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Sustainable functional foods derived from indigenous resources: the utilization of tamarind seed, bael, and bamboo shoot powders as nutritional enhancers

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Value-added products such as pasta and cookies were prepared from composite flours with 20% incorporation of three Minor Forest Products (MFPs), namely bael, bamboo shoot, and tamarind seed, separately, in refined wheat flour. Cookies were made using the basic creamery method, where 250 g of icing sugar and 250 g of fat were mixed initially to obtain a creamery texture. Following this, 500 g of composite flour was added and mixed. Next, 5 g of baking powder and 75 mL of water were added, and the dough was kneaded, sheeted, and cut. Finally, it was baked at 120 °C for 20 minutes and cooled. Pasta was prepared by the addition of 350 mL of water to the composite flours, followed by kneading and extrusion. The extruded pasta was then steamed for 20 minutes by the double-boiling method and then dried for 16 hours at 55 °C in a hot air dryer. Cookies and pasta made from 100% maida flour were taken as the control. Tamarind seed pasta and cookies had a higher protein value of 12.61 ± 0.02% and 12.62 ± 0.22%, respectively. Bamboo shoot pasta and cookies had high fibre content with values of 7.99 ± 0.55% and 7.69 ± 0.75%, respectively. Dietary fibre analysis revealed that bamboo shoot pasta, and cookies had the highest insoluble fibre (16.67 mg/100 g and 19.05 mg/100 g, respectively) and soluble fibre content (5.50 mg/100 g and 6.42 mg/100 g, respectively). Bael pasta and cookies were observed to have a high potassium content. A high amount of vitamin C was also observed in bael pasta (132.8 mg/100 g) and cookies (152.99 mg/100 g) compared to the control. Moreover, bael also seems to show very good antioxidant activity with 46.7 ± 0.45 μg mL^{-1} for pasta and 19.39 ± 0.99 μg mL^{-1} for cookies. The Total Phenolic Content (TPC) analysis revealed that the pasta and cookie samples had higher TPC than the control, with bael having the highest value in both pasta (2981.75 ± 171.7 mg GAE/100 g) and cookies (2027.58 ± 80.66 mg GAE/100 g). Amylose content was found to be higher for all the products than their control, which aids in improving their textural properties. The sensorial properties and textural properties of bamboo shoot pasta (overall acceptability 7.2) and cookies (overall acceptability 7.3), and tamarind seed pasta (overall acceptability 6.9) and cookies (overall acceptability 8.0) are up to the level of consumer acceptability, while bael pasta (overall acceptability 6.0) and cookies (overall acceptability 6.7) require further improvement. All the products developed have the potential to become functional foods with further incorporation and optimization.

Sustainability spotlight

This study investigates the sustainable potential of underutilized minor forest products (MFPs)—specifically bael, bamboo shoot, and tamarind seed powders—as nutritional enhancers in pasta and cookie formulations. These indigenous crops, which are abundant in dietary fiber, protein, vitamins, and minerals, were effectively incorporated into functional food products, resulting in notable improvements in health-related attributes such as antioxidant activity, protein content, and fiber levels. The utilization of these locally sourced and naturally available ingredients aligns with Sustainable Development Goals 2 (Zero Hunger) and 3 (Good Health and Well-Being) by promoting dietary diversification and enhanced nutrition. Moreover, the valorization of these resilient forest products has the potential to encourage sustainable agricultural practices and reduce reliance on water-intensive crops, thereby indirectly supporting Sustainable Development Goals 12 (Responsible Consumption and Production) and 13 (Climate Action). The findings of this research underscore a promising approach to strengthening food security, empowering communities dependent on forests, and contributing to the establishment of a more sustainable food system.

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1. Introduction

Minor forest produce refers to non-timber goods obtained from forests, encompassing a diverse array of botanical resources. These include medicinal plants, nuts, resins, and fruits, which are crucial for sustenance, traditional medicine, and economic activities in forest-dependent communities. Minor Forest Products (MFPs) or Non-Timber Forest Products (NTFPs) provide diverse benefits, including economic value through income generation, cultural preservation, nutritional and medicinal contributions, market diversification, and sustainable land use promotion.[1] Among the MFPs, tamarind seed, bael, and bamboo shoot are three important ones possessing high nutritional value and many nutraceutical benefits.[2–4] These three MFPs were specifically used in this study because of their rich nutrient and phytochemical content, traditional ethnomedical value, underutilisation within the context of food systems, and potential to scale up as functional foods.[4–7]

Functional foods and nutraceuticals are a primary focus of research and development in the food industry. These two terms are confusing and are often interchanged. Agri-residues can be a valuable source for formulating functional ingredients, natural additives, biodiesel, dyes, and animal feed.[8] Functional foods do not have a single definition, and so, generally, they can be defined as "whole foods along with fortified, enriched, or enhanced foods that can potentially improve health when consumed as part of a varied diet regularly at effective levels", can be considered as nutritious fast foods.[9] Nutraceuticals refer to a type of medicinal substance that is extracted or condensed and used to promote good health, slow down the aging process, safeguard against long-term illnesses, and enhance lifespan.[10]

Bael is an Indian fruit from the citrus family *Rutaceae* that is not commonly used or appreciated. It contains numerous alkaloids, coumarins, resins, essential oils, phenolic compounds, and tannins, giving it the qualities of a nutraceutical.[11] It is a highly nutritious fruit that offers numerous health benefits due to its rich content of fatty acids, amino acids, various organic acids, minerals, carbohydrates, and vitamins.[12] The potential for this product to be developed as a functional food is tremendous.[5]

Bamboo shoot, which is a tender developing culm, is another indigenous forest product that is a rich source of various nutritional compounds, including dietary fibre, phenolic compounds, and phytosterols.[13] They are regarded as nutraceuticals because of their high edible fibre content and low-fat content.[14]

Tamarind is an MFP that is used extensively. However, its seeds, which have good potential in the food domain, are highly underutilized.[15] The tamarind seeds contain a significant amount of protein (24.61% crude protein on a dry weight basis) and can be incorporated into various food items to enhance their protein profile.[16] The seed is also recognized for its versatile qualities and can be utilized across various industries such as food,[17] pharmaceuticals, cosmetics, and textiles.[15] The nutritional properties indicate that tamarind kernel powder is as nutritious as pulses, legumes, and major cereal crops.[18]

This research paper aims to evaluate the nutritional and nutraceutical potential of value-added products produced with these MFPs, their nutraceutical characteristics, health advantages, potential as functional foods, and their contributions to sustainable food systems.

2. Materials and methods

2.1. Materials

Bael powder, deshelled tamarind seed powder, and bamboo shoot powder were purchased from various dealers in Madhya Pradesh, Tamil Nadu, and New Delhi. They were stored at 23 ± 1 °C and 50–60% relative humidity at the Food Business Incubation Centre, NIFTEM-T, Thanjavur, Tamil Nadu, India. They were sealed in 200 gauge high-density polyethylene (HDPE) pouches, which offer low moisture vapor transmission, and stored under controlled ambient conditions to minimize moisture absorption, caking, and degradation of bioactive compounds. The analytical grade reagents utilized were all bought from Hi-media and Sigma Aldrich Pvt Ltd. Ingredients that were required to make the products were purchased locally from the Thanjavur market.

2.2. Methods

2.2.1. Raw materials. Bael powder, bamboo shoot powder, and tamarind seed powder.

2.2.1.1. Powder preparation. All three powders (bael, bamboo shoot, and tamarind seed) were sifted twice using a 0.8 mm sieve before being used to make pasta and cookies.

2.2.2. Formulation of composite flours to prepare different value-added products. The formulation of composite flours was obtained by incorporating 20% of minor forest products such as tamarind seed, bamboo shoot, and bael powder along with refined wheat flour, an incorporation level chosen to balance nutritional enhancement with desirable sensory and functional properties, while allowing room for further optimization in future studies (Fig. 1). The composite flours were used for the preparation of RTC pasta and cookies.

2.2.3. RTC pasta and cookie preparation. The pasta was made with the prepared composite flours (Fig. 2). For preparing tamarind seed pasta, initially, 350 mL of water was added to the tamarind seed composite flour. It was kneaded well, and the pasta flour mixture was fed into an extruder. The extruded pasta was steamed for 20 minutes (double boiling) and then dried for 16 hours at 55 °C in a hot air dryer to obtain RTC pasta. The same procedure was repeated for bamboo shoot pasta and bael pasta. Pasta made from 100% maida flour was considered the control.

Cookies were also made with the prepared composite flours (Fig. 2). Cookies were made by the creamery method, where 250 g of icing sugar and 250 g of fat were mixed until they got their creamery texture. Afterward, 500 g of tamarind seed composite flour was mixed with the cream mix. 5 g of baking powder and 75 mL of water were then added, followed by kneading of the dough. It was then sheeted, and the dough sheets were cut into desired shapes. Afterwards, it was baked at 120 °C for 20 min, followed by cooling, packing, and storing.

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Fig. 1 Composite flours prepared by 20% incorporation of MFPs.

Fig. 2 Value-added products prepared from the composite flours.

The same procedure was repeated for bamboo shoot cookies and bael cookies. Cookies made from 100% maida flour were considered the control.

2.2.3.1. Sample preparation. The pasta and cookies prepared were used in their original form for texture analysis, colour analysis, and cooking time (for pasta alone). For other analyses, the pasta and cookies were ground into powder form.

2.2.3.2. Proximate analysis of pasta and cookies. The ground pasta and cookie samples were estimated for their moisture, fat, ash, protein, crude fibre, carbohydrate content, and energy using the standard AOAC method as described above for the powders.[19]

2.2.3.3. Colour analysis of pasta and cookies. The L^*, a^*, and b^* values of all six products, as well as their respective controls, were recorded using a Hunter Lab Colorimeter (Colourflex EZ model: 4510, Hunter Associates Laboratory, Reston, VA).

2.2.3.4. Texture analysis of pasta and cookies. The textural properties of cookies and cooked pasta samples were measured using a texture profile analyzer (texture analyzer HD plus, Stable Microsystems, Godalming, UK). The cooked pasta samples were analyzed for hardness, gumminess, chewiness, resilience, springiness, and cohesiveness, while for cookies, breaking strength, cutting strength, hardness, and resilience were measured. Additionally, the RTC pasta sample and control were analyzed for their hardness and fracturability.

The texture profile analysis (TPA) of cookie samples was carried out using a texture analyzer operated in compression mode. An aluminum cylindrical probe (P/35, 35 mm diameter) was employed to compress the cookies at their geometric center. The test was conducted in distance mode with a deformation height ranging between 5.5 mm and 10.0 mm, corresponding to approximately 25–30% strain. The stress area was standardised at 962.11 mm^2. The crosshead speed conditions were maintained at a pre-test speed of 1.0 mm s^{-1}, a test speed of 1.7 mm s^{-1}, and a post-test speed of 10.0 mm s^{-1}. The trigger was set to auto-force mode with a threshold of 10 g to initiate

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compression. All cookie samples were analysed under these standardised conditions to ensure reproducibility and reliability of the textural measurements.

The TPA of the pasta samples was carried out using a texture analyser operating in compression mode. An aluminum cylindrical probe (P/35) with a 35 mm diameter was used for the measurements. The test was conducted in distance mode, with a target distance of 3.0 mm corresponding to 10% strain. The trigger was set to auto-force mode with a threshold of 5.0 g. The crosshead speed conditions were standardised, with a pre-test speed of 1.0 mm s^{-1}, a test speed of 2.0 mm s^{-1}, and a post-test speed of 2.0 mm s^{-1}. Data were acquired at a rate of 50 points per second to ensure accuracy and reproducibility. These parameters were uniformly applied across all the pasta samples to maintain consistency and reliability of the results.

2.2.3.5. Sensory evaluation. The sensory evaluation of the value-added products was performed in the School of Sensory Science at NIFTEM-T, Thanjavur, Tamil Nadu. A 9-point hedonic scale method was used for analyzing the samples. The analysis was performed by 50 semi-trained panellists in the age group of 18–35. The panellists evaluated the colour, flavour, texture, mouthfeel, and overall acceptability of the samples.

2.2.3.6. Cooking loss and optimal cooking time for pasta. Cooking loss was determined using the procedure presented by Ozyurt *et al.* (2015)[20] with slight modifications. In 300 mL of boiled distilled water, 10 g of pasta was added. After 20 minutes, the samples were removed and drained for 2 min. The final weight of the samples was taken, and the cooking loss was determined using the formula given below.

$$\text{Cooking loss (\%)} = [(\text{weight of drained residue})/(\text{weight of uncooked pasta})] \times 100$$

To determine OCT, 30 g of pasta was cooked with periodic stirring in 300 mL of boiling water. Samples were taken out and crushed between two transparent plates after 3 minutes. Every 30 seconds, this process was repeated until the white core vanished, indicating that the pasta was fully cooked. The OCT was the point at which there was no longer a visible white line separating the plate's crushed pasta.[21]

2.2.3.7. Quantification of minerals in RTC pasta and cookies. Analysis of major minerals, such as potassium (K), iron (Fe), and calcium (Ca), was conducted using ICP-OES equipment, following the prescribed method in the AOAC methodology[19] at the NABL-accredited food quality testing laboratory at NIFTEM, Thanjavur.

2.2.3.8. Dietary fibre analysis of RTC pasta and cookies. The analysis of dietary fibre present in pasta and cookies was performed in the NABL-accredited food quality testing laboratory at NIFTEM Thanjavur.

2.2.3.9. Quantification of vitamin C in bael pasta and cookies. The quantification of vitamin C content present in bael cookies and pasta was performed in the NABL-accredited food quality testing laboratory at NIFTEM Thanjavur.

2.2.3.10. Amino acid profiling of tamarind seed pasta and cookies

2.2.3.10.1. Sample preparation. A modified amino acid extraction method was employed, with the specific alterations described in the subsequent procedure. The samples were hydrolysed with 6 M HCl at 110 °C for 17 h. After hydrolysis, the remaining acid was removed by rotary evaporation to avoid thermal degradation of sensitive amino acids. The sample was resuspended in 25 mL of sodium citrate buffer at pH 2.2, which stabilizes the amino acids and aligns with the optimal pH conditions required for pre-column derivatization before UHPLC analysis.

2.2.3.10.2. UHPLC conditions. The amino acid is determined by the UHPLC method.[22] Instrument: Nexera UHPLC (Shimadzu) with an SIL-30AC autosampler, column: Shimpack GIST (C18), 5.0 μm (250 mm L × 4.6 mm ID), mobile phase: A: 25 mmol L^{-1} phosphate potassium buffer (pH 6.9), B: 45/40/15 acetonitrile/methanol/water, time program: B conc. 10% (0.01) → 11% (0.35 min), → 45% (35.00 min) → 100% (40.00–45.00 min), → 10% (50.00 min), flow rate: 1.0 mL min^{-1}, column temp.: 40 °C, injection volume: 10 μL, detection: RF-20Axs Ex. at 350 nm, Em. at 450 nm, → Ex. at 266 nm, Em. at 305 nm (9.0 min), cell temp.: 20 °C, and flow cell: conventional cell. The amino acid profile was performed at the NABL-accredited food quality testing laboratory at NIFTEM, Thanjavur.

2.2.3.11. Determination of total phenolic content of cookies and pasta. TPC was determined by following the procedure described by ref. 23 with some modifications.

2.2.3.11.1. Preparation of the extract. 1 g of each type of cookie and pasta along with their respective controls (all in ground form) was mixed with 10 mL of acidified aliquot (pH = 2; 0.1 M HCl) of methanol : water (1 : 1, v/v) and was kept at 30 °C in a shaker at 250 rpm overnight. After incubation, the samples were centrifuged for 10 minutes at 2800 rpm. The supernatant formed was collected and filtered using a Whatman No. 1 filter paper. The final volume was made up to 25 mL using the extracting solvent. The extraction method was done in triplicate, and the samples were also analyzed in triplicate.

2.2.3.11.2. Folin–Ciocalteu method. The TPC for all the extracts was measured using the Folin–Ciocalteu method. Initially, 1 mL of extract (100–500 μg mL^{-1}) solution was mixed with 2.5 mL of 10% (w/v) Folin–Ciocalteu reagent. After a duration of 5 minutes, 2 mL of 75% sodium carbonate was added, and the mixture was incubated at 50 °C for 10 minutes with intermittent agitation. After incubation, the cooled samples were analyzed for their absorbance using a UV Spectrophotometer (Shimadzu, UV-1800) at 765 nm against a blank without extract. The outcome was expressed as mg g^{-1} of gallic acid equivalents in milligrams per gram (mg GAE/g) of dry extract.

2.2.3.12. Determination of the antioxidant activity of cookies and pasta. The antioxidant activity of the samples was measured by following the procedure given by Rehman[24] with some modifications. 3 mL of sample (100 μg mL^{-1} methanol) was mixed with a freshly made 1 mL DPPH solution (0.004% w/v in 99% methanol). For twenty minutes, the mixture was incubated at room temperature in the dark. Following incubation, the

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mixture was vortexed, and a spectrophotometer was used to measure the absorbance at 517 nm. The reference was ascorbic acid, while the blank was 99% methanol.

2.2.3.13. Determination of the amylose and amylopectin ratio of pasta and cookies. Initially, a beaker was filled with 40.00 mg of pure potato amylose. Following the addition of 1 mL of 95% ethanol and 9 mL of 1 N NaOH, the mixture was heated for 15 minutes in a boiling water bath. After allowing the solution to reach room temperature, it was poured into a 100 mL volumetric flask. Distilled water was added to top off the solution. The solution was then divided into 1 mL, 2 mL, 3 mL, 4 mL, and 5 mL volumetric flasks and covered with aluminium foil. Then, by adding 0.2 mL, 0.4 mL, 0.6 mL, 0.8 mL, and 1 mL of 1 N acetic acid solution, respectively, a series of standard solutions were made. Following that, 2 mL of a 0.2% iodine solution was added to each flask and shaken. A UV-Vis spectrophotometer was then used to measure the absorbance of each of the prepared solutions after they had been placed in a dark box for 20 minutes. A standard curve was created and plotted against the concentration of amylose and absorbance. A 100 mL volumetric flask was filled with 5 mL of 0.09 N NaOH solution to create the blank solution. After adding 1 mL of 1 N acetic acid and iodine solution, the mixture was left in the dark for 20 minutes, and the absorbance was measured using a SHIMADZU UVmini-1240. The sample was treated in the same way, except that instead of standard amylose, 100 mg of our sample flour was used. However, rather than preparing a series of solutions, 5 mL of starch solution (samples) was reacted with 1 mL of 1 N acetic acid and 2 mL of 0.2% iodine. At 620 nm, absorbance was measured.[25]

3. Data analysis

All the experiments were repeated in triplicate, and the results are presented as mean values accompanied by their respective standard deviation (SD). The data obtained were analyzed for statistical significance employing analysis of variance (ANOVA) in Minitab software (version 20.3.0.0) at $p < 0.05$.

4. Results and discussion

4.1. Proximate composition of the value-added products

The result of the proximate composition is given in Table 1. It was observed that the control and bael pasta had similar carbohydrate content, whereas bamboo shoot pasta and tamarind seed pasta had lower amounts. In the case of cookies, the carbohydrate content of bael cookies was found to be similar to that of the control. Carbohydrates are essential for the body as they are the main source of energy, and they also contribute to maintaining blood glucose levels and improving digestive health.[26] The protein content of tamarind seed pasta and cookies was found to be the highest (higher than the control). These are essential for the growth, repair, and maintenance of body tissues.[27] It was found after amino acid profiling that tamarind seed pasta and cookies have many amino acids present in them, including essential amino acids such as lysine. These amino acids aid in various biological processes, including muscle development, immune function, and neurotransmitter synthesis.[28] The ash content of bamboo shoot pasta and cookies was found to be the highest compared to the control and the other two respective samples. The major contribution to this is the high iron content present in bamboo shoot pasta and cookies, which was observed in the results of mineral analysis. Similar results were observed in crude fibre content as well. These results were in line with the results obtained after dietary analysis, wherein it was observed that bamboo shoot pasta and cookies had the highest soluble and insoluble dietary fibre content. These are indigestible plant components that provide numerous health benefits, and they contribute to maintaining healthy digestive function by promoting regular bowel movements and preventing constipation.[29] The fat content of all three samples, both pasta and cookies, was found to be lower than their respective control, which is quite advantageous, as consumption of high-fat foods may lead to high blood cholesterol, obesity, and heart disease.[30]

4.2. Colour analysis

From the colour analysis given in Table 1, it was observed that the L^* values of bamboo shoot pasta and tamarind seed pasta do not show any significant differences. This may be because neither tamarind seed nor bamboo shoot possesses any intense colouring pigment. Additionally, the bleaching of maida flour, which is incorporated at a level of 80%, could also affect it. In the case of cookies, tamarind seed cookies and the control have similar L^* values. However, in the case of bael pasta and cookies, L^* values are much lower due to the presence of the pigment carotene.[31] In addition to the presence of pigments, the darkness of bael cookies could also be due to the baking conditions. To sum up, in the aspect of visual appearance, tamarind seed pasta, tamarind seed cookies, bamboo shoot pasta, and bamboo shoot cookies are more acceptable than bael pasta and cookies.

4.3. Texture profile analysis

4.3.1. Cooked pasta. From the texture analysis of pasta, which is given in Table 2, it was observed that the hardness, springiness, and gumminess of tamarind seed pasta are highest when compared to the control and other samples due to its polysaccharides.[15] Some studies show that the addition of polysaccharides can improve or modify the overall texture quality of pasta by strengthening the starch-gluten network, enhancing water retention and gel structure, and thereby increasing firmness and chewiness.[32] The chewiness of bamboo shoot pasta was higher than that of tamarind seed pasta and bael pasta, but less than that of the control. This is due to the fact that chewiness is related to the fibre content, which is high in the bamboo shoot.[33] These results show that consumer acceptability will be higher for tamarind seed pasta, followed by bamboo shoot pasta, and then bael pasta due to their different textural attributes.

4.3.2. RTC pasta (uncooked). Results show that the hardness of uncooked pasta is highest for bamboo shoots, followed by tamarind seed, bael, and control, respectively. This again is because of the bamboo shoot's higher fibre content.[34] In the case of tamarind seed, it is due to its polysaccharides.[35] The fracturability values of uncooked pasta are similar for both bael and bamboo

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Table 1 Proximate composition, dietary fiber content, quantification of minerals and vitamin C content, and colour profile of value-added products[a]

Parameters (g/100 g)	Maida pasta (control)	Bael pasta	Bamboo shoot pasta	Tamarind seed pasta	Maida cookies (control)	Bael cookies	Bamboo shoot cookies	Tamarind seed cookies
Moisture	8.63 ± 0.15^{a}	7 ± 0.58^{b}	6.67 ± 0.17^{bc}	5.8 ± 0.38^{c}	2.24 ± 0.03^{c}	6.28 ± 0.39^{ab}	6.69 ± 0.18^{a}	5.66 ± 0.51^{b}
Ash	2.03 ± 0.07^{c}	2.57 ± 0.12^{b}	4.72 ± 0.7^{a}	2.5 ± 0.00^{b}	0.95 ± 0.03^{c}	1.9 ± 0.53^{bc}	4.74 ± 0.71^{a}	2.5 ± 0.00^{b}
Protein	10.82 ± 0.06^{b}	4.8 ± 0.56^{d}	8.13 ± 0.04^{c}	12.61 ± 0.02^{a}	7.87 ± 0.03^{b}	4.3 ± 0.2^{d}	5.46 ± 0.54^{c}	12.62 ± 0.22^{a}
Crude fibre	0.95 ± 0.02^{c}	3.88 ± 0.29^{b}	7.99 ± 0.55^{a}	3.35 ± 0.44^{b}	0.84 ± 0.02^{c}	2.21 ± 0.3^{b}	7.69 ± 0.75^{a}	3.13 ± 0.66^{b}
Fat	0.78 ± 0.04^{a}	0.4 ± 0.41^{c}	0.61 ± 0.2^{b}	0.73 ± 0.39^{a}	27.26 ± 0.04^{a}	25.46 ± 0.12^{b}	20.43 ± 0.3^{c}	24.46 ± 1.27^{b}
Carbohydrates	76.78 ± 0.12^{a}	77.75 ± 1.76^{a}	71.89 ± 1.05^{b}	72.41 ± 0.44^{b}	60.84 ± 0.07^{a}	59.84 ± 0.71^{a}	54.99 ± 0.26^{b}	51.63 ± 1.14^{c}
Energy (kcal)	357.6 ± 0.72^{a}	367.5 ± 0.20^{a}	325.6 ± 4.22^{b}	370.1 ± 4.66^{a}	520.2 ± 0.56^{a}	485.7 ± 2.99^{b}	425.7 ± 1.90^{c}	477.2 ± 16.45^{b}
Insoluble DF	0.05 ± 0.01^{h}	3.09 ± 0.03^{e}	16.67 ± 0.03^{c}	0.78 ± 0.03^{g}	7.06 ± 0.04^{d}	18.14 ± 0.04^{b}	19.05 ± 0.04^{a}	1.97 ± 0.03^{f}
Soluble DF	1.5 ± 0.03^{f}	4.72 ± 0.03^{c}	5.5 ± 0.03^{b}	0.2 ± 0.02^{h}	2.17 ± 0.03^{e}	3.75 ± 0.02^{d}	6.42 ± 0.03^{a}	0.38 ± 0.02^{g}
Total DF	1.55 ± 0.02^{g}	7.81 ± 0.03^{e}	22.17 ± 0.03^{b}	0.98 ± 0.02^{h}	9.23 ± 0.03^{d}	21.89 ± 0.03^{c}	25.47 ± 0.03^{a}	2.35 ± 0.03^{f}
K (ppm)	2164.43 ± 0.86^{d}	5686.07 ± 1.1^{a}	1944.13 ± 1.06^{f}	BDL	2331.9 ± 0.79^{c}	3157.33 ± 0.76^{b}	2110.17 ± 1.26^{e}	BDL
Ca (ppm)	28.87 ± 0.16^{b}	BDL	0.2 ± 0.01^{f}	1.91 ± 0.02^{d}	51.67 ± 0.16^{a}	BDL	0.97 ± 0.02^{e}	2.4 ± 0.02^{c}
Fe (ppm)	17.67 ± 0.16^{e}	BDL	25.8 ± 0.1^{a}	22.1 ± 0.1^{b}	19.2 ± 0.1^{d}	BDL	20.1 ± 0.1^{c}	19.17 ± 0.16^{d}
Vitamin C (mg/100 g)	0.21 ± 0.01^{b}	52.8 ± 0.1^{a}	BDL	BDL	0.11 ± 0.01^{b}	53 ± 0.2^{a}	BDL	BDL
L^*	54.73 ± 0.32^{a}	19.98 ± 0.49^{c}	52.17 ± 1.16^{b}	51.41 ± 3.36^{b}	64.3 ± 1.67^{a}	37.31 ± 2.72^{c}	51.12 ± 1.56^{b}	58.59 ± 3.36^{a}
a^*	3.56 ± 0.17^{b}	4.76 ± 0.1^{a}	2.64 ± 0.14^{c}	3.79 ± 1.76^{b}	5.23 ± 0.66^{c}	13.11 ± 0.41^{a}	10.86 ± 0.46^{a}	8.28 ± 1.75^{b}
b^*	24.98 ± 0.31^{a}	6.48 ± 0.08^{d}	13.85 ± 0.4^{c}	14.66 ± 0.6^{b}	21.15 ± 1.02^{a}	16.44 ± 1.82^{b}	19.71 ± 0.19^{a}	19.75 ± 0.6^{a}

[a] The presented values represent the mean ± standard deviation of observations that were performed in triplicate. The values with identical letters within a row do not indicate statistical significance ($P \le 0.05$). BDL: below detection limits.

Table 2 Texture profile of cooked pasta and RTC pasta[a]

Parameters	Cooked maida pasta (control)	Cooked bael pasta	Cooked bamboo shoot pasta	Cooked tamarind seed pasta	RTC maida pasta (control)	RTC bael pasta	RTC bamboo shoot pasta	RTC tamarind seed pasta
Hardness (g)	240.009 ± 0.16^{b}	210.89 ± 0.22^{c}	207.27 ± 0.20^{d}	283.258 ± 0.08^{a}	2062.49 ± 2.18^{d}	2291.27 ± 1.99^{c}	6163.10 ± 2.04^{a}	4357.35 ± 2.33^{b}
Springiness (mm)	0.994 ± 0.13^{a}	0.94 ± 0.09^{a}	0.954 ± 0.08^{a}	1.01 ± 0.12^{a}	—	—	—	—
Cohesiveness (%)	0.669 ± 0.08^{c}	0.833 ± 0.11^{b}	1.158 ± 0.40^{a}	0.783 ± 0.10^{bc}	—	—	—	—
Gumminess (g)	201.112 ± 0.15^{b}	175.6 ± 0.24^{d}	188.794 ± 0.23^{c}	221.765 ± 0.19^{a}	—	—	—	—
Chewiness (g)	205.642 ± 0.25^{a}	165.064 ± 0.17^{c}	195.002 ± 0.19^{b}	165.064 ± 0.21^{c}	—	—	—	—
Resilience (g)	0.523 ± 0.08^{a}	0.479 ± 0.18^{a}	0.503 ± 0.09^{a}	0.56 ± 0.13^{a}	—	—	—	—
Fracturability (mm)	—	—	—	—	0.15 ± 0.09^{c}	0.53 ± 0.03^{b}	0.48 ± 0.06^{b}	0.83 ± 0.03^{a}

[a] The presented values represent the mean ± standard deviation of observations that were performed in triplicate. The values with identical letters within a row do not indicate statistical significance ($P \le 0.05$).

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Table 3 Texture profile of cookies[a]

Parameters	Maida cookies (control)	Bael cookies	Bamboo shoot cookies	Tamarind seed cookies
Hardness (g)	4760 ± 0.11^{d}	6626 ± 0.16^{b}	9125 ± 0.09^{a}	6035 ± 0.08^{c}
Cutting strength (N)	29.74 ± 0.14^{d}	33.443 ± 0.16^{b}	36.762 ± 0.2^{a}	32.456 ± 0.17^{c}
Breaking strength (N)	31.78 ± 0.17^{b}	32.781 ± 0.13^{a}	25.815 ± 0.16^{c}	31.994 ± 0.15^{b}
Resilience (N m)	0.0996 ± 0.04^{a}	0.1056 ± 0.03^{a}	0.1734 ± 0.02^{a}	0.1295 ± 0.03^{a}

[a] The presented values represent the mean ± standard deviation of observations that were performed in triplicate. The values with identical letters within a row do not indicate statistical significance ($P \leq 0.05$).

shoot pasta, and the fracturability of tamarind seed pasta is the highest. It may be due to the reduced, stronger internal structure of pasta samples. The greater the breaking force, the greater its preference due to its intactness during cooking and storage.[36]

4.3.3. Cookies. Texture analysis of cookies shows that bamboo shoot cookies have the highest hardness values when compared to the control, bael, and tamarind seed cookies (Table 3). Moreover, bael and bamboo shoots have similar hardness values. This depends on the baking conditions, the makeup of starch, and interactions between the starch and proteins.[37] The results of cutting strength show that the bamboo shoot cookies have the highest cutting strength value when compared to the other three samples, including the control (lowest). This may be because of the water content incorporated in the dough of the samples and the presence of fibre that tends to retain more water.[38] Bael cookies appear to have a higher breaking strength, followed by tamarind seed cookies and control cookies, having similar values. Trends in the breaking strength may account for the sugar crystallization that follows the glassy solid state after the baking, which results in the breaking strength of the biscuits.[39] All three sample textural parameters lie within the consumer acceptability and have quite good textural qualities.

4.4. Sensory evaluation

Sensory properties like texture, colour, flavour, and mouthfeel were evaluated, and the overall acceptability was evaluated. The results are shown in Fig. 3. Control pasta had the highest score in all of the attributes, especially in texture (8.6) and overall acceptability (8.4). Bamboo shoot pasta had a high score among the experimental samples with an overall acceptability of 7.2, texture 7.4, and flavour 6.9. It was the most comparable to the control and preferred by most panellists. The tamarind seed pasta was next with a chewier texture (6.6), good mouthfeel (6.8), and an overall acceptability of 6.9. Conversely, bael pasta scored the lowest in all sensory parameters, especially in flavour (5.4) and overall acceptability (6.0). Some panellists indicated that it might be possible to mask its undesirable flavour profile by adding flavour-enhancing agents like saffron, cinnamon, or cardamom. There was a similar trend in the cookies as well. Control cookies received the highest overall acceptability score (8.6). Its texture (8.4) and flavour (8.2) were also rated well. Tamarind seed cookies were the most popular among the supplemented cookies (overall acceptability 8.0, flavour 7.8, and mouthfeel 7.5), because of their pleasant toasty flavour, and bamboo shoot cookies had satisfactory scores as well (overall acceptability 7.3 and texture 7.1). However, bael cookies were rated lower (overall acceptability 6.7 and flavour 6.4), though

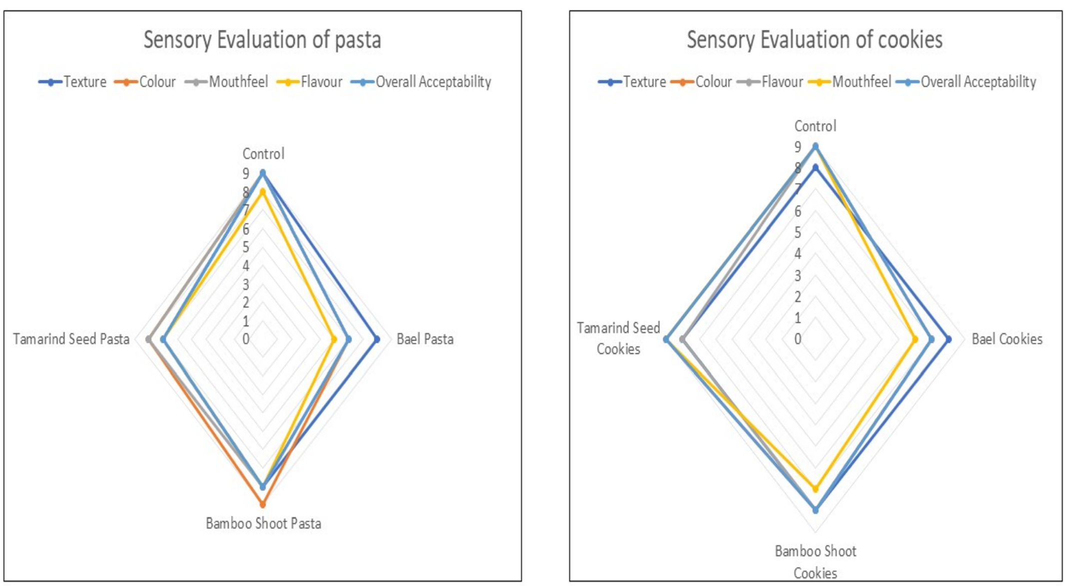

Fig. 3 Sensory evaluation of pasta and cookies.

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Table 4 Cooking loss and optimum cooking time of pasta

Product	Optimum cooking time (min)	Cooking loss (%)
Maida pasta (control)	13	6.87
Bael pasta	14	8.7
Bamboo shoot pasta	14	6.93
Tamarind seed pasta	14	7.01

still acceptable to some panellists. In general, tamarind seed cookies are more acceptable, followed by bamboo shoot cookies.

The perceived lower palatability of bael-based products is not only due to their sensory perception but also their phytochemical composition. Panellists often reported a unique medicinal or herb-like taste in bael pasta and cookies, characterised by their astringency and mild bitterness. This correlates with the previously identified bioactive constituents in bael, which contain coumarins (marmelosin, marmesin, scoparone, and scopoletin), tannins, flavonoids, and alkaloids, all of which are linked with bitter-astringent flavor profiles and herbaceous mouthfeel.[40,41]

4.5. Cooking loss and optimum cooking time (OCT) of pasta

From the results, which are shown in Table 4, it was noted that cooking loss ranges from 6.87% to 8.70%. Cooking loss below 12% is regarded as a marker of good-quality pasta, and all samples met this standard, confirming their superior quality.[42] The reduced cooking loss, compared to the control, can be attributed to molecular networking, starch gelatinization, and protein–starch interactions formed during extrusion.[43] In contrast, the control pasta showed greater loss, likely due to its finer particle size and gluten content.

Studies show that cooking time also depends on starch gelatinization.[42] Tabulated results reveal that the cooking time of control pasta is 13 minutes, which is again because of its fine structure and high gluten content, and for other bael, bamboo shoot, and tamarind seed pasta, it took 14 minutes to cook. Furthermore, it has been observed that bael pasta breaks its structure while cooking and needs more optimization. Cooking time may not vary since only a level of 20% incorporation is done, which does not have a significant impact.

4.6. Quantification of minerals and vitamin C content of pasta and cookies

From Table 1, it was concluded that the potassium content of the bael pasta (5686.70 ppm) and cookies (3157.66 ppm) is the greatest, followed by that of their respective control samples (2164.43 ppm and 2331.91 ppm, respectively). It can also be observed that the controls have the highest amount of calcium (28.86 ppm and 51.66 ppm, respectively), followed by our samples. The calcium content did not increase with the incorporation of tamarind seed powder, bamboo shoot powder, and bael powder. This indicates that further optimization of the samples is required. Bamboo shoot pasta and cookies have the highest amount of iron (25.81 ppm), followed by tamarind seed samples and control samples. Iron is known to promote sleep, prevent anaemia,[44] and strengthen the immune system. The RDA of potassium is 3000 mg kg^{-1}, calcium is 1000 mg kg^{-1}, and iron is 18 mg kg^{-1}.[45] It can be said that the incorporation level can be increased to 40% for optimization to meet the RDA requirements. However, the sensory properties may get affected, and hence the processing should be standardized for better results. In the case of vitamin C, bael pasta and cookies have a significantly higher value (52.8 mg/100 g and 52.99 mg/100 g, respectively) than the control sample (0.21 mg/100 g). The RDA of vitamin C is 100–120 mg.[46] Compared to orange juice, which is a popular product with a vitamin C content of 15–45 mg/100 g, the bael-based products with only 20% had quite high amounts of vitamin C.[47] Thus, we can conclude that our minor forest products have their unique contribution to providing health benefits. For example, bael and bamboo shoot pasta are rich in potassium, which can aid in blood pressure regulation; similarly, bael pasta has abundant vitamin C content, which can boost the immune system of our body.

4.7. Dietary fibre content of pasta and cookies

From the dietary fibre analysis, it was noted that bamboo shoot pasta (22.17 mg/100 g) and cookies (35.47 mg/100 g) have the highest total dietary fibre compared to the control and other samples (Table 1). The insoluble dietary fibre content was 16.67 mg/100 g in bamboo shoot pasta and 29.05 mg/100 g in cookies. Similar results were observed in their soluble dietary fibre content as well (5.50 mg/100 g and 6.42 mg/100 g, respectively). This was followed by bael pasta and cookies. This significant increase in the dietary fibre content of bamboo shoots and bael pasta, and cookies is mainly due to the high amount of cellulose, hemicellulose, and lignin.[48] These factors can improve the textural properties and stabilize the structure of the food products. The 20% incorporation of bael, bamboo shoots, and tamarind seed flour is more suitable since it shows a significant increase in dietary fibre with acceptable sensory properties. Additionally, the RDA for dietary fibre is 25–30 g, whereas the RDA of soluble dietary fibre is 6–8 g, and that of insoluble dietary fibre is 19–22 g.[46] They contribute to many health benefits, like lowering cholesterol, controlling blood sugar, preserving intestinal health, and maintaining weight.[49] From this, it is safe to conclude that bamboo shoot pasta almost meets the RDA requirements of dietary fibre, thus increasing its potential to become a functional food.

4.8. Amino acid profile of tamarind seed pasta and tamarind seed cookies

The amino acids present in tamarind seed pasta and cookies are lysine, glutamic acid, aspartic acid, and traces of histidine, alanine, phenylalanine, arginine, and serine, as shown in Table 5. The results show that the amount of lysine and phenylalanine in the control was more compared to tamarind seed pasta. In the case of cookies, lysine, histidine, and aspartic acid were found to be higher for the control compared to the tamarind seed cookies, with the amount of lysine being the

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Table 5 Amino acid profile of tamarind seed pasta and cookies

Amino acid	Maida pasta (control) (mg g^{-1})	Tamarind seed pasta (mg g^{-1})	Maida cookies (control) (mg g^{-1})	Tamarind seed cookies (mg g^{-1})
Lysine	0.0374 ± 0.0006^{a}	0.0293 ± 0.0004^{a}	0.0279 ± 0.0003^{a}	0.0188 ± 0.0003^{a}
Glutamic acid	0.0062 ± 0.0003^{b}	0.0078 ± 0.0001^{b}	0.0044 ± 0.0002^{b}	0.0042 ± 0.0002^{b}
Aspartic acid	0.0043 ± 0.0001^{c}	0.0056 ± 0.0002^{c}	0.0025 ± 0.0001^{c}	0.0022 ± 0.0001^{cd}
Phenylalanine	0.0029 ± 0.0001^{d}	0.0026 ± 0.0001^{f}	0.0016 ± 0.0001^{d}	0.0018 ± 0.0001^{d}
Histidine	0.0026 ± 0.0001^{d}	0.0043 ± 0.0002^{d}	0.0026 ± 0.0001^{c}	0.0025 ± 0.0001^{c}
Alanine	0.0016 ± 0.0001^{e}	0.0033 ± 0.0002^{e}	0.0018 ± 0.0001^{d}	0.0023 ± 0.0002^{c}
Arginine	0.001 ± 0.0001^{ef}	0.0004 ± 0.0001^{g}	0.0008 ± 0.0001^{e}	0.0009 ± 0.0001^{e}
Serine	0.0005 ± 0.0001^{f}	0.0003 ± 0.0001^{g}	0.0003 ± 0.0001^{f}	0.0003 ± 0.0001^{f}

highest when compared with other amino acids in protein profiling. After the incorporation of 20% tamarind seed composite flour for preparing the pasta, the overall protein increment was observed to be 16.54%. In terms of increment in amino acids, glutamic acid showed a 25.80% increment, aspartic acid showed a 30.23% increment, and histidine showed a 65.38% increment. There was an increment of 106.25%, 60%, and 40% in alanine, arginine, and serine, respectively. In the case of tamarind seed cookies, the protein increment was observed to be 7.59%. It can be said that for a 7.59% increment in protein, the amino acid increase is 4.65% for glutamic acid, 12% for aspartic acid, and 12.5% for both phenylalanine and arginine, while in the case of serine, there is neither a decrease nor an increase. To get further increments in other amino acids which are below the detectable level and also to increase the amino acids that are already present, the incorporation level can be increased to 40% with proper optimization.

In comparison with WHO/FAO adult essential amino acid requirement recommendations (mg/kg body weight/day), *e.g.*, lysine 30 mg kg^{-1} day^{-1} and phenylalanine & tyrosine 25 mg^{-1} kg^{-1} day^{-1}, our fortified foods, although lower than the control for lysine, make a substantial contribution to these daily intakes when eaten as part of a balanced diet.[50] Compared to lentil-fortified pasta, which was found to increase lysine from 0.31 mg g^{-1} in control to 1.28–1.72 mg g^{-1} in fortified samples (4 to 5 times higher),[51] our tamarind seed pasta shows a modest but considerable rise in the amino acid profile. Furthermore, legume-fortified pasta preparations (*e.g.*, 10–15%) have shown a 60–88% rise in lysine and 10–33% in threonine, *i.e.*, our 20% tamarind seed incorporation is closely aligned with the existing legume-based fortification level.[52]

4.9. Total phenolic content of pasta and cookies

As shown in Table 6, the TPC values of pasta samples ranged from 210.50 to 2981.75 mg GAE/100 g, whereas for the cookie sample, they ranged from 254.25 to 2027.58 mg GAE/100 g. Based on the results, bael pasta (2981.75 mg GAE/100 g) and cookies (2027.58 mg GAE/100 g) had the greatest TPC. Thus, the TPC of bael pasta and cookies was found to be statistically much higher than that of the other two samples and the control, which is explained by the fruits' numerous anti-nutritional qualities that may be beneficial to human health. The rest of the pasta samples, like bamboo shoot pasta and tamarind seed pasta, also have a higher value than the control, which shows that they can be good sources of dietary phenolics. For optimization, bamboo shoot powder, bael, and tamarind seed powder can be incorporated at 20% since they show a good increment in phenolic content while maintaining the sensory qualities. These phenolic chemicals have several benefits, including the ability to protect against cardiovascular disease and anti-cancer properties.[53]

4.10. Total antioxidant activity of pasta and cookies

The antioxidant values of pasta ranged from 5.67 to 19.39 μg mL^{-1}, where it was observed that bael pasta possesses the

Table 6 TPC analysis, antioxidant activity, amylose, and amylopectin ratio of pasta and cookies[a]

Product	TPC (mg GAE/100 g)	Antioxidant activity (μg mL^{-1})	Amylose (%)	Amylopectin (%)
Maida pasta (control)	210.5 ± 10^{b}	13.9 ± 0.93^{d}	50.29	49.71
Bael pasta	2981.75 ± 171.7^{a}	46.7 ± 0.45^{a}	70.37	29.63
Bamboo shoot pasta	223 ± 10^{b}	17.9 ± 0.63^{b}	51.77	48.23
Tamarind seed pasta	257.58 ± 42.84^{b}	15.69 ± 0.14^{c}	64.1	35.9
Maida cookies (control)	273 ± 8.75^{b}	5.65 ± 0.37^{d}	63.7	36.3
Bael cookies	2027.58 ± 80.66^{a}	19.39 ± 0.99^{a}	83	17
Bamboo shoot cookies	254.25 ± 20.65^{b}	9.08 ± 1.35^{c}	64.66	35.34
Tamarind seed cookies	284.25 ± 17.32^{b}	11.98 ± 0.51^{b}	60.44	39.56

[a] The presented values represent the mean ± standard deviation of observations that were performed in triplicate. The values with identical letters within a column do not indicate statistical significance ($P \leq 0.05$).

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highest value (Table 6). Similar results were observed in the case of cookies as well. It shows that bael has excellent antioxidant activity due to its antioxidant compounds.[5] The control pasta and cookies, which are made up of maida, have less antioxidant activity compared to all the samples and hence cannot be considered as functional as the others. Furthermore, because all the pasta and cookie samples exhibit higher antioxidant activity and improve overall attributes, they have strong potential to serve as functional foods.[54] The reason for the higher antioxidant activity of bael could be attributed to its high phenolic content when compared to bamboo shoots, tamarind seed, and the control. Thus, it is safe to conclude that bael pasta and cookies have the potential to become antioxidant-rich products by optimization and increasing their incorporation.

4.11. Amylose and amylopectin ratio of pasta and cookies

Table 6 illustrates the notable variations in the formulation's amylose and amylopectin amounts. It is observed that the control pasta had the lowest amylose level (50.29%) and the highest amylopectin level (49.71%), whereas bael pasta had the highest amylose level (70.31%) and the lowest amylopectin level (29.63%). Conversely, the values of the bamboo shoot pasta and tamarind seed pasta were 51.77% and 64.10% for amylose and 48.23% and 35.90% for amylopectin, respectively. In the case of cookies, bael cookies had the highest amylose content (83%) and the lowest amylopectin content (17%), whilst the tamarind seed cookies had the lowest amylose content (60.44%) and the highest amylopectin content (39.56%). The bamboo shoot cookies and control cookies, on the other hand, had values of 64.66% and 63.7% amylose and 35.34% and 36.3% amylopectin, respectively. Because of its linear starch structure, amylose reduces stickiness and enhances the cooking quality of pasta as it gets cooked. On the other hand, because it is easily absorbed, a high amylopectin level might produce a sticky and wet product, which is undesirable.[28] As a result, the optimum amylose values in all of the pasta and cookie samples, which are more than 50%, contribute to their appealing sensory qualities. Also, when considering the amylose to amylopectin ratio, it has been said that a higher amylose to amylopectin ratio lowers the glycemic index, which means that they cause a slower and more gradual increase in blood sugar levels when consumed compared to food with a higher glycemic index. A lower glycemic index is preferred due to its ability to prevent blood sugar level spikes.[40] All of the pasta and cookie samples show a higher amylose to amylopectin ratio than the control pasta, which ultimately shows it has a low glycemic index when compared to the control.

5. Conclusion

According to the detailed analysis, the potential of bael, bamboo shoot, and tamarind seed powders as nutritional enhancers in pasta and cookies is high. The bael-enriched products are a good source of potassium, vitamin C, and antioxidants, but their darker colour and poor sensory acceptance suggest the need to improve formulation. Bamboo shoot incorporation provides high fiber content and desirable chewiness in pasta, while cookies exhibit superior hardness and structural integrity—qualities attributed to their starch–protein–fiber matrix. The addition of tamarind seed powder significantly increased the amount of protein, particularly in pasta, and led to the formation of firm, chewy textures that were well accepted by the consumers. Analysis of dietary fibers confirmed the higher presence of fiber in the bael and bamboo shoot products, and protein profiling validated the role of tamarind seeds in the enhancement of amino acids. Higher amylose content in all enriched pasta samples enhanced the non-stick texture. Overall, these indigenous ingredients enhance both the nutritional and functional qualities of food products, and further optimization of their incorporation and processing could increase their value as sustainable functional foods. Moreover, these ingredients promote sustainable food systems as well. The use of these MFPs in value-added products will help minimise the use of resource-intensive ingredients and valorise by-products such as tamarind seeds. Furthermore, the local sourcing of these ingredients can lead to the empowerment and betterment of rural communities and their livelihoods, as well as the promotion of circular economy practices. The future research should be directed at optimization of formulation, sensory improvement, and scalability testing. Pilot studies are also required to evaluate their practicality in real-world food systems. The research will assist in creating resilient, inclusive, and health-promoting food environments through the promotion of functional and sustainable innovations.

Author contributions

Midhun J: data curation; formal analysis; investigation; methodology; validation; writing – original draft. Muthamil Selvi K: data curation; formal analysis; investigation; methodology; validation; writing – original draft. Neethi Sri S: data curation; formal analysis; investigation; methodology; validation; writing – original draft. Tamminana Jeeviteswara Rao: investigation; methodology; validation; writing – original draft, review, and editing. Addanki Mounika: investigation; methodology; validation; writing – original draft, review, and editing. Shanmugam Akalya: conceptualization; design of experiments; project administration; supervision; writing – review and editing.

Conflicts of interest

The authors declare no competing interests.

Data availability

The data supporting this article, including the experimental datasets and analysis results, are available with the article at the Royal Society of Chemistry under DOI: **https://doi.org/10.1039/D5FB00285K**.

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