservation throughout the storage period.

3.7 Sensory Evaluation of Millet-based Vermicelli on Storage

The sensory evaluation of browntop millet-based vermicelli and control vermicelli stored in metallized polyester packages at ambient conditions for a period of three months is presented in Table 7. It was observed that as the storage period progressed, the mean sensory scores for appearance, colour, consistency, flavour, taste and overall acceptability of both products declined from the 0th day to the 90thday.For the control vermicelli, the mean sensory score for overall acceptability decreased gradually from 8.09 at the beginning of the storage period to 7.71 after 90 days. A similar trend was noted for the browntop millet-based vermicelli, where the overall acceptability score fell to 6.59 by the end of the storage period. Despite the decline, both the millet-based and control vermicelli remained in good condition and were deemed acceptable by consumers even after 90 days of storage. Statistical analysis revealed that the decline in sensory scores from the 0th day to the 90th day was not significant ($p \leq 0.05$), suggesting minimal impact on sensory quality during storage. These findings align with previous research (Beniwal and Jood 2015, Bharath Kumar and Prabhasankar 2016, Devi et al. 2011) which reported that vermicelli products retained their organoleptic properties throughout similar storage periods. Comparable results were also observed on pasta and noodles, where fluctuations in sensory perception were noted during a 90-day storage period (Savita et al. 2024). The present findings indicate that both control and millet-based vermicelli maintained their sensory attributes and consumer acceptability over the three-month storage period, reinforcing the stability of these products under ambient conditions.

3.8 Microbial Load of Browntop Millet-based Vermicelli on Storage

The microbial quality of control and optimized browntop millet vermicelli was analyzed in terms of total bacterial count, mold and *E. coli* presence over a 90-day storage period at ambient conditions. Table 8 presents the influence of storage duration on the microbial load of the vermicelli samples. Both control and optimized browntop millet vermicelli were packed in metallized polyester and stored under ambient conditions. The results indicated that the packaging material and storage temperature significantly affected the microbial population in the vermicelli samples.The total bacterial count increased with prolonged storage, ranging from 0.41×10^4 to 3.08×10^4cfu/g by the 90th day. Yeast and mold counts, initially absent but increased significantly to 3.41×10^3cfu/g by the end of the three-month storage period. *E. coli* was not detected at any point during the storage period. The increase in total bacterial population over time was likely due to the storage conditions and the gradual rise in moisture levels. However, millet vermicelli exhibited a lower bacterial count than the control, possibly due to the phytonutrients present in millets. Statistically significant differences were observed between the vermicelli samples regarding storage duration and the increase in microbial load, with a 5 per cent level of significance. The findings reported a lower microbial load of bacteria (2.33×10^{-5}Cfu/g) and yeast &molds (1.62×10^{-4}Cfu/g) in vermicelli after six months of storage (Shobha et al. 2015). On the other hand, higher total plate count (8.36×10^{-2}Cfu/g) in vermicelli supplemented with kinnow pulp residue, further highlighting the variability in microbial development based on ingredient composition and storage conditions (Singla et al. 2022).

3.9 Bio-chemical Changes of Browntop Millet-based Vermicelli on Storage

The bio-chemical parameters of control and browntop millet vermicelli were assessed over a 90-day storage period, with the results presented in Table 9. Moisture content gradually increased in both samples, with browntop millet vermicelli rising from an initial 8.52 per cent to 9.74 per cent at day 90. Similarly, wheat vermicelli showed an increase from 8.15 per cent to 9.57 per cent over the same period. Water activity followed a comparable pattern, reaching 0.60 for control vermicelli and 0.65 for browntop millet vermicelli by the end of the 90 days. The free fatty acid content exhibited a sharper rise in browntop millet vermicelli, increasing from 0.37 per cent at the start to 1.16 per cent at day 90,

Table 6. Cooking properties of millet-based vermicelli

Parameters	Vermicelli		t - test
	Control (Wheat flour)	Browntop millet	
Cooking time (min)	8.10 ± 0.17	7.15 ± 0.32	5.75*
Swelling power (ml)	3.13 ± 0.06	2.81 ± 0.12	4.98*
Solids loss (%)	6.84 ± 0.14	12.24 ± 0.55	10.68*
Cooking weight (g)	41.36 ± 0.79	38.18 ± 0.57	2.13^{NS}

*Note: Values are expressed as mean ± standard deviation of three determinants, *Significant at ($p \leq 0.05$) and NS - Non-significant*

Table 7. Sensory evaluation of millet-based vermicelli on storage

Vermicelli	Duration (Days)	Appearance	Colour	Consistency	Aroma	Taste	Overall acceptability
Control (Wheat flour)	Initial	7.95 ± 0.72^{a}	7.80 ± 0.66^{a}	8.00 ± 0.81^{a}	7.85 ± 0.98^{a}	7.90 ± 0.97^{a}	8.09 ± 0.81^{a}
	30	7.76 ± 0.52^{a}	7.69 ± 0.44^{a}	7.92 ± 0.72^{a}	7.61 ± 0.84^{a}	7.80 ± 0.90^{a}	8.02 ± 0.76^{a}
	60	7.57 ± 0.58^{a}	7.52 ± 0.49^{a}	7.76 ± 0.74^{a}	7.47 ± 0.79^{a}	7.61 ± 0.84^{a}	7.83 ± 0.74^{a}
	90	7.38 ± 0.57^{a}	7.28 ± 0.54^{a}	7.57 ± 0.65^{a}	7.28 ± 0.62^{a}	7.33 ± 0.64^{a}	7.71 ± 0.62^{a}
Browntop millet	Initial	7.28 ± 0.62^{a}	6.80 ± 0.99^{a}	7.07 ± 0.79^{a}	6.73 ± 1.15^{a}	6.80 ± 1.08^{a}	7.04 ± 0.77^{a}
	30	7.19 ± 0.58^{a}	6.69 ± 0.82^{a}	6.97 ± 0.69^{a}	6.64 ± 1.08^{a}	6.73 ± 1.01^{a}	6.92 ± 0.65^{a}
	60	7.04 ± 0.48^{a}	6.57 ± 0.65^{a}	6.85 ± 0.63^{a}	6.47 ± 0.95^{a}	6.61 ± 0.89^{a}	6.76 ± 0.52^{a}
	90	6.90 ± 0.29^{a}	6.42 ± 0.49^{a}	6.61 ± 0.48^{a}	6.38 ± 0.89^{a}	6.47 ± 0.73^{a}	6.59 ± 0.47^{a}

Note: Values are expressed as mean ± standard deviation of three determinants. Rows differ significantly ($p \le 0.05$) based on Duncan's test

Table 8. Effect of storage on microbial load of millet-based vermicelli

Microorganism	Duration (Days)	Control (Wheat flour)	Browntop millet
Bacteria (×10^4)	Initial	0.41^{d}	ND
	30	1.00^{c}	1.50^{c}
	60	1.91^{b}	1.83^{b}
	90	3.08^{a}	2.58^{a}
Yeast and molds (×10^3)	Initial	ND	ND
	30	1.08^{c}	1.08^{c}
	60	1.41^{b}	1.25^{b}
	90	3.41^{a}	2.00^{a}
***E. coli* (×10^2)**	Initial	ND	ND
	30	ND	ND
	60	ND	ND
	90	ND	ND

Note: Values are expressed as mean ± standard deviation of three determinants. Rows differ significantly ($p \leq 0.05$) based on Duncan's test and ND - Not detected

Table 9. Effect of storage on bio-chemical properties of millet-based vermicelli

Bio-chemical parameters	Duration (Days)	Control (Wheat flour)	Browntop millet
Moisture (%)	Initial	8.15 ± 0.15^{c}	8.52 ± 0.08^{c}
	30	8.56 ± 0.20^{bc}	8.89 ± 0.13^{bc}
	60	8.94 ± 0.12^{ab}	9.47 ± 0.17^{ab}
	90	9.57 ± 0.25^{a}	9.74 ± 0.12^{a}
Water activity(a_w)	Initial	0.31 ± 0.02^{c}	0.32 ± 0.02^{c}
	30	0.38 ± 0.04^{b}	0.36 ± 0.01^{c}
	60	0.46 ± 0.01^{b}	0.47 ± 0.02^{b}
	90	0.60 ± 0.05^{a}	0.65 ± 0.02^{a}
Free fatty acids (%)	Initial	0.21 ± 0.00^{d}	0.37 ± 0.02^{d}
	30	0.34 ± 0.02^{c}	0.72 ± 0.04^{c}
	60	0.55 ± 0.01^{b}	0.90 ± 0.02^{b}
	90	0.82 ± 0.03^{a}	1.16 ± 0.01^{a}
Peroxide value (meq.kg^{-1})	Initial	1.46 ± 0.03^{c}	2.48 ± 0.15^{d}
	30	1.70 ± 0.05^{b}	2.95 ± 0.06^{c}
	60	1.82 ± 0.08^{b}	3.51 ± 0.09^{b}
	90	2.05 ± 0.12^{a}	4.13 ± 0.05^{a}

Note: Values are expressed as mean ± standard deviation of three determinants. Rows differ significantly ($p \leq 0.05$) based on Duncan's test

while wheat vermicelli displayed a more moderate increase from 0.21 per cent to 0.82 per cent. The peroxide value, an indicator of lipid oxidation, also escalated more significantly in browntop millet vermicelli rising from 1.16 meq.kg^{-1} initially to 4.13 meq.kg^{-1} by day 90, in contrast to the wheat vermicelli, which increased from 1.46 meq.kg^{-1} to 2.05 meq.kg^{-1}. These findings suggested that lipid degradation occurred at a faster rate in browntop millet vermicelli compared to the control sample. Statistical analysis revealed a significant effect ($P \leq 0.05$) of the storage period on the moisture content, water activity, free fatty acids and peroxide values of the vermicelli samples. Several studies have reported similar trends in cereal-based food products during storage under different packaging materials and conditions (Gull et al. 2017, Jalgaonkar et al. 2017, Malleshi et al. 1989). Comparable observations were found on vermicelli supplemented with kinnow pulp residue, particularly with respect to changes in water activity during storage (Singla et al. 2022).

4. CONCLUSION

The development of extruded products based on browntop millet offers a nutritious and health-conscious alternative to conventional refined wheat flour vermicelli. Substituting millet at 50 per cent significantly enhanced the fiber, fat and mineral content particularly iron, copper and zinc, while maintaining satisfactory protein levels. Despite a slight decline in sensory attributes such as appearance and consistency at higher levels of millet incorporation, the nutritional advantages were compelling. Browntop millet vermicelli delivered superior essential minerals and fiber compared to the control samples, along with the added benefit of a shorter cooking time. Furthermore, the vermicelli demonstrated excellent shelf stability, with lower bacterial and yeast counts sustained over a 90-day storage period. These findings underscore the potential of browntop millet as an ideal ingredient for producing fiber-rich extruded products that not only support health but also show strong consumer acceptance and extended shelf life.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

DATA AVAILABILITY STATEMENT

The availability of supporting data is with the corresponding author and will be provided at any point of time if demanded and feel that it is required.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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