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Effect of Finger Millet on Nutritional, Rheological, Cooking and Pasting Profile of Asian Noodles

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Abstract

Background and Objectives: Asian noodles are cost-effective, appealing, affordable, and convenient snack food consumed worldwide, and are good source of protein and energy. However, the major ingredient of Asian noodles is wheat, and these wheat-based noodles are deficient in dietary fiber and micronutrients. Finger millet (FM) being rich in various micronutrients and dietary fiber, can be used to improve the nutritional value of noodles and can be used commercially to provide food security. The goal of this investigation was to evaluate the effect of blending FM flour (FMF) with wheat flour on noodle quality attributes.

Findings: Noodles were prepared with a blend of FMF (ranging from 0 - 60%) and wheat flour and studied for nutritional physicochemical analysis, functional properties, cooking attributes and overall sensory qualities. When 60% FMF was added to noodles, it resulted in higher content of crude fiber (2.87%), dietary fiber (11.68%), amylopectin (38.53%), and increase in pasting temperature (74.70 °C), browning index (BI) (1.95), hardness (320.25 g), cooking loss (20.41%), and cooking time (190 s) was observed. The study conclusively revealed that dough for noodles with 60% FMF incorporation had poor sheeting properties and springiness. FM's redness and high phenol content resulted in decreased L^* (80.26 - 51.89) and b^* (18.56 - 5.34) values. The overall acceptability was reduced from 9.42 - 7.64 during sensory evaluation by semi-trained panelists. The investigation concluded that 30% incorporation of FMF produced dough with good sheeting properties and functional characteristics and resulted in good quality noodles preparation.

Conclusion: The dough prepared with the incorporation with FMs had detrimental dough handling and sheeting property; the noodles prepared with 30% FMF incorporation resulted in good quality noodles in term of nutrition and overall acceptability in sensory evaluation considering color, flavor, aroma, elasticity, and chewability of the noodles.

Significance and Novelty: This study proposed that adding FM will enhance both the nutritional value of noodles and the consumption of millet. This method could be used to enhance the role of FM in the food industry and to leverage the nutritional advantages of these grains.

Keywords

Finger millet, Noodles, Wheat flour, Food security

Introduction

FM crop has a long and rich history, with its origins dating back to ancient times in East Africa, specifically in the African Great Lakes region. Accord-

ing to historical evidence and archaeological findings, FM cultivation in Africa can be traced back more than 5,000 years ago. Following sorghum, pearl millet, and foxtail millet, FM is the fourth most significant millet, accounting for approximately 10% of global millet production. FM (*Eleusine coracana* L.), a small grain extensively cultivated around the world, has gained recognition for its manifold nutritional quantities. FM contains different bioactive compounds like total phenols (265 - 373 mg/100 g), flavonoids (200 mg/100 g), tannins (0.61%), phytates (0.48%), polyphenols (0.2% - 3.0%), and dietary fiber (15% - 20%), positioning it as a rich source of vital nutrients [1, 2]. This nutritional richness has been suggested as the basis to explore FM as a suitable ingredient for food formulation. FM was traditionally consumed in the form of porridge, flatbread, and fermented beverages. Due to lifestyle associated diseases functional foods are in huge demand by the consumer and embarked the leading food manufacturer to research and develop different functional foods using natural ingredients [3, 4]. FM noodles have great potential in this category. Noodles are consumed by large populations throughout the world but are deficient in macro and micronutrients like protein, dietary fibers, minerals and bioactive compounds. The high fiber content, complex carbohydrates and good profile of bioactive compounds in FM make it an optimal ingredient for the development of food products aimed at promoting health and wellness. Wheat flour is the major ingredient used for the manufacturing the noodles and the observation has been made that wheat flour does not have adequate quantities of an important amino acid, lysine [5]. FM is abundant in lysine, threonine, and valine [6] and thus can be utilized to improve the profile of amino acids in the developed products.

An ideal noodle should possess attributes like a golden appearance, springiness, smooth texture, firmness, non-stickiness, and an appealing flavor. The quality of wheat flour for noodle making depends on numerous factors including protein content and quality, gluten content (both wet and dry), mineral composition, and fiber content, each of which influences the dough's characteristics and the quality of the finished product.

Swami et al. [7], added 20% FM in vermicelli and performed proximate and sensory attributes with varied guar gum (0 - 2.5%) to improve the textural properties. Vermicelli with 2% guar gum has better textural attributes with acceptable sensory profile. Dissanayake and Jayawardene [8], prepared FM incorporated rice noodles and reported that noodles with 50% FM are highly acceptable in the sensorial analysis however the noodle breakage was increased with increment of FM which further led to grueling loss during cooking. Shukla and Srivastva [9] prepared FM incorporated wheat noodles and found that noodles with 30% FM have better nutritional, sensorial, and glycemic index. Given this context, there seems to be an urge to explore the addition of FMF within wheat flour and its potential impacts on dough behavior and noodle quality parameters. As a result, the purpose of this study was to explore how adding FMF to wheat flour affected the rheological and pasting behavior, as well as the quality of the noodles.

Materials and Methods

Raw material

For noodle preparation, the wheat variety C306 and FM variety HR911, which has a red, amber hue, were selected. The wheat grains were milled to obtain wheat flour. The FM grains were ground into whole-grain flour using a grinder and screened through 200 μ sieve. The obtained flour samples were then stored in airtight containers and placed in a deep freezer to maintain product integrity. Before the flour was incorporated into the noodle mixture, it was duly thawed.

Noodle preparation

Noodles were prepared by combining wheat flour and FMF (from 0% - 60%), using an optimal level of water, with minor ingredients as mentioned by Chhikara et al. [10], with slight modifications. A crumbly dough was prepared, which was rested for 5 min at room temperature. The dough was passed between two smooth rollers in a noodle machine, maintaining a consistent gap. The resulting dough sheet, of approximately 1.5 mm in thickness, was then cut via a cutting roller fitted to the noodle machine. The fresh noodles underwent a steaming process for 2 min, utilizing saturated steam at a temperature of 98 °C and a pressure of 0.1 kg within a confined vessel. After being steamed, the noodles were deep-fried in pure soybean oil, at a temperature of 140 °C, for a duration of 60 s. The remaining surface oil was removed from the fried noodles with the assistance of pressure from filtered hot air. For subsequent examination, these noodles were then sealed in airtight plastic bags.

Chemical analysis

Raw material and finished product were evaluated for moisture, fat, protein, and ash levels, carried out in compliance with the standards of the AACC [11]. The carbohydrate content was calculated by deducting the total amounts of moisture, protein, fat, and ash from 100. The AOAC [12] methods were used to estimate both crude and dietary fibers. Amylose and amylopectin content were quantified through the iodine colorimetric method. Total phenolic content was assessed using Folin-Ciocalteu's spectrophotometric procedure [13]. All the tests were performed in triplicates for a broad and precise evaluation.

Pasting characteristics of FM dough

While analyzing the pasting characteristics of noodle dough, especially in instances involving the incorporation of FM (0%, 10%, 20%, 30%, 40%, 50%, and 60%) into wheat flour, the Rapid Visco Analyzer (Newport Scientific Pvt. Ltd, Australia) was used to study pasting profile. Noodle flour (3.0 g on 14% moisture basis) was taken and mixed with 25 ml of distilled water to form a suspension. The suspension was then exposed to a staggered cycle incorporating both heating and cooling phases at a consistent shear force to study peak viscosity (PV), breakdown viscosity (BDV), trough viscosity (TV), setback viscosity (SBV), and final viscosity (FV).

Quality evaluation

Oil uptake, cooked weight, cooking time, and cooking loss

Oil uptake of noodles was determined by Soxhlet apparatus method [12]. The cooked weight, cooking time and cooking loss of the noodle strand were measured [11]. The difference gave the cooked weight, indicating the water absorption capacity. The cooked weight of the noodles was assessed post-cooking, indicating the extent to which the noodles absorb water during the cooking process. Cooking time was assessed using a simple stopwatch, timing from the moment the noodles were placed in boiling water until they reached an optimal cooked state, as determined by slide test and accounted for in seconds. Cooking loss was generally measured by filtering the cooking water after boiling the noodles, drying the residue, and weighing it. The weight indicated the amount of solids lost during cooking.

Color

Color attributes (L^*, a^*, and b^*) of noodle samples were evaluated using a colorimeter from Hunter Lab, namely the MiniScan XE Plus. Total color difference (ΔE), Chroma (indicating color intensity or saturation), the hue angle (θ°), and the BI, were measured [14].

Texture analysis of noodles

The texture characteristics of the noodles, hardness and springiness, were analyzed using texture analyzer (Model TA-XT 2i) with software Texture Expert Exceed (version 2.61), Stable Microsystems, UK. The single strand of the noodle was securely fastened to the platform and subjected to 75% deformation in a compression mode using a cylinder probe (38 mm) at a speed of 1.0 mm/s. From the textural profile analysis curve, textural parameters of hardness and springiness were obtained. A total of eight repeat measurements of each noodle sample and all measurements were taken within 20 min of cooking the noodle. Hardness usually refers to the peak force during the first compression and is often measured in units of force Newtons. Springiness describes the ability of the noodle to spring back to its original form after the deforming force is removed.

Sensory analysis

Noodle samples were evaluated for attributes such as color, flavor, aroma, elasticity, chewability, and overall acceptance by using a 9 - point hedonic scale. An evaluation panel consisting of 32 semi-trained panelists conducted the sensory assessment. The panel's training involved introductory sessions that familiarized them with specific characteristics and consumer preferences for noodles.

Statistical evaluation

The statistical examination of the experimental data was performed using SPSS software. This involved the calculation of means and standard deviations for the various parameters examined in the noodle samples. In addition to descriptive statistics, correlation regression analysis was conducted to understand the relationships between different variables and to predict future outcomes based on these relationships. The SPSS software facilitated the systematic and accurate analysis of the gathered data.

Results

Characterization of wheat and FMF

Wheat flour contained 13.21% moisture, 0.42% ash, 10.08% protein, 0.43% fat, 1.26% crude fiber, 7.81% dietary fiber, and 73.65% carbohydrate. However, FMF contained 12.32% moisture, 2.16% ash, 8.55% protein, 2.61% fat, 3.72% crude fiber, 16.42% dietary fiber, and 70.64% carbohydrates. The dietary fiber content in FMF was significantly higher than that of wheat flour. Calcium, iron, zinc, and phosphorus were found to be 26, 7.6, 1.6, and 253 mg/100 g, and 312, 8.1, 1.36, and 305 mg/100 g for wheat and FMF respectively. The total phenolic content was observed to be higher in FMF (394.5) as compared to wheat flour (92.7 mg/100 g). Similar results have been reported by Panghal et al. [2]. These findings clearly suggested that FM is nutritionally far superior to wheat flour.

Pasting characteristics

PV refers to the maximum viscosity that the mixture achieves on swelling of starch granules. The different viscosity parameters were found to decline with increment in the level of FMF (Table 1). The starch in noodles completely undergoes gelatinization during the cooking process, even when the cooking time is brief. It is observed that cooked starch hydrates at a faster rate, resulting in reduced viscosity [15]. TV represents the minimum value on the RVA profile, often corresponding to the point of highest shear stress during cooking. High TV means more stability against stirring or shearing during heating, which is crucial for noodle consistency. Higher FM incorporation might lower TV, potentially leading to softer, less firm noodles. The TV of flour, without FM, was recorded as 1798.89 cP. Upon incorporation of FMF, there was a marginal decrease, ranging from 1582.58 cP to

Table 1: Pasting properties of FM noodles.

Level of FMF incorporation (%)	PV (cP)	TV (cP)	BDV (cP)	FV (cP)	SBV (cP)	Pasting temperature (°C)
0	1980.63	1798.89	1352.85	3224	1689.27	65.7
10	1815.35	1693.56	1265.34	3056.47	1597.32	67.1
20	1786.42	1582.58	1124.58	2914.29	1523.56	68.5
30	1670.23	1498.68	1056.32	2780.24	1412.45	69.8
40	1562.32	1423.56	965.47	2689.38	1356.78	71.3
50	1454.26	1365.28	873.26	2545.36	1280.23	72.8
60	1362.78	1243.56	756.45	2386.23	1202.35	74.7

1243.56 cP. BDV indicates the stability of the dough during cooking which affects the cooking quality of noodles. A high breakdown value suggests that the noodles may disintegrate or become sticky during cooking. It exhibited a downward trend from 1352.85 cP to 756.45 cP with the incorporation of FMF. The FV of control wheat flour showed a higher value 3224 cP, which subsequently dropped to 2386.23 cP when FMF was introduced. A higher FV largely implies a higher degree of retrogradation, i.e., the re-association and reformation of starch molecules after cooling. The quantity of FM in the dough can affect this property. As higher amounts of FM led to a lower FV, the resultant noodles might be softer than those mostly composed of wheat. This property is critical in the analysis as it not only determines the texture and firmness of the cooked noodles. The SBV wheat flour was recorded as 1689.27 cP which showed marginal decline 1202.35 cP on addition of FMF. SBV relates to the noodles' texture after cooking and cooling. High setback values often lead to a firmer texture, as this suggests that the starch molecules have re-associated, causing the dough to harden. Pasting temperature is the temperature at which the viscosity of the mixture starts to increase. FM might elevate the pasting temperature, a property which might help it withstand higher cooking temperatures. A higher pasting temperature was manifested, rising from 65.7 °C (control wheat flour) to 74.7 °C with the calculation of FMF (Table 1). This increase in pasting temperature can be attributed to the dilution of starch available for gelatinization. Lower pasting temperature and higher paste viscosities were observed for finer flours, indicating a higher proportion of gelatinized starches in smaller particle-size flours. In essence, there was a significant correlation between FM noodle PV and constituents like amylose (r = 0.985), amylopectin (r = -0.992), springiness (r = 0.990), and overall acceptability (r = 0.985).

Noodle quality

The quality of noodles was assessed based on a variety of factors including oil absorption, cooked weight, cooking duration, cooking loss, and sensory features like color, flavor, freshness, breakability, chewiness, hardness, and springiness. The effect of oil uptake in FM noodles, when prepared with different ratios of wheat and FMF, was observed (Table 2) suggesting a significant ($p \leq 0.05$) gradual decrease from 18.12% - 16.40% on increasing FM concentration (Table 2). The protein and fiber content within FMF were indeed found to influence the flour's oil absorption capacity. As the proportion of FMF in the noodle dough increased, the amount of protein and fiber in the dough also increased. These components had the potential to interact with the oil differently compared to regular wheat flour, affecting the oil absorption capacity. The higher fiber content could potentially reduce oil absorption capacity as dietary fibers could encapsulate oil molecules, decreasing the overall oil penetration in the food product. Thus, increasing FMF in the dough could potentially decrease the overall oil absorption in the noodle product [16].

The cooked weight of FM noodles was observed to decrease as the proportion of FMF increased. This could be attributed to the compositional differences between FMF and wheat flour. Higher fiber content resulted in weakening of the protein-starch network which further affected the dough matrix structure and texture of the noodles. Shukla and Srivastava [9] reported decline in cooked weight on addition of FMF in noodles.

The cooking time of FM noodles was observed to increase as the proportion of FMF was increased in the recipe. The control wheat noodle had a cooking time of 150 s, but with the addition of the FM, this increased from 150 s to 190 s (Table 2). This could be attributed to the fact that FMF has a lower water absorption capacity compared to wheat flour. This led to the requirement of more water to cook noodles composed of higher proportions of FMF, subsequently extending the cooking time. FMF carries different properties compared to wheat flour, including lower starch content and divergent protein structures. These variations can intrude on the gelatinization and hydration processes during cooking, ultimately leading to an extended cooking time for FM noodles, as documented by Yenasew and Urga [17].

The cooking loss in FM noodles was observed to increase from 14.8% - 20.41% (Table 2) as the proportion of FMF increased. This increase could be linked to the weakening of the protein-starch network and degradation of amylose networks caused by the incorporation of FMF. Similar results have been reported for oat noodles [18] accounting to the weakening of the protein-starch network by the inclusion of oat flour.

Texture analysis of noodles depicted inclination in hardness from 226.78 - 320.25 g on incorporation of FMF (Table 2). This occurrence was credited to the presence of tannins in the FMF. Similar increment in hardness values have been observed in multigrain noodles [19] and FM-based cookies [20]. An increasing proportion of FMF in the noodle formulation led to decreases in both springiness, from 145.53 - 95.02 (Table 2). It was observed that the springiness of wet noodles diminished as the inclusion of FMF increased and was attributed to the distinctive composition and structure of FMF. Similar results have been reported in foxtail enriched noodles [21].

Table 2: Quality attributes of noodles made from wheat flour and flour integrated with FM.

Level of FMF incorporation (%)	Oil uptake (%)	Cooked weight	Cooking time (s)	Cooking loss (%)	Hardness (g)	Springiness
Control	18.12	25.50	150.00	14.80	226.78	145.53
10	18.00	24.08	150.00	15.14	245.69	138.78
20	17.60	23.15	160.00	15.78	267.34	131.26
30	17.50	22.30	165.00	16.24	274.39	120.36
40	17.00	21.60	170.00	17.80	284.69	110.85
50	16.60	20.90	180.00	19.23	301.23	105.62
60	16.40	20.30	190.00	20.41	320.25	95.02

Color is a pivotal factor in assessing the sensory attributes, consumer appeal, and market worth of a food product [14]. On incorporation of FMF in noodle formulation, substantial changes in color spectrums are observed. The lightness (L^*) and greenness (b^*) value dropped from 80.26 - 51.89, and 18.56 - 5.34 respectively. On the other hand, a^* value representing the redness of the sample increased from -2.36 to 6.01. This change in color characteristics is accounted for by the polyphenolic pigments found within the pericarp, the aleuronic layer, and the endosperm section of FM. The Maillard reaction, known for producing brown pigments during cooking, plays a central role in reducing the L^* values [22]. About the total color change (ΔE), there is a gradual increment from 21.65 to 42.24 as the FM level rises, which is a result of the increased redness and the decrease in lightness value. The BI, an indicator of cooking performance and level of non-enzymatic browning in a product, increased from -22.45 to 1.95 with the introduction of FMF. The rise in the BI can be associated with an increased extent of Maillard reactions, facilitated by the high amounts of amino acids like glycine, tyrosine, lysine, and tryptophan present in FM. Both L^* ($r = -0.997$) and b^* ($r = -0.995$) values were observed to have a negative correlation with the amount of FMF incorporated, demonstrating the direct influence of FMF on color perception. Similar color characteristics have been reported in millet-corn flour incorporated alkaline noodles [23] and in pearl millet incorporated pasta [24].

Sensory characteristics of noodles

Noodles were evaluated for different sensory attributes and exhibited significant variation (Figure 1). The color of noodles is a key sensory characteristic and is often one of the first factors that consumers perceive. On incorporation of FM, noodles were substantially darker (9.5 - 7.8), potentially ranging from brownish to greyish hues. The darker color was associated with healthier or whole-grain options by some consumers, and thus scored in acceptable value. The taste of FM had a somewhat distinct earthy flavor which affected the taste profile (9.5 - 7.92) of the noodles. Aroma produced from cooking noodles was unique and FM addition (0 - 60%) substantially impacted consumer acceptance (9.32 - 7.96). Likewise, with an increase in FMF, there was a sequential drop in noodle breakability and chewiness, from 9.23 to 6.94 and 9.56 to 7.56, respectively (Figure 1). Incorporating FMF led to a drop in total gluten content in the noodles, which impacted their pliability. It is found that an addition of non-wheat flour, such as soya flour, can significantly affect the chewability of noodle products. Nevertheless, the overall acceptability of the noodles remained within an acceptable range 9.20 - 7.64, although there was a definitive drop from the score of pure wheat noodles 9.42. Similar decline in sensorial attributes on increment in level of incorporation of FM in rice noodles has been observed and 20% FM level was found most acceptable [25]. In the present study, the addition of FMF altered the color, taste, texture, and chewiness of the noodles, however, these changes are within acceptable ranges. It was noticeable that noodles containing 60% FMF scored the lowest for overall acceptability, suggesting limited wider acceptance (Figure 1). Thus, it may be concluded that incorporating around 30% FMF in the noodles would be acceptable, striking a fine balance between maintaining sensory acceptability and enhancing the nutritional, phytochemical, and health advantages offered by FM.

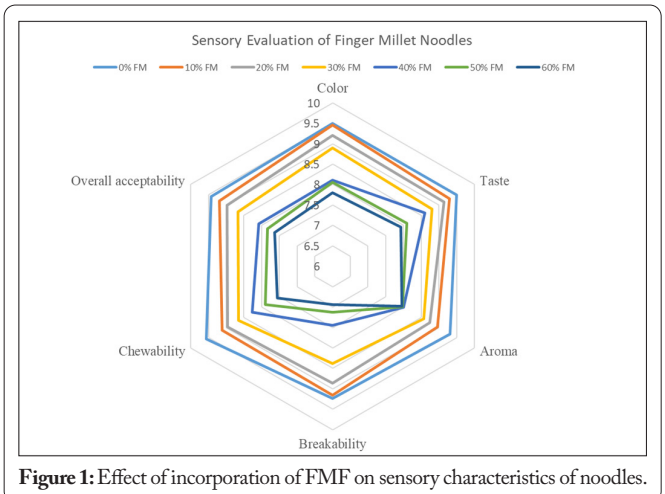

Figure 1: Effect of incorporation of FMF on sensory characteristics of noodles.

Conclusion

The study concluded that incorporation of FMF in noodle formulation can be suggested as a sustainable approach for nutritional enrichment of noodles in a healthier way. The incorporation of FM substantially reduced the oil uptake which is considered as a major health concern by smart consumers. However, FM addition also affected the cooking and textural characteristics, but values are in acceptable range. The noodles generated with FMF displayed less lightness and a higher BI, which had an impact on their general acceptability. Interestingly, the lower setback values indicate that the inclusion of FM could slow down noodle stalling, thereby extending the freshness. Sensory analysis suggested that noodles with 30% FM incorporation level were highly acceptable by panelists showing an interest of consumers in darker products. This study advocates the usage of FM in noodle preparation as a functional and healthy ingredient. The outcome of the present study also motivates researchers and industry professionals to formulate millet-based products at commercial level to meet nutritional security in a sustainable manner.

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Conflict of Interest

None.

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