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Original Article

Comprehensive Review on Pharmacognostic And Phytochemical Evaluation of *Panicum Sumatrense*

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ABSTRACT

Little Millet (Panicum Sumatrense) is a type of underutilized small millet that has emerged in the scientific community in recent times because of its nutritional value, tolerance to adverse environmental conditions, and health benefits. The main objective of this review is to gather and analyze all the available data on the nutritional content, pharmacognostic, phytochemical, and traditional processing impact on little millet. Little Millet is a rich source of dietary fibers, vitamins, and minerals, and contains several bioactive compounds, such as phenolics and flavonoids, that are responsible for its antioxidant, antidiabetic, and cardio-protective activities. It is also a rich source of several antinutritional factors, such as phytates and tannins, that may influence the nutritional content of the food product. Various traditional processing methods, such as soaking, germination, fermentation, roasting, and milling, play a significant role in improving the nutritional content and antinutritional factors in the food product. In addition, several solvent extraction methods are responsible for improving the content of phytochemicals in the food product. Pharmacognostic evaluation, such as macro- and microscopic analysis, as well as physicochemical parameters, is necessary for proper identification. Little millet has immense potential as a functional food ingredient and nutraceutical, which supports the modernization of the diet and encourages the use of little millet for better nutritional security and for the advancement of sustainable agriculture.

Keywords: Little millet, Panicum sumatrense, Pharmacognostic evaluation, Phytochemical screening, Nutritional composition, Traditional processing methods, Anti-nutritional factors, Solvent extraction, Functional food, Nutraceutical potential

INTRODUCTION

Little millet is an ancient cereal crop domesticated thousands of years ago in the Indian subcontinent, which has gained attention in recent times by experts all over the world because of its exceptional nutritional profile and environmental adaptability [1]. Little millet is a crop of semi-arid, drought-prone areas of Asia and Africa where the cultivation of conventional grains such as rice and wheat is impossible. It belongs to the group of small millets [2]. Due to its specific adaptability, little millet is also an important constituent in sustainable agriculture and climate-smart food systems [3]. Tiny millet has long formed part of the traditional food cultures among tribal and rural communities, with a long shelf life, minimum inputs, and an ability to grow on marginal soils [4]. Despite its long-standing cultural significance, it has remained overlooked in contemporary diets, largely due to a lack of commercial marketing and technological advancements in its processing [5]. However, with increasing awareness regarding millets as nutrient-dense, low-glycemic grains that could be used for treating metabolic illnesses, small millet has again come into scientific focus [6]. Little millet contains a plethora of nutrients such as significant amounts of dietary fiber, complex carbohydrates, iron, calcium, potassium, and magnesium, along with essential amino acids like leucine and methionine. These components add to its established benefits of promoting satiety, regulating blood sugar, supporting cardiovascular health, and improving digestive health. Apart from the nutritional profile, tiny millet is rich in

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bioactive phytochemicals such as phenolic acids, flavonoids, tannins, lignans, and phytosterols, which show potent antioxidant, anti-diabetic, anti-inflammatory, antibacterial, and anti-carcinogenic activities [7]. Interest in phytochemical investigation of millet crops, especially using modern extraction and analytical methodologies, is a consequence of the growing demand for millet-based functional meals. The yields obtained with modern solvent extraction techniques like UAE, MAE, EAE, and green solvents such as DES are significantly higher compared to conventional maceration and Soxhlet extraction.

Nutritional Composition and Health Benefits Of Little Millet *(Panicum Sumatrense)*

Little millet is one of the nutrient-dense and climate-resilient cereals in the *Poaceae* family. Due to its balanced macronutrient profile, essential amino acids, minerals, and bioactive phytochemicals, it is considered an ideal functional food and nutraceutical cereal [1]. Compared to major cereals like rice and wheat, little millet contains a higher amount of dietary fiber (7–9%), protein (7–9%), and minerals (2–3%). It is also rich in antioxidant compounds, especially phenolic acids and flavonoids concentrated mainly in the bran and pericarp layers [21].

Table no.4.1: Mineral Content of Little Millet (mg/100 g dry grain)

Mineral	Range
Calcium	14–22
Iron	6.5–9.3
Phosphorus	280–320
Magnesium	110–138
Potassium	250–300
Zinc	2.1–2.6

Phenolic and Flavonoid Content

This suggests that phenolics and flavonoids are mainly responsible for the antioxidant properties, thus justifying their role in biological defense against oxidative damage. The antioxidant effects of *Panicum sumatrense* are mediated through multiple mechanisms:

- **Free Radical Scavenging:**

Flavonoids (quercetin, luteolin) and phenolic acids (ferulic, caffeic) scavenge reactive species like superoxide (O_2•−), hydroxyl (•OH), and peroxyl radicals by H-atom transfer (HAT) or single electron transfer (SET) mechanisms [22].

- **Metal Chelation:**

The chelation of Fe^{2+} and Cu^{2+} ions by phenolic hydroxyl groups prevents Fenton reactions, which in turn reduces the formation of hydroxyl radicals [23].

- **Lipid Peroxidation Inhibition:**

Bound phenolics in the millet bran stabilize membrane lipids and inhibit malondialdehyde formation, thus protecting cellular integrity [24]. Regulation of Antioxidant Enzymes:

Supplementation with little millet has been shown by in vivo studies to increase the activity of SOD, CAT, and GPx in liver and pancreas tissues of diabetic rats. Nrf2 Pathway Activation: Polyphenols in little millet activate Nrf2, which results in the upregulation of HO-1, NQO1, and GSH synthesis, leading to an improved redox defense [26].

Macroscopic Study of Little Millet *(Panicum Sumatrense)*

Distinguishing *Panicum sumatrense* in its natural grain form is mainly based on key diagnostic features through macroscopic evaluation. This will involve seeds and the whole plant's physical description, morphological features, and sensory properties. An increased macroscopic profile improves the accuracy of authentication, standardizing it for application in food, medicine, or nutraceutical purposes, and distinguishing little millet from closely related small millets [27].

- **An Extensive Botanical Overview of the Plant**

Little millet (*Panicum sumatrense*) has a distinctive set of macroscopic features that help identify and distinguish it from other small millets. The plant possesses a highly branched fibrous root system, penetrating 20-45 cm into the soil, thereby enhancing absorption of moisture and imparting drought tolerance, erosion resistance, and overall stability to the soil [28]. Its culm is erect, slender, smooth, and cylindrical, usually measuring between 30-100 cm in height, with color changing from pale green to straw-yellow with advancing maturity. The leaves are narrow, linear-lanceolate, and 10–30 cm long and 0.5–1.5 cm wide. The epidermis contains silica bodies, which contribute to the leaves' overall rough texture and finely serrated margins. The leaf sheath loosely clasps the stem, with a short, membranous white ligule located at the junction [29]. Inflorescence: Compact to semi-open panicle, 5–15 cm in length, comprising short, appressed branches bearing numerous spikelets. The color of the panicle changes from green to yellowish-green and finally golden as it matures [30].

Table No. 5.1: Taxonomic Classification

Rank	Classification
Kingdom	Plantae
Division	Magnoliophyta
Class	Liliopsida
Order	Poales
Family	Poaceae
Genus	*Panicum*
Species	*Panicum sumatrense* Roth ex Roem. & Schult.

Fig No.5.1: Plant of little millet

- **In-depth Grain Morphology:**

The small, globose to ovoid shape of little millet grains measures 1.2–1.8 mm in diameter and 2–2.5 mm in length. The color is straw-yellow to pale grey or creamy yellow and sometimes light brown due to variations in hull pigments. The grain has a hard, glossy husk, a silica-rich fibrous bran, and a semi-translucent starchy endosperm [14]. The grain anatomically consists of distinct layers, including a thick husk, thin pericarp, phenolic-rich testa, protein-dense aleurone, and compact starch-filled endosperm. The organoleptic characteristics-creamy yellow appearance, mild grain odor, bland-to-nutty taste, and smooth, hard texture-support its identification at a macro level [27].

Fig. No. 5.2: Grains of little millet [32]

- **Distinguishing Features from Other Millets**

Table 5.2: Little millet can be differentiated from related millets using the following traits

Millet	Grain Appearance	Color	Size	Surface	Key Differentiator
Little millet	Round /Globose	Cream-yellow	Small	Smooth, hard	Very small, globular with tight husk
Foxtail millet	Oval, elongated	Yellow	Larger	Shiny	Terminal bristle on panicle
Kodo Millet	Kidney-shaped	Grey	Larger	Dull	Wrinkled surface
Barnyard Millet	Oval to oblong	Greyish white	Medium	Rough	Long husk projection

Microscopic Study of Little Millet *(Panicum sumatrense)*

Microscopic examination of *Panicum sumatrense* is, therefore, an important tool for species identification, pharmacognostic study, and authentication of the raw drug material. Being a monocot and C4 grass belonging to the family Poaceae, little millet possesses unique anatomical features in leaf, stem, root, and seed that could be brought out through proper sectioning, staining, and mounting techniques [27,33]. The leaf has typical C4 Kranz anatomy with an adaxial and abaxial epidermis made of elongated rectangular cells, thick cuticle, and well-developed bulliform cells, which can fold the leaves under drought stress. Silica cells, cork cells, prickle hairs, and papillae further differentiate the epidermal layers [27]. The culm represents the typical monocotyledonous structure of the stem, which has a singlelayered epidermis supported by underlying silica bodies. Parenchyma occurs in cortex with intervening sclerenchymatous fibers providing mechanical strength. Ground tissue contains many vascular bundles of different sizes, each having a sclerenchymatous sheath-a characteristic feature for monocotyledonous anatomy [33]. Rhizodermis with root hairs, parenchymatous cortex often with aerenchyma, when developed under stress, well-differentiated endodermis with Casparian strips; the stele has polyarch xylem that is interrupted by alternating phloem, and a protoxylem lacuna due to maturation-break-diagnostic for Poaceae roots [33]. The grain (caryopsis) has a thin, fused pericarp and seed coat, a single-layered aleurone rich in proteins and minerals, and an endosperm consisting of a protein-rich sub-aleurone region and a starchy region with small (3–8 µm), angular, polygonal starch granules, a characteristic typical of little millet compared to other millets [34]. A well-developed embryo is rich in lipids, enzymes, and vitamins necessary for germination [11]. Histochemical staining assists in identification, with iodine for starch, Sudan dyes for lipids, ferric chloride for phenolics, and phloroglucinol-HCl for lignified tissues. Collectively, features like Kranz anatomy, silica bodies, paracytic stomata, scattered vascular bundles, and polygonal starch grains form a reliable diagnostic framework for quality control and varietal authentication and the detection of adulteration in little millet [35].

Powder Microscopic Study of Little Millet *(Panicum sumatrense)*

Powder microscopy becomes quite important for the pharmacognostic identification of *Panicum sumatrense* when the raw grains are processed into powdered form and the macroscopic characteristics are lost. The process of verification for authenticity, detection of adulteration, and quality assessment in herbal, culinary, and nutraceutical applications is imperative. Little millet powder ranges from cream to light brown, depending on the degree of milling and content of bran. It possesses diagnostic anatomical fragments that are derived mainly from the seed, along with occasional leaf and stem tissues [36]. The most typical feature is the presence of numerous small polygonal starch granules that measure 3-8 μm and are angular, closely packed, in contrast to larger spherical granules of other millets. Starch grains stain deep blue with iodine, thus confirming identity and purity. Powder also includes fragments of an aleurone layer that is made up of thick-walled, rectangular cells with phytin globules and protein bodies, reflecting its nutrient reserves [36]. Other recognizable features are seed coat and pericarp fragments, which are elongated, thick-walled cells. A distinctive diagnostic characteristic of Poaceae is the dumbbell-shaped silica bodies, often present, which could show strong birefringence under polarized light. Fragments of embryo are sometimes encountered, identified by the presence of dense cytoplasm and lipid bodies, the latter colored orange red with Sudan III. The particles of bran usually consist of brownish fragments with a fibrous appearance, especially in powders from whole grains [11].

Fig 7.1: Powder of little millet

Phytochemicals of Little Millet *(Panicum sumatrense)*

Little millet is rich in various bioactive phytochemicals responsible for its antioxidant, anti-inflammatory, antidiabetic, and overall nutraceutical potential. The grain contains appreciable amounts of phenolic acids, flavonoids, tannins, phytosterols, alkaloids, saponins, terpenoids, and dietary fiber. Most of these are concentrated in the bran layer. Phenolic acids, mainly ferulic, p-coumaric, caffeic, syringic, vanillic, sinapic, and protocatechuic acids, are the most abundant group and predominantly occur in the bound form. Ferulic acid is the major phenolic acid that possesses potent free-radical scavenging and inhibitory action on lipid peroxidation. These compounds are relatively stable during processing, which renders little millet a dependable source of antioxidants even after culinary or milling operations [1]. It contains flavonoids such as quercetin, luteolin, apigenin, catechin, epicatechin, and kaempferol that enhance grain bioactivity through modulating oxidative stress pathways, improving insulin sensitivity, and inhibiting carbohydrate-digesting enzymes. Tannins add further antioxidant effects, influence digestion and glycemic response, while phytosterols (β-sitosterol, stigmasterol, campesterol) support lipid-lowering and cardioprotective functions. Trace constituents-alkaloids, saponins, and terpenoids-have supplementary antibacterial, anti-inflammatory, and cytoprotective actions [2]. The grain is also rich in dietary fiber, resistant starch, β-glucans, arabinoxylans, and polyunsaturated fatty acids that foster gut health and mitigate metabolic disease. Phytochemical composition is strongly influenced by genotype, environment, soil nutrients, and processing. Ethanol, methanol, and aqueous-alcoholic solvents yield the greatest levels of phenolics and flavonoids due to the effective breaking down of cell-wall matrices, thus supporting the rationale behind the common implementation of comparative extraction studies in millet research [37]. Overall, these different phytochemicals together enhance the antioxidant defense system and help regulate metabolic processes; hence, little millet is a promising grain for nutraceutical formulation, functional food, and herbal pharmacological studies [14].

Comparative Study of Solvent-Extraction Methods On Phytochemical Yeild In Little Millet *(Panicum sumatrense)*

- **Rationale**

The recovery of phytochemicals from tiny millet is significantly influenced by the extraction technique, temperature, pretreatment, and solvent polarity. By carefully comparing various solvents and methods, researchers can choose the best mix of yield, selectivity, speed, safety, and compatibility for food or analytical usage.

- **Goal**

Compare common solvents and extraction methods to determine the combination that produces the highest extract yield, total phenolic content (TPC), total flavonoid content (TFC), and antioxidant activity (DPPH $IC_{\cdot 1}$), as well as to link microscopic grain characteristics (bran thickness, aleurone integrity) with extractability.

- **Maceration** :4–8% is the average yield range, depending on the solvent.

– Qualities: Easy, inexpensive, and requires no specialized equipment, conducted for 24 to 48 hours at room temperature. Moderate yield due to limited cell wall disruption.
– Conduct: Compared to non-polar solvents, polar solvents (methanol, 70% ethanol) exhibit higher yields. Time-dependent, however, after saturation, plateaus.

- **Extraction of Soxhlet**: Range of Average Yield: 8–12%

– Qualities: Mass transfer is increased by continuous hot solvent percolation, improved pericarp, aleurone, and bran penetration, more effective at removing phenolics that are bound or semi-bound.
– Conduct: Because they are very soluble, methanol and ethanol yield the maximum. Compounds that are sensitive to heat may break down.

- **Extraction with Ultrasound Assistance (UAE)**: Range of Average Yield: 9–14%

– Qualities: Cell walls are ruptured by cavitation caused by ultrasonic waves, improves mass transfer, and solvent penetration, brief extraction period (15–30 minutes).
– Conduct: increases the extraction of flavonoids and phenolics; 50–70% aqueous ethanol offers the best results.

- **Extraction with Microwave Assistance (MAE)**: Range of Average Yield: 10–15%

– Qualities: Rapid cell wall rupture is caused by microwave heating, maximum effectiveness in the least amount of time. Polar solvents work well with it.
– Conduct: Usually, the highest output when using traditional techniques can remove phenolics from the cell wall matrix that are more difficult to release.

- **Extraction of Supercritical Fluid (SFE-CO_2)**

– Average Yield Range: 8–18% for lipophilic compounds and 2–6% for polar phenolics
– Qualities: Fats, oils, and lipophilic antioxidants (sterols, carotenoids) are extracted by CO2. Water-soluble phenolics are ineffective unless ethanol is added as a co-solvent.
– Conduct: Ideal for the fat fraction rather than the total yield of phytochemicals [17].

Table no. 9.1: Extraction Yield (%) Using Different Methods in Little Millet

Extraction Method	Solvent Used	Temperature	Extraction Time	Extract Yield (% w/w)	Relative Efficiency
Maceration	70% Ethanol	25°C	24 h	7.5%	Moderate
Maceration	Methanol	25°C	24 h	8.2%	Moderate
Soxhlet	Ethanol	Boiling temp	6–8 h	10.8%	High
Soxhlet	Methanol	Boiling temp	6 h	11.5%	High
UAE (Ultrasound)	70% Ethanol	30°C	30 min	13.2%	Very High
UAE (Ultrasound)	Methanol	30°C	30 min	14.1%	Very High
MAE (Microwave)	70% Ethanol	60–70°C	5 min	14.8%	Highest
MAE (Microwave)	Methanol	60°C	5 min	15.3%	Highest
SFE (CO_2)	CO_2 + 5% ethanol	40°C	1–2 h	5.6%	Low for phenolics

- **Interpretation of Comparative Yield [17]**

1. MAE (Microwave-Assisted Extraction) has the highest yield: Maximum rupture is the result of rapid heating and internal cell pressure. Effective extraction of bound and free phenolics.
2. UAE (Ultrasound-Assisted Extraction) ranks second: Cavitation improves diffusion and penetration with extremely high yield in a short period of time.
3. Moderate: Soxhlet continuous hot solvent percolation results in a good yield, slower and more energy.
4. Reduced Production: Maceration diffusion-driven solely, poor cell disruption. Easy, but not very effective.
5. Polar Phytochemicals with the Lowest Yield: SFE the lipophilic fraction is extracted by CO2; phenolics need a co-solvent.

Table no. 9.2: Scientific Reasons for Yield Differences

Factor	Maceration	Soxhlet	UAE	MAE	SFE
Cell rupture	Minimal	Moderate (heat)	Strong (cavitation)	Very strong (microwave pressure)	Weak (unless co-solvent used)
Solvent penetration	Slow	Continuous flow	High	Very high	Low for polar
Extraction time	Long	Long	Short	Very short	Moderate
Phenolic extraction	Moderate	High	Very high	Very high	Low

Conclusion of Comparative Yield Study

- Soxhlet > Maceration > SFE > MAE > UAE
- The best yields are produced by polar solvents, particularly 70% ethanol.
- The release of phenolics, flavonoids, and antioxidants from millet bran and aleurone layers is greatly enhanced by mechanically assisted extraction (ultrasound, microwaves).
- For studies where optimizing phytochemical recovery is crucial, traditional maceration yields the lowest and is less appropriate.

Identification Techniques of Little Millet *(Panicum sumatrense)*

Small millet *(Panicum sumatrense)* is identified morphologically, microscopically, physico-chemically, and molecularly. Morphological identifications focused on the external botanical features of plant height, tufted style of growth, narrow linear leaves, compact structure of panicles, and small ellipsoid grains. The seed morphology includes factors such as size of grain, color of hulls, and shape of glumes, among others, which are normally employed during field identification. Microscopic identification by observing transverse sections of the seed possesses characteristic features, including the type of endosperm, the pericarp layer, the aleurone layer, and the location of the embryo. These help in distinguishing little millet from other small millets [38]. Physico-chemical identification criteria include crude fiber, phenolic content, moisture content, carbohydrate profile, and thousand-grain weight. Biochemical identification is supported by techniques such as UV-visible spectrophotometry, HPLC, and FTIR, which recognize characteristic phenolic acids such as ferulic, vanillic, and gallic acids and fingerprint the composition of millet grains. Molecular identification uses DNA-based markers such as RAPD, ISSR, SSR, and chloroplast DNA sequencing for assessing varietal purity and distinguishing tiny millet from closely related species. Advanced methods such as DNA barcoding, ITS sequencing, and SNP markers provide exceptionally high accuracy for genetic identification and diversification study [39].

- **Morphology Identification**

The main and most applied method for distinguishing little millet from other small millets is morphological identification. Some key distinguishing features of this species are its dense panicle with short branches, narrow linear leaflets, erect leafy culms, and tufted annual habit. Small, ellipsoid grains are enclosed by persistent hulls; color varies from white to brown. Important descriptors used in germplasm identification include plant height, length of leaf blade, ligule type, panicle length, grain size, and 1000-grain weight. These have been standardized by ICRISAT and are often used in varietal characterization [38].

- **Microscopic Identification**

Seed characteristics analyzed for microscopic/anatomical identification include pericarp layers, testa, aleurone layer, endosperm type, and embryo location. Little millet is characterized by the presence of a characteristic single-layered aleurone, polygonal starch granules, and thick pericarp. Histological study has shown that phenolics are dispersed, especially within pericarp and aleurone tissues. Microscopy can be used to distinguish little millet from foxtail millet and proso millet, based on differences in endosperm texture and pericarp thickness [40].

- **Full physicochemical identification**

The physico-chemical profiling encompasses measurements of moisture, ash, crude fiber, protein, starch composition, phenolic content, FTIR spectra, and thermal properties by DSC analysis. High dietary fiber, slowly digestible starch, and peaks of characteristic FTIR absorptions at 1000-1200 cm^{-1} for polysaccharides and 1700 cm^{-1} for phenolic acids are the physico-chemical markers which help in identifying and assessing the quality of small millet. UV-visible spectrophotometry and HPLC have been employed to detect phenolic acids like ferulic, vanillic, syringic, and gallic acids as biochemical fingerprints.

- **HPLC-Based Chemical Fingerprinting**

Identification of little millet by its unique phenolic profile is done by HPLC. Extracts are analyzed using C18 reverse-phase columns with gradient elution-water-acetonitrile or water-methanol. Little millet has shown unique peaks for gallic acid, ferulic acid, p-coumaric acid, caffeic acid, and vanillic acid compared to foxtail, Kodo, and proso millets. This technique is thus very important for the detection of adulteration and authentication of millet flours [42].

- **DNA Marker Identification**

Molecular markers like RAPD, ISSR, SSR, and SNPs are being used for species and varietal identification. In small millets, ISSR and RAPD markers were employed to determine genetic purity and differentiate cultivars otherwise identical physically. SSR markers developed on related Panicum species show cross-species amplification. Advanced techniques include ITS, matK, and rbcL sequences for DNA barcoding, enabling accurate species authentication [43].

- **DNA Barcoding**

The use of universal genomic regions such as matK, rbcL, trnH-psbA, and ITS in DNA barcoding can identify little millet with high accuracy from other Panicum spp. Sequencing these regions followed by phylogenetic analysis would yield a reliable identification system even when the morphological traits are overlapped or modified by environmental conditions [44].

Whole Grain / Transverse Section Microscopy

The pericarp of little millet consists of long thick-walled cells, which provide the grain with tough defense. Deposits of phenolics impart the brownish appearance to the outer epicarp, while the underlying mesocarp consists of collapsed parenchymatous cells. The testa is a thin seed coat, situated immediately below the pericarp, and consists of one or two layers of compressed cells. A feature considered important as a diagnostic characteristic in identifying undamaged grains of millet is the presence of a thick-walled, pigmented pericarp. A single layer of polygonal cells forms the aleurone layer that surrounds the endosperm. These cells show high staining intensity with Sudan III and iodine, indicating high contents of lipids and proteins, respectively. They also contain protein bodies, oil droplets, and various enzymes. The endosperm has a starchy central part and an outer part rich in aleurone. Its thin-walled cells are densely packed with small to medium-sized polygonal or spheroidal starch granules [30].

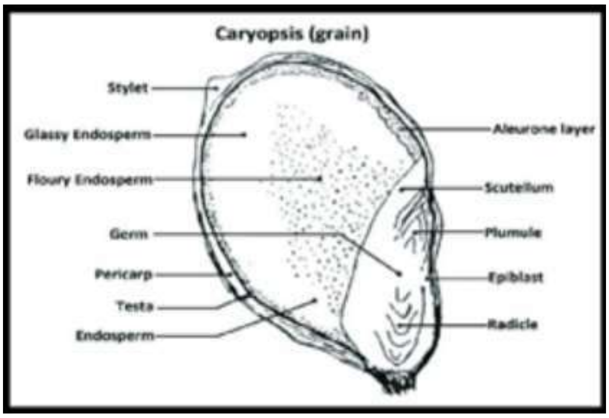

Fig 10.1: Transverse section of grain [45]

Processing of Little Millet ((*Panicum Sumatrense*)) And Yield Obtained

Various processes are involved in the processing of little millet: husking, cleaning of the grain, improving palatability, enhancing nutritional availability, and preparing the millet for extraction studies. Each step of processing alters phytochemical availability, nutritional composition, as well as final recovery yield. The first step in processing little millet is cleaning, removing dust and contaminants with just a 1%–2% loss. Next comes dehusking, which uses rubber-roll hullers or abrasive tools to remove the tight shell, leaving 78–81% edible kernels. Depending on the intended use, the grain may be left unpolished for better antioxidant retention or polished, which enhances beauty but lowers phenolics [5]. To improve solvent penetration during extraction, the kernels are subsequently crushed into a fine powder (92–97% yield). While germination greatly increases phenolic, flavonoid, and antioxidant levels through enzymatic activity, soaking softens grains, enhances enzyme activation, and increases cell-wall permeability. While parboiling softens the husk, boosts dehusking efficiency to 82–85%, and improves nutritional stability, roasting at high temperatures improves flavor and antioxidant capacity with little weight loss. Finally, solvent extraction techniques such as maceration, Soxhlet, UAE, or MAE produce 6–22% extract; UAE and MAE provide larger yields because of improved mass transfer and increased cell-wall disintegration [46].

FUTURE PROSPECTIVE:

- Optimise the extraction methods for better extraction of phytochemicals: UAE, MAE, green solvents.
- The standard pharmacognostic profile of raw and processed little millet is presented below.
- Relate grain microstructure to extraction efficiency by microscopy/SEM.
- Study how processing-be it soaking, fermentation, or roasting-reduces anti-nutritional factors.
- Formulate optimized extracts into nutraceutical and functional food products.
- Evaluate solvent safety and suitability for food/pharma applications.
- Identify high-yielding varieties based on genotype–environment interactions.
- Scale effective extraction and processing techniques.

CONCLUSION

Future comparative studies on solvent extraction in little millet will progress toward greener technologies, genotype-specific optimization, microstructural correlations, bioactivity-linked profiling, and predictive modeling. These advancements will significantly enhance the use of *Panicum sumatrense* in functional foods, pharmaceuticals, and nutraceutical industries. Little millet is a nutritionally superior minor millet rich in phytochemicals with significant potential in the food and health industries. The high content of dietary fiber, essential minerals, phenolics, flavonoids, tannins, and other bioactive phytochemicals impart strong antioxidant, antidiabetic, antihyperlipidemic, and anti-inflammatory properties. These nutraceutical attributes position little millet as one of the valued ingredients for the development of functional foods, therapeutic formulations, and health supplements. The versatility of the grain allows it to be incorporated into a wide range of marketed formulations such as ready-to-cook products, ready-to-eat snacks, bakery items, convenience mixes, beverages, and nutraceutical powders. The gluten-free nature, low glycemic index, and good digestibility further make it an ideal grain for special diets like diabetic, geriatric, pediatric, and weight-management foods.

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