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From grain to plate: Evaluating foxtail millet's nutritional properties, glycemic index, and innovations in food development

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Abstract
Millets, small-seeded grasses traditionally used in Asia and Africa, are high in health-promoting nutrients and bioactive compounds, outperforming staple cereals such as rice and wheat in terms of nutritional value. Foxtail millet, one of the oldest cultivated crops, is well-known for its medicinal properties and health benefits, which include effective blood sugar management. Its high concentrations of bioactive compounds, dietary fibers, and essential macro and micronutrients make it critical for dietary needs and overall health. To raise awareness of the nutritional benefits of foxtail millet, this study nutritionally evaluates and develop two value-added food products based on it. This study sought to assess the physicochemical properties and glycemic index of foxtail millet (*Setaria italica* L.). Foxtail millet seeds were obtained from the village in Udaipur, Rajasthan. This study glances into the nutritional value and applications of foxtail millet as a functional food. The analysis observed significant physical characteristics of foxtail millet, with a mean thousand grain weight of 2.43g and volume of 5.0 ml, consistent with previous studies. The bulk density was 0.23g/ml, and the millet had mild swelling and water absorption capacities. Proximate analysis revealed a moisture content of 5.78g per 100 g, with higher crude fiber 8.93 g and protein 9.22 g levels in procured varieties. The in-vitro glycemic index was low (52.49), indicating potential benefits for blood sugar management. Two value-added products, panjiri and waffles, were created using 40%, 60%, and 80% foxtail millet. These findings highlight foxtail millet's ability to improve dietary health and nutritional security, encouraging and promoting its use in the development of healthier food products. Further research into foxtail millet as a versatile ingredient is fostered.

Keywords: Compounds, dietary fibers, essential

Introduction
Millets are a diverse group of small-seeded grasses, traditionally used as a primary grain source in Asia and Africa. These round cereal seeds vary in color and size based on the variety and thrive in arid and semi-arid regions like central Africa and Asia (Saleh *et al*., 2014) [20]. India was the leading producer of millets in Asia, with a production volume of 11,066 metric tons, followed by China. In Africa, Nigeria was the foremost producer, yielding 5,163 metric tons, with Niger and Sudan following (FAOSTAT). Millets are rich in health-promoting nutrients and bioactive compounds, such as dietary fibers, antioxidants, and essential macro- and micronutrients, making them superior to staple cereals like rice, wheat, and maize. These nutrients contribute significantly to global nutritional security, playing a crucial role in addressing dietary needs and enhancing overall health. According to Amadou, I. *et al*., 2014 [1] among millet varieties, the most prevalent is pearl millet (*Pennisetum glaucum*) (Basavaraj G, *et al*., 2010) [4], accounting for around 40% of global production across all cultivating regions. This is followed by foxtail millet (*Setaria italica*) (Vetriventhan M *et al*., 2016) [29], proso millet (*Panicum miliaceum*), and finger millet (*Eleusine coracana*). (Devos, (2006) [6] and Chandra D *et al*., 2016) [5] Other types of millets include Kodo millet, little millet, and barnyard millet (Sood S, *et al*., 2015) [26] (see Figure1).

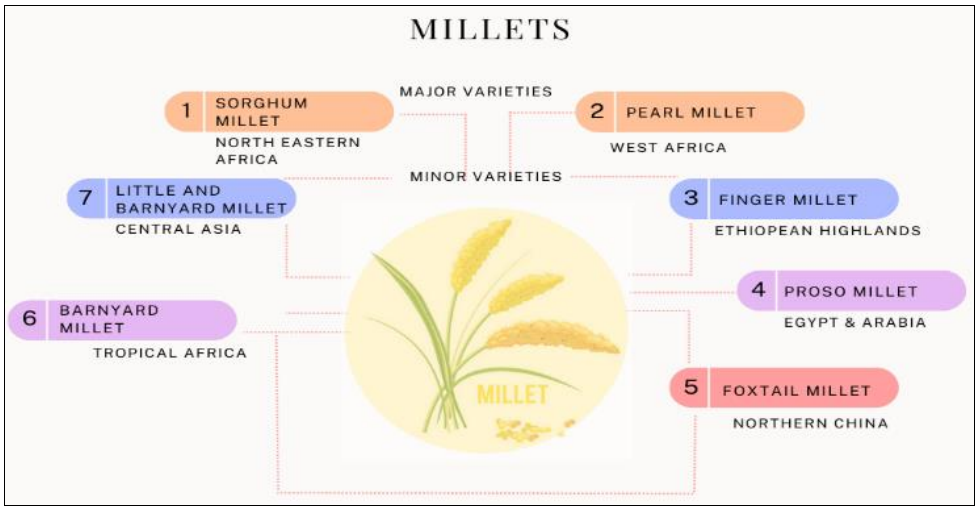

Fig 1: Classification of millets and their respective origins

Foxtail millet (*Setaria italica* L.), rank as the sixth highest yielding grain globally, is one of the oldest cultivated crops with archaeological evidence dating back 7400 to 7935 years in northern China (Austin *et al*., (2006) [3]. Foxtail millet ranks fourth in yield among all millets when grown under standard production practices that do not use pesticides, making it simpler to categorize as an organic farming product (Gupta *et al.*, 2012). Renowned for its medicinal properties, foxtail millet contains yellow pigments like cryptoxanthin, zeaxanthin, and xanthophyll. Sireesha *et al*. (2011) [25] found that aqueous extracts of foxtail millet effectively treat high blood sugar. Its health benefits, due to antioxidants, vitamins, minerals, and bioactive compounds, make it a promising functional food. Millets have been linked to various health benefits, including hypoglycemia [Kumari and Sumathi (2002)] [15], hypocholesterolemia [Hegde *et al*., 2002] [12], and antioxidant activity. Millets' high polyphenol content contributes to their excellent storage quality [Tovey (1994) [28]]. Epidemiological studies suggest that regular consumption can reduce the risk of chronic diseases like cholesterol issues and type 2 diabetes mellitus. This study aimed to evaluate the physicochemical properties, in-vitro glycemic index, and antinutritional properties of foxtail millet.

Material and methods

This study's design is based on the logical order in which the study's components are evaluated and assessed in order to get broad conclusions. The goal of the current experiment was to "Evaluate the physio-chemical properties and assessment of Glycemic Index of Foxtail millet (*Setaria italica* L.)". The flowchart (Fig 2) explains the path of study more effectively.

Procurement of the foxtail millet seeds

Foxtail millet for the study was procured from the AICRP (All India Co-ordinated Research Project) -WIA (Women in Agriculture), under Shri Ann Programme adopted village of Udaipur, Rajasthan.

Assessment of physical properties of foxtail millet powder

Physical properties were assessed using a multitude of procedures. The thousand grain weight was determined by manually counting and weighing 100 grains on an electronic balance, following the method described. The thousand grain volume was measured using the water displacement method, as described. Bulk density was calculated by compacting 50 grams of foxtail millet grains in a graduated cylinder and using the formula: Bulk Density = Weight of kernels (g) / Final volume of kernels (ml), as recommended by Okaka and Potter (1977) [19]. Swelling capacity was determined after a 24-hour soaking period, following the methodology described by Dhingra *et al*. (1992) [7]. A 1g sample was centrifuged with 10mL of distilled water at 30 ºC for 30 minutes, followed by 20 minutes at 3000 rpm. The supernatants were transferred to a pre-weighed petri dish, dried at 45 ºC for 24 hours, and weighed to determine water solubility (g/g). The water absorption capacity (mL/g) was calculated by weighing the centrifuge tube containing wet sediments.

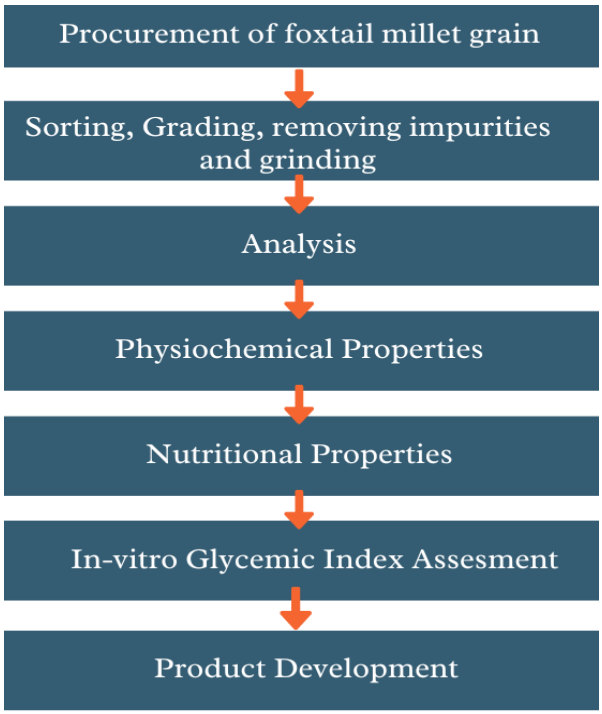

Fig 2: Methodology of the investigation

Proximate composition estimation

The proximate composition analysis was carried out using a set of standardized procedures. Moisture content was

determined by weighing the sample before and after exposure in a humidity chamber, as specified by NIN (2003) [18]. The crude protein content was determined using the Micro Kjeldahl method, as recommended by NIN (2003) [18]. The crude fat content was determined using the Soxhlet extraction technique, which followed NIN (2003) [18] guidelines. The ash content was determined by incineration of the sample and quantification of the residual inorganic matter, as per NIN (2003) [18]. The crude fiber content was determined using the standardized procedure outlined by NIN (2003) [18]. Carbohydrate content was calculated by subtracting the sum of moisture, crude protein, crude fat, crude fiber, and ash from 100, as per NIN (2003) [18] guidelines. The energy content was estimated using physiological fuel values, according to NIN (2003) [18] protocols.

In-Vitro Glycemic Index assessment of foxtail millet

An optimized in vitro methodology was employed to determine the hydrolysis index (HI) and subsequently predict the glycemic index (GI) of foxtail millet. This procedure was based on the approach described by Goñi *et al*. (1997) [9], with modifications.

Development of foxtail millet product

According to Subramanian and Vishwanathan (2007) [27], aside from Asia and Africa, foxtail millet is gaining popularity in other parts of the world, where it can be consumed in a variety of ways, such as porridge, ready-to-eat snacks, and beverages. Milling foxtail millet concentrates functional components that can be used on a large scale. According to Semith and Ozlem (2006) [22], a significant challenge in the development of value-added products is achieving optimal processing to meet specific requirements for improving human health, nutrition, and food quality, increasing energy supply, and producing safer goods.

For the current study, the procured foxtail millet was used to make value-added products, specifically waffles and panjiri, which were compared to traditional recipes containing dhania powder and wheat, which served as the control. Initially, foxtail millet was substituted for dhania powder and wheat at 40% and 60%, respectively. However, it was discovered that all foxtail millet products were acceptable even at an 80% substitution level. As a result, recipes incorporating 40%, 60%, and 80% replacements for wheat and dhania powder were created.

Organoleptic evaluation of developed food products

These formulations were then subjected to organoleptic testing to determine their sensory properties and overall acceptance. A panel of semi-trained individuals from the Department of Food and Nutrition at Maharana Pratap University of Agriculture and Technology in Udaipur evaluated the developed products' sensory qualities. The panelists evaluated various foxtail millet-based products on color, appearance, texture, taste, flavor, and overall acceptability using a nine-point Hedonic rating scale, with 9 representing "like extremely" and 1 representing "dislike extremely."

Statistical analysis of data

The mean and standard deviation for each parameter were calculated. One-way Analysis of Variance (ANOVA) was used to assess the sensory and nutritional properties of the raw ingredients as well as to compare the value-added products made from foxtail millet.

Results

The purpose of this study was to evaluate foxtail millet's nutritional properties and Glycemic Index (GI) Assessment of foxtail millet.

Physical Properties

The evaluation of foxtail millet's physical properties revealed significant characteristics that influence its suitability for a variety of applications. The mean thousand grain weight and volume were 2.43±0.4 g and 5.0±2.0 ml, respectively, The bulk density was 0.23±0.01 g/ml, indicating the density and integrity of the grains. Foxtail millet demonstrated mild swelling and water absorption capacity, indicating that grain characteristics may vary.

Proximate Properties

The proximate composition analysis of foxtail millet revealed its nutritional value. The moisture content averaged 5.78±2.3 g per 100 g, which is lower than the values reported by other studies, indicating possible environmental influences on this parameter. The crude fiber and protein contents were slightly lower 8.93±2.8 g and 9.22±2.7 g per 100 g, respectively than common foxtail millet varieties studied by indicating a balanced nutritional value. Furthermore, foxtail millet had lower crude fat and ash content than other varieties, potentially providing healthier formulation options and a richer mineral profile.

In-Vitro Glycemic Index assessment of foxtail millet

According to Subhashini and Ushadevi (2011) [24], the glycemic index (GI) is an important metric for determining a food's effect on blood glucose levels. Foods are ranked according to their ability to raise blood glucose levels when compared to a reference food, usually glucose. The in-vitro glycemic index assessment of foxtail millet yielded a mean value of 52.49, indicating that the GI of the chosen millet variety is low, but these values were slightly higher compared to other studies. This low GI value suggests that foxtail millet may be beneficial for people trying to manage their blood sugar levels, adding to its potential as a health-promoting food.

Table 1: Distribution of Nutritional properties of Foxtail Millet

S.No.	Nutritional Properties of Foxtail Millet	Mean ± SD
1	Thousand kernal Weight (gm)	2.43±0.4**
2	Thousand Kernal Volume (ml)	5.0±2.0**
3	Bulk Density (g/ml)	0.23±0.01
4	Swelling Capacity (ml)	0.21±0.06**
5	Water Absorption Capacity (ml)	0.53±0.03**
6	Moisture (g)	5.78±2.3**
7	Crude protein (g)	9.22±2.7**
8	Fat (g)	3.13±0.5**
9	Ash (g)	2.34±1.9**
10	Crude fiber (g)	8.93±11.8**
11	Carbohydrates (g)	70.6 ± 8.59**
12	Energy (kcal)	347.45 ± 48.08**
13	In-vitro GI Assessment	52.49 ±1.92**

Values are (Mean ± SD) of three independent observations
**Significant at 5%

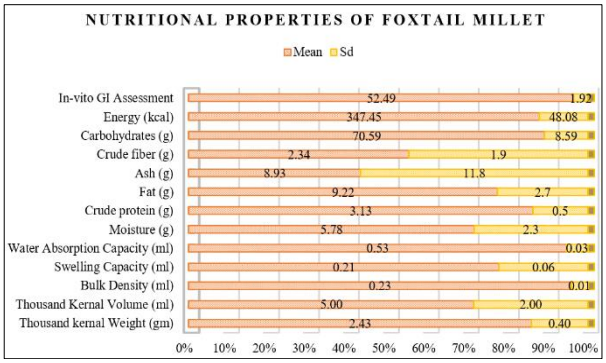

Fig 1: Distribution of Nutritional properties of Foxtail Millet

Table 1 and figure 1 shows that, according to the analysis of variance (one-way classification), the nutritional properties of foxtail millet were found to be significant at the 5% critical difference level, with the exception of bulk density, which did not vary significantly.

The foxtail millet products contained varying amounts of foxtail millet. Two value-added products, panjiri and waffles, were created. The study used foxtail millet in three different proportions: 40%, 60%, and 80%. The recipes were standardized and then tested for organoleptic properties.

Organoleptic evaluation of developed food products

In the organoleptic evaluation, From the given 3 proportions of foxtail millet, the panel members chose the 60% foxtail millet formulation (T_2) over the other two proportions used to create value-added products. These results were assessed using a nine-point hedonic scale. Foxtail millet panjiri was more acceptable than foxtail millet waffles. The mean scores and standard deviations for panjiri and waffles were 8.3±0.43 and 8.1±0.44, respectively, indicating high acceptance for both products, with a slight preference for the panjiri, as shown in table 2. This demonstrated a stronger preference for traditional food over modern food.

Development of foxtail millet products

Table 2: Distribution of Foxtail millet according to sensory attributes of panjiri and waffles

Variation	Sensory Attributes of Panjiri and waffles					
	Color	Flavor	Taste	Texture	Appearance	Overall Acceptability
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Control Panjiri	8±0	7.6±0.52	8±0.96	7.4±0.52	7.6±0.84	7.7±0.39
T_2 Panjiri	8.4±0.52	8±0.67	8.2±0.42	8.4±0.52	8.6±0.84	8.3±0.43
Control Waffles	7.6±0.5	7.9±0.87	7.6±0.84	7.9±0.57	7.7±0.42	7.7±0.57
T_2 Waffles	8.5±0.52	7.9±0.56	7.7±0.48	8.3±0.48	7.8±0.57	8.1±0.44

Discussion

The physiochemical properties such as thousand grain weight and volume showed lower values confirming previous findings by Nazni and Shobhna (2016) [16] and showed consistent values with bulk density and swelling capacity compared to quality studies by Sangma D. V, V (2019) [21]. The proximate composition was slightly less compared to study findings by Gurupriya (2019) [11], In fact we found that protein and fiber content was slightly lower compared to study conducted by Sharma and Niranjan (2017) [23]. The GI content was slightly higher compared to study investigated by Arora *et al.*, (2023) [2].

Summary

Millets have been grown in Asia since 2700 BC, making them one of the most ancient food grains. Millets are recognized as functional foods and nutraceuticals because they contain essential dietary fibers, proteins, energy, minerals, vitamins, and antioxidants required for human health. Foxtail millet, which thrives in arid climates, is underutilized in modern food products despite its health benefits. This study fills that gap by developing and standardizing products containing foxtail millet. Foxtail millet (*Setaria italica*) is known for its health benefits, such as high fiber content, protein quality, and essential minerals and vitamins. This study sought to investigate the incorporation of foxtail millet into nutritious and palatable food products, specifically panjiri and waffles, and to assess the impact on nutritional quality and sensory characteristics. The investigation included a detailed assessment of foxtail millet's quality attributes, specifically its physicochemical properties and nutritional composition. Subsequently, the research involved the development and standardization of value-added products, such as panjiri and waffles, incorporating varying proportions of foxtail millet. Sensory evaluations indicated a high level of consumer acceptance, with scores ranging from "moderately liked" to "very much liked." Notably, products containing up to 60% foxtail millet were particularly well-received.

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