PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol 11(sp4): 01–10
https://doi.org/10.14719/pst.5431

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REVIEW ARTICLE

Millet bran: The underrated ingredient with a potential to transform human nutrition

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OPEN ACCESS

ARTICLE HISTORY
Received: 01 October 2024
Accepted: 02 November 2024
Available online
Version 1.0 : 29 December 2024
Version 2.0 : 17 May 2025

Check for updates

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

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Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

CITE THIS ARTICLE
Kittur P, Meenakshi V, Vijayalakshmi R, Mini ML, Kalaiselvan A, Ilamaran M. Millet bran: The underrated ingredient with a potential to transform human nutrition. Plant Science Today.2024;11(sp4):01-10. https://doi.org/10.14719/pst.5431

Abstract

Millets are consumed by people across the globe. Millet bran (MB), a byproduct of preliminary processes like dehulling, debranning and milling, is often discarded or utilized as animal feed. Foxtail millet bran(FMB) consists of 9.39% crude oil, 12.48% crude protein, 51.69% crude fiber, 7.50% ash, and 8.29% moisture. Kodo millet bran (KMB) has a nutrient profile of 4.92% protein, 79.84% carbohydrates, 2.83% fat, 48.42% overall dietary fiber, 5.33% ash and 7.07% moisture. Little millet bran has a phenolic concentration of 465.67 µg, whole grain contains 148.53 µg, and pearled grain has 78.63 µg. Proso millet bran is composed of 9% fat, 26% carbohydrates, 36% dietary fiber and 14% protein, along with 3 mg gallic acid equivalent/g of phenolics. Bran is a promising ingredient for creating innovative functional and therapeutic foods since it contains good nutrients like protein, fat, dietary fiber, phenols, phytonutrients, flavonoids, and antioxidants. Hydrolytic rancidity is the primary challenge in using bran as food, and the only way to prevent it is through a process called stabilization, which inactivates the enzymes responsible for this issue. Stabilization of bran is crucial to preventing the formation of free fatty acids (FFA) due to the action of lipase. This review addresses stabilization techniques, health and therapeutic benefits and industrial applications for developing MB-based food products like bakery products, beverages and bran oil.

Keywords

bran; debranning; industrial applications; stabilization; therapeutic property

Introduction

Millets provide a notable return on investment, even under the pressures of climate change. Their climate-resilient features contribute to sustainable agriculture without chemical fertilizers (1). Sorghum (*Sorghum bicolor*), pearl millet (*Pennisetum glaucum* L.), finger millet (*Eleusine coracana* L.) and small millets like barnyard millet (*Echinochloa frumentacea* L.), proso millet (*Panicum miliaceum* L.), kodo millet (*Paspalum scrobiculate* L.), little (kutki) millet (*Panicum sumatrense*) and foxtail millet (*Setaria italica* L.) are widely cultivated in India that are adaptable to different agroclimatic conditions. Historically, the nation produced and consumed many millets, covering nearly the same region as wheat and rice (2). Millets are distinctive among cereals for their high calcium levels, dietary fiber, polyphenols and protein.

In recent years, millet-based dishes have increasingly been promoted for their role in a balanced diet and managing various health issues (3). However, the area designated for cultivating nutri cereals experienced a significant decline in the post-Green Revolution era. Between 1950-1951 and 2018-2019, this reduction amounted to 41.65%, indicating a substantial shift in agricultural priorities and practices that impacted the production of these important crops (2). The primary factors contributed to this decline include low yield compared to other food crops, absence of price incentives and input subsidies, subsidized supply of high-quality cereals via the public distribution system (PDS), shift in consumer preference since consequences of processing challenges, low longevity of flour and low social standing associated with millets (4). Additionally, the importance given to rice and wheat during the Green Revolution (5).

Bran is the tough outer layer of millet obtained during the initial processing stages, such as husking, polishing, dehulling, debranning, and milling (6, 7). These processes make grains more palatable and easier to cook or further process (6, 8).

The quantity of bran extracted varies from grain to grain according to the grain's structure and processing variables such as time, equipment and degree of dehulling or milling. For instance, bran constitutes 13-19% of the total grain weight in wheat (9) and 5-8% in rice (10). Millet bran, rich in fiber, can aid digestion and promote gut health. It can help control blood sugar levels, especially beneficial for diabetics or pre-diabetics. Millet bran's omega-3 to omega-6 ratio may reduce inflammation blood pressure and enhance blood vessel function, potentially reducing heart disease and stroke risk. Alpha-linolenic acid may aid cognitive function, memory, and learning, especially during childhood. Studies suggest omega-3 fatty acids may benefit individuals with neurological diseases. Further research is needed to understand their health benefits and impact on human health (11).

The husk and bran content of minor millets vary, with foxtail millet having 13.5% husk and 1-2% bran (12), while kodo millet and barnyard millet have up to 37% and 23% of each, respectively (13-15). Primary operations such as milling, dehulling, dehusking and debranning typically result in the removal of around 16-17% of bran in small millets. The production statistics pertaining to small millets demonstrate that roughly 0.062 to 0.066 metric tons of bran is yielded post-dehulling. This bran, which is acquired as a by-product, is either discarded or utilized as livestock feed (16).

During the refinement process, bran is removed, significantly reducing nutrients, dietary fiber, tannins, flavonoids, antioxidants, and polyphenols, suggesting that bran is an excellent source of these vital elements (17-21). The objective of this study on utilizing MB is to enhance nutrition through its fiber and vitamins, support health by reducing chronic disease risk, and promote sustainability by repurposing an agricultural byproduct. Additionally, it aims to assess the potential benefits for local farmers, provide gluten-free options and preserve culinary heritage, all while exploring market opportunities in the growing health food sector.

Production scenario of millet in India

Millets in India are broadly categorized into major and minor millets based on their size and scale of cultivation. Pearl millet and sorghum are major millets, while finger millet, foxtail millet, kodo millet, proso millet, small millet, barnyard millet and browntop millet are minor millets. India is the world's biggest millet producer. Most of India's states cultivate one or more types of millet crops (22). India produces 16.9 million tons of millets, or around 6% of the nation's total food grain supply, on approximately 12.7 million hectares. The production of 10.1 million tonnes of pearl millet is cultivated on around 7.4 million hectares. Finger millet (1.1 million ha) yields 1.58 million tonnes, sorghum (4.35 million ha) yields 4.63 million tonnes, and other millets (0.44 million ha, yielding 0.35 million tonnes) are the next most productive crops. Over 95% of the region planted under millet cultivation is composed of sorghum, pearl millet and finger millet and less than 5% is made up of small millets, such as barnyard millet, foxtail millet, little millet, kodo millet and proso millet (23).

Debranning techniques adopted for millets and cereals

Every minor millet grain has the same fundamental structure as other millet grains: an endosperm, a germ, a pericarp, a seed coat or testa and an aleurone layer (24). According to botanical characteristics, millet is divided into caryopses and utricles. In caryopses, the pericarp adheres to the seed firmly, but in utricles, the pericarp and seed coat are only connected at one point, making the pericarp easily removed. Foxtail, proso and barnyard are utricle types, whereas kodo millet is caryopsis (25, 26). However, some studies have categorized proso under the utricle type and kodo, foxtail and barnyard under the caryopsis type (27). This disparity emphasizes the intricacy and diversity of botanical classifications, implying that additional study could be required to create a firmer categorization scheme for millets.

Traditional manual hand pounding is still used for basic processing steps, such as dehulling and decortication. Three distinct methods for dehulling small millets are abrasive decortication, rubbing technique and metal friction decortication. Small millets can be ground into fine powder using hammer mills, burr mills and plate or disk mills (28). Due to their small size, a significantly larger amount of the grain-specifically, the bran, bran-rich fraction and husk-is lost during processing, resulting in a higher loss of nutrients (29). Because of its nutritional value, bran (or hull) from millets, including proso, foxtail, pearl millet, jowar, etc., are processed as livestock feed (30).

A secondary product of millet processing produces millet bran (31, 32). Various researchers have documented the utilization of rice dehullers, millers, barley pearlers, or abrasives because of smaller grain sizes and the absence of specifically designed dehullers for processing minor millet grains (28). This is the limiting factor for using bran in value-added products. Several scientists have reported the procedures involved in dehusking, dehulling, polishing, or milling grains to extract hull and bran from millets for research purposes, as depicted in Fig. 1.

Stabilisation of bran

Despite the nutritional advantages, bran is primarily disposed of due to its shortened shelf life caused by the synthesis of FFA (38). Therefore, bran needs to be stabilized immediately after being obtained. Stabilization is the process of inhibiting hydrolytic degradation. A FFA level of more than 10 mEq/kg for human consumption is unsuitable (39). Lipase activity and formation are the primary indicators of hydrolytic degradation in rice bran (RB).

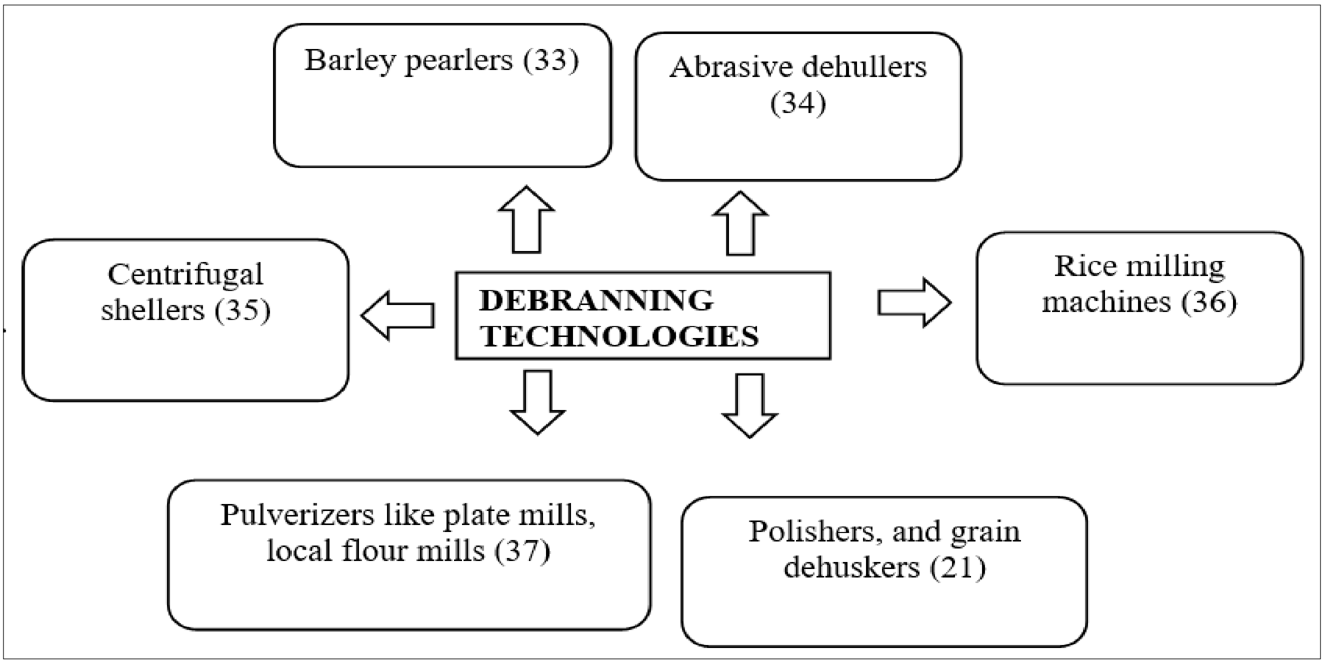

Fig. 1. Different debranning machineries used for processing of millets.

Lipoxygenase and peroxidase activities are less common indicators of RB deterioration. However, FFA is the most frequently used measure due to its straightforward determination (40). Many authors have documented the successful stabilization of cereal bran using various techniques, as shown in Table 1.

Millet bran was stabilized using a 900W microwave for 2.5 minutes (49). Chemicals like acetic acid, phosphoric acid and sodium metabisulphite failed to limit the rise in FFA. However, hydrochloric acid at a concentration of about 30 ml/Kg helps substantially in managing the lipase activity and decreases the FFA (50). Rice bran was microwave-heated (2450 MHz for 3 minutes) to stabilize it. Stabilized RB was infected with lactic acid *Bacillus* culture to make probiotic-treated RB. The FFA percentage in RB that had been probiotic-treated ranged from 4.35 to 7.95 over the first four weeks of storage, while it varied from 4.10 to 7.50 in RB that has been stabilized from the first to the fourth week (51). Microwave heating at 100% power for 1-2 minutes and dry heating at 120°C for 10-15 minutes is used to stabilize the RB. Both heat stabilization and microwave heating were more effective than dry heating at keeping RB from rancid (52).

Free fatty acid, peroxide, anisidine and iodine levels were examined to track chemical changes during proso millet bran (PMB) 180 days of storage at room temperature and in a refrigerator. During the duration of the storage, there was no discernible alteration in the iodine value of 137±2. There was a substantial interaction between the storage circumstances and time for the FFA levels, peroxide and anisidine. The initial thirty days of preservation saw a significant rise in FFA content until the ninetieth day. In both storage conditions, a similar trend was seen. Hydrolytic rancidity development results in an increase in the content of FFA (53).

Numerous attempts have been made to enhance bran stabilization by utilizing microwaves, ohmic heating, and infrared treatments. Stabilization and increased rice bran oil (RBO) extraction yield can be obtained by using ohmic heating with an electrical field of 100 V/cm intensity and an alternating electric current of 60 Hz (54).

To stabilize RB and assess the stability efficiency by residual lipase activities, a comparison was made between 11 distinct treatments, comprising 6 heating treatments and 5 non-heating treatments. The findings suggested that RB may be stabilized by microwave, extrusion, steaming, -80°C, ultraviolet light and infrared heating (55). While oil peroxide values and color may increase, extrusion and microwave methods are appropriate for large-scale, fast industrial processing. The RB stabilized by steaming and oil extracted by immersion had the lowest α-tocopherol (11.12±0.48 µg/g) and γ-oryzanol (957.18 ± 53.7 µg/g) compared to the greatest α-tocopherol (42.38 ± 0.53 µg/g) and γ-oryzanol (1190.1 ± 89.3 µg/g) in the ohmically stabilized RB. Ohmically stabilized RBO has a greater overall antioxidant capacity than steaming (56).

On the other hand, the UV (ultraviolet) irradiation process is an easy and energy-efficient stabilization technique that doesn't affect nutrients or oil quality. The RB stabilization through extrusion processing enhanced its functional attributes. It increased the quantity of dietary fiber and improved the capacity to hold water and foam but lowered the capacity to hold oil. Phytic acid concentration was also decreased by stabilization in contrast to unstabilized bran (57).

FSSAI (Food Safety and Standards Authority of India) specifications for millet bran /cereal bran

The RBO must exhibit clarity and be devoid of rancidity, impurities, sediments, foreign substances, water and artificial colorings or flavorings. Clarity is determined by the absence of cloudiness after storing the filtered sample at 35°C for 24 hours. Refining is necessary to make RBO suitable for human consumption (58). Specification for RBO is given in Table 2.

Nutritional profile of different millet bran

The nutritional composition of MB differs across various millet types. Here's an overview of the nutritional profiles of some common MB (Table 3).

Proso millet bran

The quantity of fat in various types of proso millet and bran varied. White-coloured proso MB types had 3.95 - 6.84% (free) and 0.33 -

Table 1. Summary of different stabilization methods and their effect

Technique for stabilization	Criteria for stabilization	Assessment of stabilization	Result of stabilization	Reference
Extrusion	70°C, 90°C, 110°C and 130°C, with screw speed set at 300 rpm	Acid value Peroxide value Lipoxygenase activity Lipase activity	After 28 days of accelerated storage at 37°C, the acid value of untreated RB was approximately 6 mg KOH/100 g. In contrast, the acid values of stabilized samples were around 1.7 mg KOH/100 g, except for the atmospheric steam-treated RB.	(41)
Microwave heating	700 W, 2450 MHz for 1, 3 and 5 minutes (moisture content was adjusted to 21% before the treatment). MW power densities were 2, 4 and 6 W/g	FFA Peroxide value	The FFA content in RB treated with microwave (MW) at a power density of 6 W/g for 5 minutes was 1.12%, while the untreated control had an FFA content of 58.5% after 28 days of storage at room temperature.	(42)
Microwave heating	850, 925, and 1000 W for 3, 4.5 and 6 minutes	FFA Acid value Peroxide value	Stabilization was examined in three RB milling fractions and composite RB. The findings suggest stabilizing at 925 W for 3 minutes is optimal for the RB milling fractions.	(43)
Infrared heating	Medium wave IR radiation at 500, 600, and 700 W IR power for 3.0, 5.5 and 7.0 minutes	FFA	Stabilization was studied in three RB milling fractions. Stabilizing at 700 W using infrared power for 7 minutes resulted in a shelf life of 90 days, with no significant change in the FFA content of the RB fraction obtained from the first whitening step.	(44)
Infrared heating	2400 W, unspecified radiation intensity at 100, 120 and 140°C for 5, 10, 15 and 20 minutes	Peroxide value FFA	The FFA content of raw RB rose from 4.4% to 62.8% after 6 months of storage at 25-30 °C. In contrast, RB was treated with infrared (IR) at 140 °C for 15 and 20 minutes and its FFA content was maintained at approximately 7%.	(45)
Hot air-assisted radio frequency (HA-RF)	A 6 kW, 27.12 MHz pilot-scale free -running oscillator RF system integrated with a hot air oven	FFA Peroxide value Lipoxygenase activity Lipase activity	Rice bran treated with hot air-radio frequency (HA-RF) heating to 100 °C for 15 minutes can be stored at 35 °C for up to 60 days while remaining below acceptable quality thresholds without any negative effects on product quality.	(46)
Infrared heating	Infrared drying apparatus until the surface temperature of the RB reached 85 °C	FFA Peroxide value Lipase activity Lipoxygenase activity Peroxidase activity FFA Peroxide value	The FFA content of untreated RB rose from 5.41% to 49.87%, while that of infrared (IR)-treated RB increased from 5.21% to 14.11% after 20 days of storage at 20 °C. Lipase, lipoxygenase, and peroxidase activities were significantly higher in the IR-treated samples by the end of the storage period.	(47)
Ohmic heating electrical	The initial moisture contents were 20%, 30% and 40%. The applied voltages were 132 V, 150 V, 168 V, 189 V and 216 V, with a frequency of 50 Hz. The field strengths used were 44, 50, 56, 63 and 72 V/cm	FFA Peroxide value	After 75 days of storage, the FFA content of ohmically heated bran was 4.77%, while raw RB had an FFA content of 41.84%.	(48)

FFA: Free fatty acid, MW: Microwave, IR: Infrared, RF: Radio frequency

Table 2. FSSAI Standards for rice bran oil

Parameter	Specification
Moisture and volatile matter	Not more than 0.1% by weight
Saponification value	180 - 195
Acid value	The accepted threshold is a maximum of 0.5
Iodine value (Wij's method)	90 - 105
Refractive index at 40°C Or Butyro-refractometer reading at 40°C	1.4600 - 1.4700 51.0 - 66.4
Unsaponifiable matter,% by weight (a) for chemically refined (b) for physically refined Oryzanol content	(a) Not more than 3.5% (b) Not more than 4.5% Not less than 1.0%
Flash point (Pensky marten closed method)	Not less than 250°C

Table 3. Nutritional profile of various millet brans

Millet bran	Moisture (%)	Protein (%)	Fat (%)	Fiber (%)	Ash (%)	Reference
Foxtail millet bran	6.10 - 9.07	6.78 - 12.93	5.65 - 9.63	42.56- 51.69	2.15 -7.78	(59)
Proso millet bran	7.32	1.78-26.33	1.92- 8.96	31.63	5.77- 8.44	(53)
Kodo millet bran	5.53 -7.07	4.92	2.83	48.42	5.33 – 7.74	(60)
Sorghum bran	6.13	6.7	4.6-4.9	18.04	2.15 - 7.78	(61)
Barnyard bran	6.79	5.15 - 5.19	4.04	38.4%	9.11 - 23.10	(62)

0.49% (bound) lipids, while red variants had 3.45 - 4.29% and 0.30 - 0.70%, respectively. Bran of the red and white kinds had a total lipid content ranging from 4.14 to 7.27 %. Ninety percent of the fatty acids in proso millet flour and bran are composed of oleic linoleic and palmitic acid (33).

Proximate analysis of four different types of proso MB was studied (Table 4). Crude fiber, crude protein and crude fat content were highest in yellow proso MB, starch content was highest in white proso MB and ash content was highest in black proso MB (63).

Functional properties like oil holding capacity (OHC) and water holding capacity (WHC) were studied. WHC and OHC were higher in the husks than in the bran. The white proso millet husks had the highest levels of WHC (2.53 g/g) and OHC (1.61 g/g). The OHC of the yellow and black proso millet brans was the greatest, while the yellow proso millet brans' WHC was maximum (63).

Foxtail millet bran

The phenol content of milled FMB was higher than that of whole or pearled grain; the highest phenol content (mg/100 g) was found in foxtail bran (510.53 ± 50.34), followed by whole grain (132.76 ± 8.66) and the lowest phenol content (104.00 ± 0.00) in pearled grain (64).

It was noted that 9.39 ± 0.17% crude oil, 12.48 ± 0.41% crude protein, 51.69 ± 2.14% crude fiber, 7.50 ± 0.18% ash and 8.29 ± 0.16% moisture were found in FMB. Tocopherol in the oil extracted from FMB was 64.83 ± 0.83 mg/100 g. It was mostly made up of 15.53 ± 0.31 mg/100 g oil of α-tocopherol and 48.79 ± 0.46 mg/100 g of oil of γ-tocopherol. Additionally, linolenic (66.5%), oleic (13.1%) and saturated fatty acids, including stearic and palmitic acid, were present in foxtail millet bran oil (FMBO) (16).

Foxtail millet bran can serve as a natural source of antioxidants, both as a nutraceutical and for the food industry. The predominant unsaturated fatty acids in FMBO are linoleic and oleic acid, making up more than 80% of the oil. Saturated fatty acids comprise a small part of the fatty acid, accounting for about 14% of the total. Furthermore, it was discovered that FMO possesses comparatively elevated levels of tocols, sterols, γ-oryzanol and squalene-all of which have the potential to be advantageous (65).

The functional and physicochemical characteristics of FMB dietary fiber (FMBDF) were examined, and the possibility of extracting dietary fiber from the bran using enzyme techniques was examined. The findings showed that FMB was an excellent way to produce dietary fiber. The results of the functional and physicochemical property experiments indicated that the FMBDF had a swelling power of 2.06 ml/g and a water-holding capacity of 3.24 g/g. Its capacity to adsorb bile salts (76.65 mmol/g for sodium taurocholate and 143.03 mmol/g for sodium cholate) explains its capacity to decrease cholesterol (59).

According to fatty acid composition analysis, defatted foxtail millet bran (DFMB) oil has a higher mono-unsaturated fatty acid content than RB, peanut and olive oils. Large amounts of mono-unsaturated fatty acid, which can lower cholesterol, were present in the FMBO. Still, there was a lack of poly-unsaturated fatty acids necessary for human health (16). Fig. 2 illustrates the high concentration of mono-unsaturated fatty acid (87% mono-unsaturated, 9% saturated fatty acid 4% and poly-unsaturated) in FMBO (66). Therefore, FMBO, which is also high in mono-unsaturated fatty acids, may be a more nutrient-dense dietary source than known olive oil on the market.

Kodo millet bran

A study revealed the quantity of protein (4.92%), carbohydrates (79.84%), fat (2.83%), overall dietary fiber (48.42%), ash (5.33%) and moisture (7.07%) in 100 g of KMB (60). Kodo millet bran exhibited the maximum antioxidant potential due to significantly greater levels of dietary fiber (61.52%), phytic acid (630 mg/100 g), flavonoids (22.37 µg retinol equivalent/g) and total phenols (449.27 mg gallic acid equivalent/100 g) (67).

Little millet

Upon milling little millet, 27% of the hull was produced. Compared to whole grain (148.53 ± 6.31) and pearled grain (78.63 ± 1.79), bran had a phenol concentration (465.67 ± 20.1). For both millets, there was no noticeable difference in the phytic content, zinc, or copper in the whole grain or its milled fractions (64).

Sorghum bran

Sorghum bran can function as a nutraceutical because it is an excellent source of fiber, antioxidants and phytonutrients. The percentage of dietary fiber in sorghum bran varied from 40% to 45%. When sorghum bran is employed in product development, its high fiber and phytate content lowers the product's calorific value (68). 3-Deoxyanthocyanidins were found in sorghum and sorghum bran, which have antioxidant qualities equivalent to anthocyanins and were resilient to pH changes. Black sorghum bran had twice as much anthocyanins (10.1 mg/g) as red (3.6 mg/g) and brown (3.6 mg/g) sorghum bran. Bran contained three to four times more anthocyanins than whole grains reported. Thus, it was discovered that black sorghum was the most promising crop to use as a natural food coloring source (69).

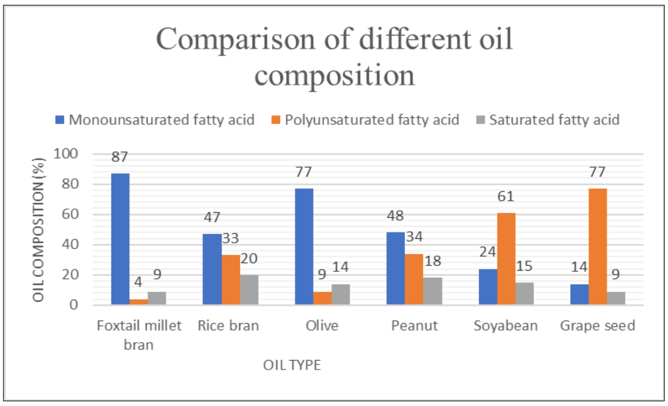

Fig. 2. Comparison of different oil composition (66).

Table 4. Proximate analysis of brans of different color proso millet bran

Parameter	Red	White	Yellow	Black
Crude protein (%)	14.75±0.08	14.56±0.04	16.23±0.03	13.13±0.01
Crude fat (%)	20.43±0.01	20.29±0.07	24.27±0.36	22.24±0.18
Crude fiber (%)	35.80±0.37	36.23±2.31	39.92±0.91	39.19±0.43
Starch (%)	6.36±0.27	7.11±0.34	6.62±0.38	4.63±0.10
Ash (%)	8.54±0.11	8.51±0.09	6.17±0.03	8.69±0.13
Moisture (%)	7.62±0.06	6.74±0.23	6.41±0.15	6.82±0.17

Application of millet bran in food processing

Breads and buns

Sorghum bran supplement (15%) gave bread outstanding phenolic and antioxidant content without compromising the bread's physical characteristics, such as specific volume or appearance. The bran gave the loaves a dark brownish color (dahlberg 55). Similarly, bread with 12% brown sorghum bran, 5% flaxseed and 2% soy flour added dark brown color to the loaves and improved dietary fiber, antioxidants and palatability (70).

Breads supplemented with 0, 5, 10, 15 and 20% RB showed that up to 10% incorporation was acceptable. Sensory acceptance fell as the percentage of bran increased. Based on gravimetric tests, each unit of bran showed an increase in water absorption, a decrease in volume and a rise in weight. Farinograph revealed that when bran addition increased, dough mixing stability decreased (71).

Muffins

Rusks and muffins were made by incorporating barnyard millet bran (BMB) with wheat flour at varying percentages (0, 5, 10, 15, 20, 25 and 30%). When BMB was added, the hardness of the rusk and muffin increased. Muffins at 15% and rusks at 30% were suitable (49).

Foxtail millet bran (0, 10, 15, 20, 25 and 30%) made muffins instead of refined wheat flour. Physical properties like height, weight and baking loss were measured over five replications. The muffin height increased as bran content increased and the color of the muffin became darker with bran incorporation. The panel members accepted muffins enriched with 30% MB (72).

Beverages

To create an antioxidant-rich wine from FMB, research found that foxtail millet bran wine (MBW) had six times more polyphenols than millet wine (MW) and demonstrated stronger antioxidant activity in the 2, 2-diphenyl-1-picrylhydrazyl (DPPH), trolox equivalent antioxidant capacity (TEAC) and ferric reducing antioxidant power (FRAP) tests. It was determined that vanillic acid, p-coumaric acid, syringic acid, and ferulic acid were the four phenolics in it. Additionally, MBW has more amino acids than commercially produced millet wine (CAMW) and MW. Results showed that it is possible to use MB wine as a nutritional supplement, nutraceutical, or functional beverage (73).

Production of millet bran oil and extraction methods

Millet bran oil

Originally from China, foxtail millet is one of the earliest crops to be cultivated and is currently grown worldwide (66). The nutritional and medicinal benefits of millet have been well documented (74). The oil extracted from FMB is high in linoleic acid (66.5%) and oleic acid (13.1%). Stearic acid (6.3%) and palmitic acid (6.4%) are two of the saturated fatty acids. Linoleic acid (71.2%) was the predominant fatty acid in the millet oil. Dilinoleoyl-monoolein (LLO, 17.2%) and trilinoleate (LLL, 29.3%) were identified as the two predominant triacylglycerols, as determined by the 1,3-random-2-random hypothesis (16).

Supercritical solvent extraction techniques

In recent years, there has been a growing interest in supercritical carbon dioxide extraction (SCE). This technology employs carbon dioxide in a supercritical state, above its critical temperature and pressure, making it an attractive solvent for temperature-sensitive materials (75). The subcritical carbon dioxide (CO_2) Soxhlet method is a novel approach that combines the advantages of Soxhlet extraction and CO_2 extraction to yield RBO effectively. Using the subcritical CO_2 process, the oil contains about ten times more oryzanol and tocol compounds and lower FFA levels and peroxide values than oil extracted with hexane (76). Traditional methods mainly use solvents and cold-pressing techniques to extract bran oil. Using commercial-grade hexane in solvent extraction (SE) presents several disadvantages, including poor color quality in RBO, substantial air pollution, and health risks due to its toxicity (77). Subcritical propane extraction (SPE), SCE and traditional SE were used to extract the FMBO. Examinations were conducted on the yield, physicochemical characteristics, fatty acid profile, tocopherol content, and oil oxidative stability. Foxtail millet bran oil yields by SPE, SCE, and SE were 21.79%, 19.65% and 17.14% of the raw material's weight, respectively. These values corresponded to 75.54%, 86.60% and 96.03% of the total quantity of oil. Based on gas chromatography (GC) analysis, the variation in the fatty acid profile was insignificant. Still, the methods of extraction had a substantial impact on the physicochemical attributes (peroxide value, color, and saponification value) (78). Through HPLC analysis, the primary vitamin E components found in the produced oils were determined to be α- and β-tocopherols. SPE proved to be more effective than SE and SCE in extracting tocopherols. The oil recovered by SPE demonstrated the highest oil oxidative stability in the Rancimat test, which may have been caused by its low peroxide value and high tocopherol content. Compared to SCE and SE, SPE used smaller periods and lower pressures in consideration of the oil quality. SPE proved an effective and focused technique for obtaining oil from FMB (79).

Solvent extraction techniques

Solvents are used to extract oil from seeds that have relatively little oil or pre-pressed oil cakes to increase oil yields. The economic benefits of commercial-grade hexane have made it a popular choice worldwide. It is a powerful solvent that is easy to recover and has good solubility. Hexane, however, is linked to several issues. It causes serious environmental problems such as air pollution and ends up producing bran oil with low color quality. Its toxicity also presents health risks. Numerous efforts have explored alternative solvents, including halogenated hydrocarbons, alcohols, carbon dioxide, hydrocarbons (utilized in supercritical fluid extraction), and water (80). Because of their higher safety, other short-chain alcohols, such as isopropanol, and ethanol, have also been suggested as an alternate extraction solvent (81, 82). For high yields of high-quality crude edible oil, d-limonene, an agricultural by-product of the citrus sector, is a good substitute for hexane-based solvents (83). However, due to its high boiling point and elevated latent heat, limonene is not ideal for edible oil extraction because of its high energy cost. Energy-efficient solvent recovery techniques, like membrane separations, may help overcome this issue, making limonene-based oil extraction more cost-effective.

Mechanical extraction techniques

The mechanical or cold pressing method doesn't utilize heat treatment or organic solvents. It is an alternative to traditional practices and shows promise in oil extraction due to its lower labor and cost requirements than SE. Cold pressing offers advantages in terms of safety, efficiency and simplicity. Furthermore, oils extracted through this method boast superior nutritional properties and chemical-free end products, increasing interest in cold-pressed plant oils. (84). Given the drawbacks of SE-such as the toxicity and cost of solvents and significant environmental impacts -alternative extraction methods are gaining traction. The desire for high-quality crude oil, a focus on environmental sustainability and the ability of mechanical systems to support continuous processes are essential factors driving this shift (85).

Therapeutic properties of millet bran

Consuming whole grains is linked to a lower chance of developing several diseases, including constipation, type II diabetes, hypercholesterolemia, cardiovascular disease and several gastrointestinal malignancies (86). Whole grains are nutrient-rich, including dietary fiber, vitamins, minerals, phytochemicals and phenolic compounds. The grain's bran contains most of these nutrients (87, 88). Therefore, a considerable amount of fiber, minerals and phenolic chemicals are present in millet and wheat brans, which contribute to their natural antioxidant potential and may be used to prevent or treat certain illnesses. The interaction between fiber and antioxidants may contribute to fiber's health benefits.

In addition, FMB's bound polyphenols of the inner shell (BPIS) showed anti-inflammatory properties in HT-29 cells and nude mice produced by lipopolysaccharide (LPS). When BPIS was applied to LPS-induced HT-29 cells, pro-inflammatory cytokines like IL-1β (interleukin-1β) and IL-6 (interleukin-6) were downregulated, and anti-inflammatory cytokines like IL-10 (interleukin-10) were increased. By using BPIS, tumor tissue growth was also inhibited. In light of this, BPIS may be employed as a pro-oxidant agent to reduce inflammation (79).

A new 35 kDa protein was isolated and purified from FMB (89). The findings demonstrated that by triggering cell cycle G1-phase arrest, the crude protein dramatically inhibited colon cancer cell growth *in vitro* and in xenografted tumors in nude mice. Foxtail millet bran-derived peroxidase (FMBP) inhibited colon cancer cells' migration ability, making it a potential treatment for colon cancer patients (90). The FRAP (ferric reducing antioxidant power) and DPPH (2, 2-Diphenyl-1-picrylhydrazyl) assays demonstrated significant antioxidant activity in FMBO. It was also beneficial in reducing ethanol-induced liver damage in mice (91).

Challenges of utilizing millet bran

Utilizing MB presents several challenges. Firstly, there is a lack of efficient debranning machinery, which hampers processing effectiveness. Additionally, the high costs of extracting MB oil make it less competitive than other oil sources. Compounding these issues is the insufficient research on the toxicity and therapeutic benefits of MB, which limits its acceptance in the market. Furthermore, stakeholders often have low awareness of the nutritional advantages of MB, affecting its potential for wider adoption. Lastly, in some social circles, using MB for human consumption is viewed unfavorably, hindering its utilization (11).

Conclusion

Emerging trends in health-conscious diets and sustainable food sources align well with the benefits of MB. As consumers seek nutritious options, MB's high fiber, vitamins and minerals support digestive health and overall well-being. Its resilience and low water requirements enhance its sustainability, attracting environmentally conscious consumers. Despite being underutilized compared to other cereal brans like RB, MB has significant potential for developing functional and nutraceutical foods due to its nutritional properties and high monounsaturated fatty acid content. Rich in fiber, minerals and phenolic compounds, it offers natural antioxidant benefits and can help prevent various health issues, including cardiovascular disease and type II diabetes. However, research into food products such as beverages, bran oil, and baked goods remains limited. Advances in debranning and stabilizing technologies could accelerate MB's industrial applications, making it a compelling ingredient for modern diets.

Acknowledgements

We sincerely thank Tamil Nadu Agricultural University for the technical support, and we would like to thank the Social Education Economical Development Society (SEEDS) Farmer Producer Organization (FPO) Virudhunagar, Tamil Nadu, for providing financial support.

Authors' contributions

PK carried out writing and proofreading of the article. VM carried out conceptualization, literature review, and correction of the article. RV designed the article. MLM helped in collecting the literature and gave technical help. AK contributed to literature collection and MI contributed in prefinal correction. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: All authors do not have any conflict of interest to declare.

Ethical issues: None

Declaration of generative AI and AI-assisted technologies in the writing process

While preparing this work, we used the Grammarly AI tool to improve grammar and increase the article's readability. After using this service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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