Mysore J. Agric. Sci., 59 (1) : 278-291 (2025)

Development and Quality Evaluation of Foxtail Millet (*Setaria italica*) Based Extruded Product

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Received : September 2024
Accepted : November 2024

Abstract

Foxtail millet (*Setaria italica*) is an underutilized grain with rich nutritional value, offering significant potential in developing health-oriented products. This study was undertaken to develop and evaluate foxtail millet-based extruded pasta for physical, nutritional, sensory and biochemical properties. Four formulations were standardized by incorporating varying levels of foxtail millet and whole wheat flour along with control [T_1 (25% millet), T_2 (50% millet) and T_3 (75% millet)]. Sensory attributes revealed that the control pasta (100% wheat flour) had the highest overall acceptability (7.90) with scores for appearance, color, texture, aroma and taste higher than those of millet-enriched products and T_3 (75% millet) had the lowest acceptability (6.40). The proximate composition indicated that foxtail millet pasta (T_2 - 50% millet) had highest fiber (3.71 g) and fat (1.55 g) compared to the control but lower moisture (7.92%), protein (13.68 g) and carbohydrate content (71.72 g). Furthermore, foxtail millet pasta (T_2 - 50% millet) showed good levels of minerals such as iron (4.22 mg), copper (0.66 mg) and zinc (3.39 mg), though it had lower potassium and magnesium than the control pasta. Antinutritional factors like phytic acid were higher in foxtail millet pasta (675.83 mg/100g). Cooking quality was comparable with millet-based pasta requiring less cooking time (7.30 min) but showed higher solids loss (12.23%) than wheat pasta. Over a 90-day storage period, foxtail millet pasta exhibited lower bacterial growth (2.75×10^4) compared to the control (3.58×10^4), whereas yeast and molds were in within permissible limits. Biochemical changes in moisture, free fatty acids and peroxide values increased over time but remained within permissible limits, indicating good storage stability. Overall, the study suggested that foxtail millet-based extruded products offers a nutritionally superior alternative to conventional wheat pasta.

Keywords : Foxtail millet, Extruded product, Proximate composition, Minerals, Antinutrients, Cooking quality

The global food landscape is evolving rapidly driven by changing consumer lifestyles, increased urbanization and the growing need for convenient yet nutritious food options. As people become more aware of the broader health benefits of their choices, the demand for nutritious and functional foods has risen significantly. Traditional foods, while rich in cultural heritage and nutritional value are often time-intensive to prepare and may not align with the fast-paced modern lifestyle. In contrast, convenience foods have surged in popularity due to their ease of preparation, long shelf life and the ability to cater to the time constraints of today's consumers. Among these, extruded products such as pastas, vermicelli, ready-to-eat snacks, breakfast cereals, baby foods etc., have become particularly popular (Yadav and Chandra, 2015). The extrusion process, a versatile and cost-effective food processing technology, allows for the creation of novel food products with desirable sensory and nutritional qualities.

Nutri-cereals, known for their mildly sweet, nut-like flavor, offer a wide array of essential nutrients, making them a valuable addition to a balanced diet. Small millets in particular are rich in protein (8.92-12.50%), carbohydrates (60-70%) and are an excellent source of dietary fiber (Dayakar Rao *et al.*, 2017). Despite the well-documented nutritional benefits of small millets (Sarita and Singh, 2016), their use as food remains largely limited to traditional consumers, especially within tribal populations. This is primarily due to the lack of readily available, consumer-friendly products, unlike those made from rice and wheat. However, in recent years, small millets have gained attention as high-fiber foods, prompting efforts to develop convenient, ready-to-use and ready-to-eat products to increase their consumption and accessibility (Yadagouda and Ravindra, 2022).

Small millets, also known as nutri-cereals, have historically been underutilized in both cultivation and consumption despite their impressive nutritional profiles. Among these, foxtail millet (*Setaria italica*) or Italian millet, stands out due to its rich history and significant health benefits. Originally domesticated in China, this ancient grain has adapted well to temperate climates and is now cultivated across diverse regions, including the Korean Peninsula, Southern Europe, India, Bangladesh and Indonesia (Hegde *et al.*, 2005 and Shobha *et al.*, 2021). In 2019-2020, India's minor millet production was 370.81 ('000 Tonnes), with Karnataka, Andhra Pradesh and Tamil Nadu leading in area and yield (Anonymous, 2021). Foxtail millet is particularly valued for its high iron and calcium content, which is essential for bone and muscle health. It contains approximately 12.3 per cent protein and 3.3 per cent minerals along with highest thiamine content 0.59 mg/100 g. Traditionally, foxtail millet has been used in medicinal practices as an emollient, astringent and stomachic, providing remedies for dyspepsia and food stagnation (Him-Che, 1985). Its gluten-free nature, coupled with a rich protein content and low carbohydrate levels, makes foxtail millet an ideal food for supporting heart health, managing diabetes, controlling cholesterol levels and promoting nervous system health.

Despite its benefits, foxtail millet is underutilized in contemporary diets, largely due to a lack of awareness and its perceived inconvenience in preparation. This research seeks to harness the nutritional advantages of foxtail millet through extrusion technology, transforming it into a convenient, ready-to-cook form that appeals to modern dietary preferences. Moreover, the incorporation of foxtail millet into extruded products aligns with the current trend of using ancient grains in food innovation, driven by consumer demand for healthier alternatives to refined grains. By utilizing foxtail millet, this study explores the development and quality evaluation of a foxtail millet based extruded product, aiming to combine the nutritional benefits of traditional grains with the convenience of modern food processing techniques.

Material and Methods

Procurement of Raw Materials

The popular variety, foxtail millet (GPUF 3) selected for the study was procured from All India Coordinated Research Project on Small millets, Zonal Agricultural Research Station, University of Agricultural Sciences, Bangalore and whole wheat flour was procured from Bengaluru Yelahanka local market. Foxtail millet was cleaned and then made into flour by using a pulverizer and passed through sieve to get a fine and uniform flour and stored in the cool and dry atmosphere for further experiments.

Single Screw Extruder

The extruder used for this experiment was laboratory single-screw extruder (make: La Monferinna, Italy; model: P12) with an automatic mixing, kneading and extruding facility in one go. It consists of a main unit, mixing chamber, mixer, container lid, front panel, knob and specially designed 'shaping dies' to create noodles or pasta in different shapes namely, macaroni, linguine, tagliatelle etc. It can be easily dismantled for cleaning purposes. It takes about 10-15 minutes to extrude the product (noodle/pasta).

Formulation and Preparation of Foxtail Millet Pasta

Four different formulations of pasta were prepared. One formulation was prepared without foxtail millet (control) and remaining three variations were formulated with foxtail millet at different substitutional levels *i.e.*, T_1 (25% millet flour and 75% wheat flour), T_2 (50% millet flour and 50% wheat flour) and T_3 (75% millet flour and 25% wheat flour) as shown in Table 1.

The foxtail millet-based cold extruded pasta products were manufactured by following the systematic procedure advocated by the pasta machine manufacturer. The sieved flours of milletand wheat were first blended and kneaded (in the machine itself) for 15 min by adding optimum quantity of water. The quantity of water was decided based on manufacturer recommendations. When the dough characteristic was optimum, it was extruded using appropriate 'dies' (Macaroni shape). The cutter speed was set to optimum level depending upon the shape of the final product. The extruded pasta was collected in trays, then dried in a convective hot air oven at 50°C for about 3 hours to obtain translucent pasta. The products were then packed in metalized polyester packaging material, thermally sealed and stored at ambient

TABLE 1

Formulation of foxtail millet-based pasta

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

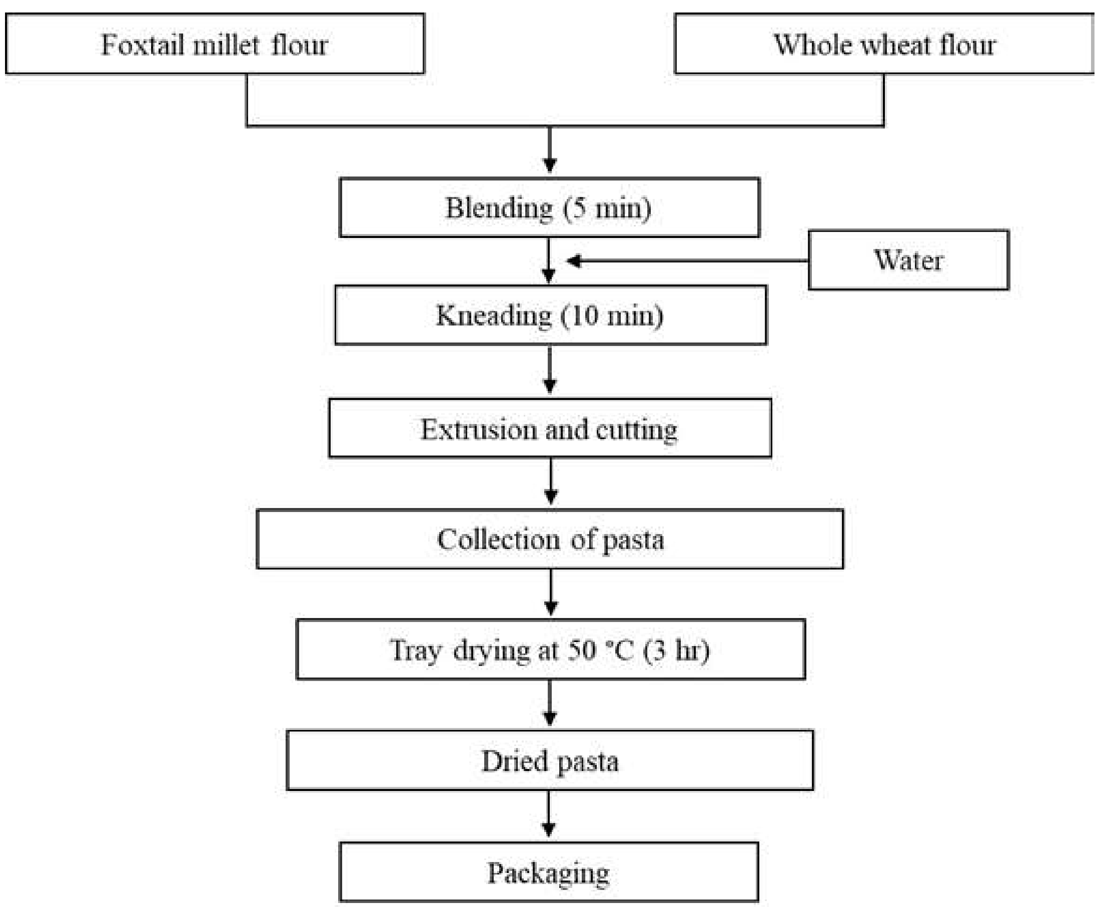

Fig. 1 : Process flow chart for production of foxtail millet based pasta

conditions. The complete flow chart for the production of nutri-cereals based cold extruded ready-to-cook pasta (Fig. 1).

Organoleptic Evaluation

The developed pasta was utilized for evaluation by a panel of minimum semi-trained individuals from the Department of Food and Nutrition, University Agricultural Sciences, Bangalore for their sensory qualities. The panelists scored pasta prepared from foxtail millet based on their appearance, colour, texture, taste, flavor and overall acceptability by using nine-point Hedonic rating scale (Nicolaset *et al*., 2010), where 9 indicated 'like extremely' and 1 indicated 'dislike extremely'.

Proximate Composition

The best pasta made from foxtail millet and a control from whole wheat flour were analyzed for micronutrients and macronutrients using AOAC methods (2005). Moisture and ash content were determined gravimetrically with moisture measured after oven drying and ash through reduction in a muffle furnace. Total fat was extracted using a Sox Plus apparatus and protein was calculated from nitrogen content *via.,* Kjeldahl titration, applying a 6.25 conversion factor. Carbohydrate content and energy values were determined using the difference method, providing a comprehensive nutritional profile.

Estimation of Minerals

The mineral analysis of foxtail millet-based pasta and control (whole wheat pasta) was conducted following AOAC methods (2005). The pasta samples were homogenized into powder and one gram of each was digested in a di-acid mixture (9:4 mixture of HNO_3: $HClO_4$) on a hot plate until a snow-white residue formed or the liquid became colourless. After cooling, the solution was diluted and filtered. Atomic absorption photometry was used to estimate copper, manganese, iron and zinc. Calcium and Magnesium were determined by titration method. Potassium and sodium by flame photometry and phosphorus by spectrophotometry.

Determination of Anti-Nutrients

The anti-nutrients such as total polyphenols, tannins and phytates were estimated for control pasta and best foxtail millet pasta. The methods followed for antinutrient analysis are as follows.

Estimation of Phytic Acid (Gao *et al.*, 2007)

About 50 mg sample was weighed into a microfuge tube, followed by the addition of 1 mL of 2.4 per cent HCl. The mixture was shaken on a mechanical shaker at room temperature for 16 hours at 220 rpm and then centrifuged at 1000 g at 10 °C for 20 minutes. Fresh tubes containing 25 mg of NaCl were used to collect the supernatant, which was then 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 at a 3:1 ratio, vortexed and centrifuged. Absorbance was measured at 500 nm.

$$\text{Calculation PA-P (mg/g)} = \frac{\text{X value} \times \text{Vol. taken for extraction (ml)} \times \text{Dilution factor}}{\text{Weight of sample (mg)}} \times 1000$$

Estimation of Tannins (AOAC, 2005)

One mL of extract was taken in 100 mL volumetric flask to which five mL of folin-denis reagent and 10mL of sodium carbonate solution was added. The contents were mixed and diluted to 100mL using distilled water and allowed to stand for 30 minutes and absorbance was measured at 760 nm. The tannin content of the samples was calculated as tannic acid equivalents from the standard graph.

$$\text{Tannins \%} = \frac{\text{Tannic acid (mg) x Dilution x100}}{\text{Sample taken for colour development (ml) x Weight of sample (g)}} \text{ x } 100$$

Estimation of Total Polyphenols (AOAC, 2005)

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 $Na_2 Co_3$ and incubate at 37°C for 60 minutes. Read the resulting blue colour complex at 765 nm

$$\text{Total polyphenols} = \frac{\text{Conc. of polyphenol mg/100g sample from graph}}{\text{Aliquot taken for estimation}} \times 5 \times \frac{100}{\text{Wt. of sample}} \times \frac{1}{100}$$

Cooking Quality

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

Optimum Cooking Time

The control pasta and foxtail millet-based pasta products (10 g) were cooked in boiling water (100 mL) over a gas stove. The optimum cooking time of pasta was determined subjectively by pressing the product between fingers periodically at 1 min. intervals. When the product was completely soft, the time was noted as optimum cooking time.

Solids Loss

Solids loss was determined by cooking pasta samples in boiling water for 20 minutes. After cooking, the cooked material was strained out and the whole filtrate was transferred quantitatively in to a pre-weighed petri dish. It was evaporated over a water bath followed by drying in a hot air oven maintained at 105 ± 2°C for 1 hour. The petri dish was again weighed with the dried solids. Then, the solid loss was calculated as:

$$\text{Solid loss (\%)} = \frac{W2 - W1}{W} \times 100$$

Where,

W - Initial weight of pasta taken for cooking

W1 - Weight of empty petri dish

W2 - Weight of petri dish with dried solids after evaporation

Swelling Power

Swelling power of pasta products was determined by method proposed by Schoch (1964). A known weight (10 g) of pasta was cooked in a glass beaker with 20 times its quantity of boiling water (200 mL) for 20 minutes over a water bath maintained at 100 ºC. After cooking, the water was strained out and the cooked pasta was dried to remove surface moisture usingfilter paper and the cooked sample was weighed.

From the initial and final weights of pasta, swelling power was calculated as:

$$\text{Swelling power (g/g)} = \frac{W2 - W1}{W}$$

Where,

W1 = Sample weight before cooking (g)

W2 = Sample weight after cooking (g)

Storage Studies

The best accepted pasta along with the control pasta was taken for the shelf life study. The pasta was developed and packed in a metalized polyester packaging material and stored at ambient temperature (28 ± 2°C). Sample was drawn from storage conditions on 0^{th}, 30^{th}, 60^{th} and 90^{th} day and analysed for parameters *viz.*, sensory evaluation, moisture, microbial load, peroxide value and free fatty acid.

Microbial Load of Developed Food Product (Tate, 1995)

The microbial analysis of the developed products was carried out by standard plate count method using Nutrient Agar (NA) for bacteria, Martins Rose Bengal Agar (MRBA) for fungi and Eosin-Methylene Blue (EMB) for *E. coli*. After solidification of medium, plates were incubated in an inverted position at 28 ± 2ºC for 2 days (bacteria) and for 4 days (moulds and *E. coli*) and emerged colonies were counted.

Free Fatty Acid

The free fatty acid was estimated by titrating it against KOH (0.1N) in the presence of phenolphthalein indicator. Titration was made till the pink colour persists for 15 seconds. Percentage of free fatty acids (FFAS) were calculated using oleic acid as a factor.

$$\text{Acid value (mg KOH/g of oil)} = \frac{a \times 0.00561 \times 1000}{\text{Weight of the sample (g)}}$$

$$\text{Per cent free fatty acid} = \frac{\text{Acid value}}{1.99}$$

Peroxide Value (Raguramulu *et al*., 2003)

Ten grams of sample was weighed and used for the fat extraction. About 0.5 mL to1 mL of extracted fat was weighed in a flask. To this add 20 mL of acetic acid and 10 mL of chloroform mixture and dissolve fat properly. One mL of potassium iodide was added and kept it for 5 minutes. Precipitation takes place by adding 30 mL of distilled water then add starch as a indicator (blue colour appears). Further it was titrated against sodium thiosulphate until violet blue colour disappears.

$$\text{Peroxide value of oil (meq/kg of sample)} = \frac{(\text{Titre-blank}) \times N \times 1000}{\text{Weight of the oil (g)}}$$

Water Activity (Abbey *et al*., 2017)

The water activity of pasta was measured at an ambient temperature (28 ± 2°C) using a Rotronic Hygro Lab water activity meter. Around 2 g of powdered sample was taken in the sample chamber and the measuring head was placed on it. The instrument was operated and the obtained constant reading was noted.

Statistical Analysis

The data was analysed in a completely randomized design using SPSS software. Mean and standard deviation for the various parameters were computed. Analysis of Variance (One-way ANOVA) was employed to assess the sensory and nutritional parameters of the developed products. A Duncan's multiple range test was used to determine significant differences between pasta samples.

Results and Discussion

Mean Sensory Scores of Foxtail Millet-Based Pasta

The sensory evaluation of pasta prepared from foxtail millet was presented in Table 2 and Fig. 2. Pasta was

TABLE 2

Sensory evaluation of foxtail millet pasta

Products	Appearance	Colour	Texture	Aroma	Taste	Overall acceptability
Control	8.00 ± 0.61 ^{a}	7.71 ± 0.76 ^{a}	7.85 ± 0.83 ^{a}	7.33 ± 0.83 ^{a}	7.47 ± 0.90 ^{a}	7.90 ± 0.60 ^{a}
T_1	7.66 ± 0.56 ^{a}	7.28 ± 0.69 ^{ab}	7.64 ± 0.77 ^{ab}	7.28 ± 0.82 ^{a}	7.38 ± 0.72 ^{a}	7.45 ± 0.65 ^{ab}
T_2	6.95 ± 0.84 ^{b}	6.90 ± 0.68 ^{b}	7.09 ± 0.68 ^{b}	7.04 ± 0.78 ^{ab}	7.04 ± 0.65 ^{ab}	7.07 ± 0.74 ^{b}
T_3	6.85 ± 0.83 ^{b}	6.19 ± 1.00 ^{c}	6.47 ± 1.17 ^{c}	6.52 ± 1.00 ^{b}	6.57 ± 0.84 ^{b}	6.40 ± 0.83 ^{c}

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

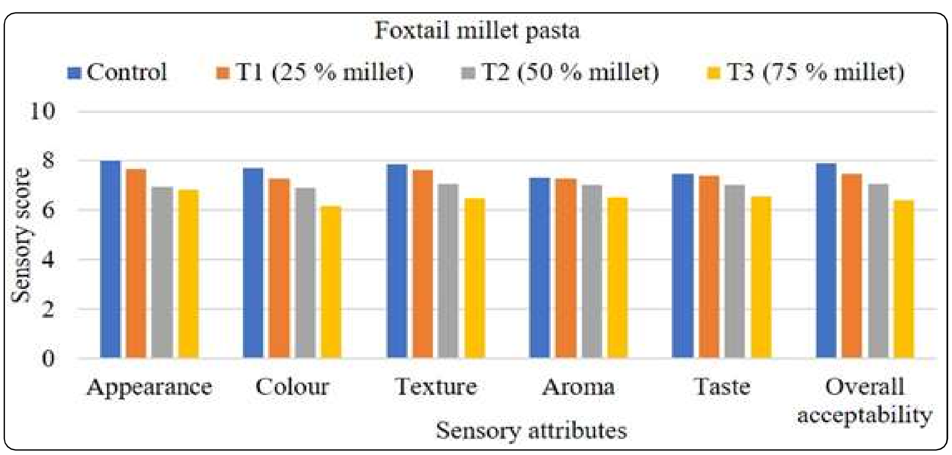

Fig. 2 : Mean sensory scores of foxtail millet pasta

developed by incorporation of foxtail millet flour at 25 per cent (T_1), 50 per cent (T_2), 75 per cent (T_3). Pasta without foxtail millet flour incorporation was used as control. The control pasta had higher mean sensory scores of 8.00, 7.71, 7.85, 7.33, 7.47 and 7.90 for appearance, colour, texture, aroma, taste and overall acceptability as compared to foxtail millet incorporated pasta. The foxtail millet incorporated pasta was best accepted at 25 per cent with mean appearance (7.66), colour (7.28), texture (7.64), aroma (7.28), taste (7.38) and overall acceptability (7.45). The 50 per cent level of incorporation showed intermediate sensory scores 6.95, 6.90, 7.09, 7.04, 7.04 and 7.07 for appearance, colour, texture, aroma, taste and overall acceptability, respectively. While, the 75 per cent level of incorporated pasta showed lower sensory scores 6.85, 6.19, 6.47, 6.52, 6.57 and 6.40 for appearance, colour, texture, aroma, taste and overall acceptability, respectively. As the incorporation level of foxtail millet increased the sensory scores are found to be decreased due to increased breakages and solubility of pasta. When statistically analysed, the mean sensory scores for appearance, colour, texture, aroma, taste and overall acceptability were found to be significant at 5 per cent level. The results indicate that pasta products can be produced by incorporating up to 50 per cent of foxtail millet flour. This may enrich the nutrition of a product and reduce the consumption of refined wheat flour. These results are consistent with those of Chillo *et al*. (2008) who reported the quality of spaghetti made from buckwheat flour and durum wheat bran. Dhas *et al.* (2021) prepared fibre enriched ready-to-cook pasta from foxtail millet and tapioca flour with satisfactory sensory scores. The control pasta showed higher sensory scores across all sensory attributes compared to treatments, which was similar to Sudha (2012), where the control pasta outperformed foxtail millet-incorporated pasta.

Proximate Composition of Foxtail Milled-Based Pasta

The proximate composition of pasta with 50 per cent foxtail millet incorporation and control pasta is depicted in Table 3, it was observed that the moisture content was lower in foxtail millet pasta (7.92%) compared to wheat flour pasta (9.02%). Protein levels were comparable with 13.68 g in foxtail millet and 14.37 g in wheat pasta. Foxtail millet pasta had a higher fat content (1.55 g) and crude fiber (3.71 g), whereas the control had lower fat (0.92 g) and fiber (1.24 g). Carbohydrates and energy values were similar in both pastas with 71.72 g and 356 Kcal for foxtail millet incorporated pasta and 72.89 g and 357 Kcal for wheat flour pasta. The incorporation of 50 per cent foxtail millet have high crude fibre and

TABLE 3

Proximate composition of foxtail millet-based pasta

Proximates	Pasta		t - test
	Control (Wheat flour)	Foxtail millet (GPUF,3)	
Moisture (%)	9.02 ± 0.04	7.92 ± 0.03	3.28 *
Protein (g)	14.37 ± 0.28	13.68 ± 0.25	2.27 NS
Ash (g)	1.54 ± 0.12	1.41 ± 0.16	1.72 NS
Fat (g)	0.92 ± 0.02	1.55 ± 0.18	13.21 *
Crude Fibre (g)	1.24 ± 0.17	3.71 ± 0.22	62.82 *
Carbohydrate (g)*	72.89 ± 0.56	71.72 ± 0.48	0.74 NS
Energy (Kcal)*	357 ± 0.87	356 ± 2.64	0.11 NS

Note : Values are expressed as mean ± standard deviation of three determinants, Carbohydrate - by difference method, Energy - by calculation method, *Significant at ($p \leq 0.05$) and NS - Non-significant fat when compared to control pasta which may be due to incorporation of foxtail millet where the millets are very good source of fibre. Statistically significant difference was observed for the moisture, fat and crude fibre content at 5 per cent level, whereas no significant difference was found for protein, ash, carbohydrate and energy. The data revealed that the moisture, ash, fat, crude fiber and energy levels of pasta are similar to the findings of Dhas *et al*. (2021). Conversely, the protein was higher and carbohydrate content was lower in the present study. Sarojani *et al*. (2021) reported that kodo millet pasta had lower crude fiber (1.25), protein (10.50), ash (0.94) and fat (1.29), while moisture (8.31) and carbohydrate (78.96) content was higher compared to present study. The differences in nutritional content of pasta between this study and others may be attributed to type and variety of millet used in pasta preparation and processing methods.

Mineral Composition of Foxtail Millet Pasta

The mineral content of control and foxtail millet pasta is presented in Table 4. It was noticed that control pasta with whole wheat flour had 32.80 mg, 3.56 mg, 306.31 mg, 3.75 mg, 0.44 mg, 116.80 mg, 2.67 mg, 308.86 and 2.30 mg for calcium, sodium, potassium, iron, copper, magnesium, zinc, phosphorus and manganese. The pasta with 50 per cent incorporated foxtail millet pasta had from 30.66 mg/100 g of calcium, 17.46 mg/100 g of sodium, 273.73 mg/100 g of potassium, 4.22 mg/100 g of iron, 0.66 mg/100 g of copper, 102.40 mg/100 g of magnesium, 3.39 mg/100 g of zinc, 291.06 mg/100 g of phosphorus and 2.24 mg/100 g of manganese. The incorporation of foxtail millet increased the micro mineral content of 50 per cent incorporated millet pasta where the millets are rich in minerals which meet the daily requirement. The mineral composition revealed statistically significant variability at 5 per cent level for both pasta samples. The mineral content of present study falls within the range as reported by Yadav *et al.* (2014) for iron (2.7 - 4.3 mg/100 g), potassium (130 - 190 mg/100 g), sodium (8.9 - 21.1 mg/100 g), calcium (23.5 - 40.9 mg/100 g) and phosphorus (121 - 244 mg/100 g). Notably, phosphorus and potassium levels in the present study are higher, while iron, calcium and sodium values align well with their findings (Yadav *et al*., 2014). The mineral content in the present study had higher calcium (30.66 mg/100 g), zinc (3.39 mg/100 g) and iron (4.22 mg/100 g) compared to findings of Sarojani *et al.* (2021) for calcium (28.65 mg/100 g), zinc (2.35 mg/100 g) and iron (1.55 mg/100 g).

TABLE 4

Mineral composition of foxtail millet-based pasta

Minerals	Pasta		t - value
	Control (Wheat flour)	Foxtail millet	
Calcium	32.80 ± 4.28	30.66 ± 2.09	3.11 *
Sodium	3.46 ± 0.57	17.46 ± 0.92	51.44 *
Potassium	306.31 ± 12.68	273.73 ± 12.93	2.19 NS
Iron	3.75 ± 0.14	4.22 ± 0.13	3.14 *
Copper	0.44 ± 0.02	0.66 ± 0.01	27.62 *
Magnesium	116.80 ± 9.46	102.40 ± 8.15	6.06 *
Zinc	2.67 ± 0.15	3.39 ± 0.06	5.18 *
Phosphorus	308.86 ± 10.88	291.06 ± 11.38	2.01 NS
Manganese	2.30 ± 0.20	2.24 ± 0.08	0.74 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 foxtail millet-based pasta

Parameters (mg/ 100 g)	Pasta		t - value
	Control (Wheat flour)	Foxtail millet	
Phytic acid	490.64 ± 20.58	675.83 ± 33.70	9.55 *
Tannins	204.44 ± 11.51	192.61 ± 3.21	3.22 *
Polyphenols	117.91 ± 6.94	145.18 ± 6.90	5.68 *

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

Antinutrient Composition of Foxtail Millet Pasta

The antinutrient content of control and foxtail millet pasta is depicted in Table 5. The content of antinutrients significantly varied from control pasta to 50 per cent millet incorporated pasta. Foxtail millet pasta exhibited higher phytic acid (675.83 mg/100 g) and polyphenol content (145.18 mg/100 g) compared to wheat flour pasta (490.64 mg/100 g and 117.91 mg/100 g, respectively). However, tannin content was slightly lower in foxtail millet pasta (192.61 mg/100 g) than in wheat pasta (204.44 mg/100 g). This indicated that foxtail millet pasta had higher levels of certain anti-nutritional factors, particularly phytic acid and polyphenols. Duguma *et al*. (2021), reported that extruded composite flours had lower levels of phytic acid and tannins compared to present study results. The observed variations may be attributed to the processing techniques employed during sample preparation, including dehusking, boiling, mild-temperature roasting and extrusion cooking. These processes are known to influence the structural, functional and nutritional properties of the samples. Kamble *et al*. (2021) reported higher phytate (1106 mg/100 g) and lower tannin (151.12 mg/100 g) levels compared to the values in the current study.

Cooking Quality of Foxtail Millet-Based Pasta

Cooking characteristics in terms of cooking time, swelling power, solids loss and cooking weight for the optimized pasta products were evaluated and the data are illustrated in Table 6. Cooking parameters revealed that perfect shape of the pasta products was not retained by nutri-cereal flour alone. As a result, in order to improve texture and to retain shape during cooking, whole wheat flour at varying levels was added. The cooking properties of control wheat flour pasta and foxtail millet pasta revealed distinct differences. Foxtail millet pasta had a shorter cooking time (7.30 min) compared to wheat pasta (9.20 min). Swelling power was slightly higher in foxtail millet pasta (3.26 mL) than in the control (3.03 mL). However, solids loss was significantly higher in foxtail millet pasta (12.23%) compared to wheat pasta

TABLE 6

Cooking properties of foxtail millet-based pasta

Parameters	Pasta		t - value
	Control (Wheat flour)	Foxtail millet	
Cooking time (min)	9.20 ± 0.19	7.30 ± 0.15	11.99 *
Swelling power (mL)	3.03 ± 0.16	3.26 ± 0.12	3.39 *
Solids loss (%)	8.35 ± 0.17	12.23 ± 0.12	7.83 *
Cooking weight (g)	40.30 ± 0.87	42.60 ± 0.92	1.65 ^{NS}

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

(8.35%), indicating more nutrients were lost during cooking. Cooking weight was also greater for foxtail millet pasta (42.60 g) than for wheat pasta (40.30 g). These results suggest that foxtail millet pasta absorbs more water and loses more solids during cooking. Jalgaonkar *et al*. (2017) reported cooking loss varied from 6.22 per cent to 7.66 per cent which remained below than the current findings. Rekha *et al*. (2013) also reported that low gruel loss (7.1 - 8.4 g/kg) for vegetable powder-incorporated pasta as compared to present study. Similarly, Yadav *et al*. (2014) had also reported the lower gruel loss (1.02 - 1.43%) of pasta with different composition. Cooking losses were high for millet-incorporated pasta as compared to the control and other studies. This could be due to low binding of starch granules and lack of gluten network in millets.

Storage Studies of Foxtail Millet-Based Pasta

The results of storage study conducted for foxtail millet-based pasta and control pasta product stored at ambient conditions (28 ± 2°C) for a period of 3 months in metalized polyester packaging material are presented below.

Sensory Evaluation of Millet-Based Pasta on Storage

The sensory scores obtained for appearance, colour, texture, flavour, taste and overall acceptability of foxtail millet-based pasta product and control pasta stored in metalized polyester packages at ambient condition for 3 months are illustrated in Table 7. It was observed that with increasing storage period, mean sensory sores for appearance, colour, texture, flavour, taste and overall acceptability of the all pasta products declined from 0th day to 90th day. In case of control pasta, it could be seen that the mean sensory score of overall acceptability progressively declined from 7.90 at beginning of storage period to 7.38 under metalized polyester package. The same trend was observed for foxtail millet-based pasta too. At the end of the storage period, the sensory score for overall acceptability of extruded foxtail millet pasta was 6.57. Even after 90 days of storage the both millet pasta and control pasta are in good condition and are also acceptable to consumers. However, the stored control and millets pasta showed no significant decline ($p \leq 0.05$) in sensory scores from 0th day to 90th day during storage. The sensory scores of kodo millet-based pasta obtained by Sarojani *et al*. (2021) are consistent with the above-mentioned readings. Similarly, Shobha *et al*. (2015) also reported that sensory score of composite flours-based noodles affected significantly over the storage duration of 4 months. The sensory scores of pasta during storage period were on par with results reported by Kamble *et al*. (2021). Yadav *et al*. (2014) presented a slight

TABLE 7
Sensory evaluation of millet-based pasta on storage

Pasta	Duration (days)	Appearance	Colour	Texture	Aroma	Taste	Overall acceptability
Control (Wheat flour)	Initial	8.00 ± 0.61 ^{a}	7.71 ± 0.76 ^{a}	7.85 ± 0.83 ^{a}	7.33 ± 0.83 ^{a}	7.47 ± 0.90 ^{a}	7.90 ± 0.60 ^{a}
	30	7.80 ± 0.39 ^{a}	7.52 ± 0.58 ^{a}	7.66 ± 0.64 ^{a}	7.23 ± 0.68 ^{a}	7.38 ± 0.72 ^{a}	7.76 ± 0.42 ^{a}
	60	7.57 ± 0.49 ^{a}	7.38 ± 0.57 ^{a}	7.42 ± 0.58 ^{a}	7.14 ± 0.46 ^{a}	7.23 ± 0.68 ^{a}	7.57 ± 0.49 ^{a}
	90	7.33 ± 0.47 ^{a}	7.23 ± 0.52 ^{a}	7.19 ± 0.49 ^{a}	6.95 ± 0.37 ^{a}	7.04 ± 0.57 ^{a}	7.38 ±0.48 ^{a}
Foxtail millet	Initial	6.95 ± 0.84 ^{a}	6.90 ± 0.68 ^{a}	7.09 ± 0.68 ^{a}	7.04 ± 0.78 ^{a}	7.04 ± 0.65 ^{a}	7.07 ± 0.74 ^{a}
	30	6.80 ± 0.73 ^{a}	6.76 ± 0.52 ^{a}	7.00 ± 0.61 ^{a}	6.90 ± 0.68 ^{a}	6.95 ± 0.57 ^{a}	6.97 ± 0.68 ^{a}
	60	6.76 ± 0.68 ^{a}	6.66 ± 0.47 ^{a}	6.85 ± 0.63 ^{a}	6.80 ± 0.66 ^{a}	6.76 ± 0.60 ^{a}	6.85 ± 0.63 ^{a}
	90	6.61 ± 0.65 ^{a}	6.57 ± 0.49 ^{a}	6.76 ± 0.60 ^{a}	6.66 ± 0.64 ^{a}	6.59 ± 0.56 ^{a}	6.57 ± 0.49 ^{a}

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

TABLE 8
Effect of storage on microbial load of millet-based pasta

Microorganism	Duration (Days)	Control (Wheat flour)	Foxtail millet
Bacteria (×10^4)	Initial	0.25 [d]	0.33 [d]
	30	0.91 [c]	1.08 [c]
	60	1.66 [b]	1.50 [b]
	90	3.58 [a]	2.75 [a]
Yeast and molds (×10^3)	Initial	ND	ND
	30	0.75 [c]	0.83 [c]
	60	1.08 [b]	1.25 [b]
	90	2.75 [a]	2.41 [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

decrease in pasta acceptability during 90-day storage without major sensory changes.

Microbial Load of Foxtail Millet-Based Pasta on Storage

Microbial quality of control and optimized foxtail millet pasta were analysed in terms of total bacterial count, molds and *E. coli* forms during storage period of 90 days at ambient conditions. The influence of storage period on the microbial load of pasta samples is presented in Table 8. The control and optimized foxtail millet pasta samples were packed in metalized polyester and storage at ambient conditions. The results revealed that packaging material and storage temperature had a significant influence on the microbial population of pasta samples. Total bacterial count under the study tend to increase with increase in number of days of storage *i.e.*, from initial to 90 days of storage. Total bacterial count increased from 0.25×10^4 to 3.58×10^4 cfu/g among pasta samples. Yeast and mold counts were not detected at initial days, but at the end of three months storage period, the yeast and mold count of pasta samples significantly increased up to 2.75×10^3 cfu/g. *E. coli* were found to be absent throughout the storage period. During storage period there was an increase in total bacterial population which may be due to the storage condition and also due to increase in the moisture level over the storage period. However, the bacterial count was less in millet pasta than the control may be due to the phytonutrients of millets. However, there is a statistically significant differences in the pasta samples with respect to duration of storage and increase in the microbial load at 5 per cent level. Similar findings had been reported by Kamble *et al*. (2021) in multigrain pasta products where they reported a significant increase in TPC, yeast and molds that might be due to higher moisture and water activity of the products during storage. Similar observations were reported by Yadav *et al*. (2014) in pasta prepared from a blend of wheat, pearl millet with vegetable paste on 90 days storage in polyethylene bags at ambient conditions.

Bio-Chemical Changes of Foxtail Millet-Based Pasta on Storage

The bio-chemical parameters of control pasta and foxtail millet pasta were evaluated over 90 days and depicted in Table 9. Moisture content gradually increased for both samples with foxtail millet pasta

TABLE 9

Effect of storage on bio-chemical properties of foxtail millet-based pasta

Bio-chemical parameters	Duration (Days)	Control (Wheat flour)	Foxtail millet
Moisture (%)	Initial	8.26 ± 0.23 [b]	7.88 ± 0.13 [c]
	30	8.43 ± 0.15 [b]	8.19 ± 0.15 [bc]
	60	8.81 ± 0.18 [ab]	8.65 ± 0.21 [ab]
	90	9.32 ± 0.28 [a]	9.14 ± 0.21 [a]
Water activity	Initial	0.31 ± 0.02 [c]	0.33 ± 0.03 [d]
	30	0.38 ± 0.03 [b]	0.39 ± 0.02 [c]
	60	0.41 ± 0.02 [b]	0.48 ± 0.02 [b]
	90	0.54 ± 0.04 [a]	0.54 ± 0.05 [a]
Free fatty acids (%)	Initial	0.25 ± 0.02 [d]	0.35 ± 0.01 [d]
	30	0.38 ± 0.01 [c]	0.51 ± 0.03 [c]
	60	0.56 ± 0.03 [b]	0.73 ± 0.01 [b]
	90	0.75 ± 0.04 [a]	0.88 ± 0.03 [a]
Peroxide value (meq.kg^{-1})	Initial	1.52 ± 0.10 [c]	2.36 ± 0.10 [d]
	30	1.66 ± 0.13 [c]	2.75 ± 0.13 [c]
	60	1.85 ± 0.08 [b]	3.29 ± 0.14 [b]
	90	2.13 ± 0.21 [a]	3.83 ± 0.17 [a]

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

rising from 7.88 per cent initially to 9.14 per cent at day 90, while wheat pasta increased from 8.26 per cent to 9.32 per cent. Water activity showed a similar trend, reaching 0.54 for both pasta samples at the end of 90 days. Free fatty acid content in foxtail millet pasta rose more sharply, from 0.35 per cent initially to 0.88 per cent at day 90, compared to wheat pasta, which increased from 0.25 per cent to 0.75 per cent. Similarly, the peroxide value, an indicator of lipid oxidation, increased more in foxtail millet pasta, from 2.36 meq/kg initially to 3.83 meq/kg by day 90, while wheat pasta increased from 1.52 meq/kg to 2.13 meq/kg. These results indicate that foxtail millet pasta exhibited faster lipid degradation than the wheat pasta over time. The statistical analysis revealed that the storage period had significant ($P \leq 0.05$) effect on the moisture content, water activity, free fatty acids and peroxide value of pasta samples. Nagi *et al*. (2012) reported an increase in moisture content of cereal bran enriched biscuit in flexible packaging during storage period. Similarly, Kaur *et al*. (2012) reported water activity values from 0.35 to 0.75 of bran enriched pasta, which was influenced by storage period and found the product acceptable up to 4 months of storage. A similar trend of gradual increase in fatty acids and peroxide value of pasta caused by enzymatic hydrolysis of the lipids had also been reported by Chaiyashit *et al*. (2007) with an increase in the storage period.

The development of foxtail millet-based extruded products presented a nutritious alternative to wheat pasta, highlighting enhanced dietary benefits. Millet incorporation particularly at 50 per cent substitution levels improved fiber, fat and mineral content (iron, copper and zinc), while maintaining satisfactory protein levels. Although sensory attributes such as appearance and texture slightly declined with higher millet levels and also the nutritional superiority of millet products was evident, they offered greater essential minerals and fiber compared to control samples, along with a shorter cooking time. Additionally, foxtail millet pasta exhibited better shelf stability, maintaining lower bacterial and yeast counts over 90 days. This made foxtail millet an excellent ingredient for creating health-conscious, fiber-enriched extruded products with promising consumer acceptance and shelf life.

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