J. Mountain Res. P-ISSN: 0974-3030, E-ISSN: 2582-5011 DOI: https://doi.org/10.51220/jmr.v19-i2.6
Vol. 19(2), (2024), 43-52

# A Comprehensive Review on the Nutrition, Processing, Phytochemical, and Pharmacological Properties of *Eleusine coracana* (L.) Gaertn (Poaceae)

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**Received: 17.05.2024 Revised: 22.09.2024 Accepted: 10.10.2024**


**Abstract:** Millets as an efficient as other cereals grains in addressing nutritional insecurity, malnutrition and the challenges posed by burgeoning global population. Finger millet *Eleusine coracana* (L.) Gaertn is a significant agricultural crop grown in India thriving under different suboptimal agro-climatic conditions. Finger millet is considered as one of the wonder crop that has immense climatic-resilience properties as well as health benefits which are primary attributed to its for its exceptional nutritional profile. Further the phenolic components present in the seed coat exhibit excellent properties namely anti-oxidant, anti-osteoporosis, anti-diabetic and enzymes inhibitory properties. Additionally, it displays seemingly improved healing properties, which makes this crop an excellent candidate for fulfilling major pharmacological requirements. Moreover, the processing of finger millet is a significant factor for their commercial value in marketing but Government support and consumer awareness are essential for explore the whole potential of finger millet to address global challenges. Additionally, research and development are essential to create value-added food products from finger millet, enhancing its potential as a sustainable and climate-resilience crop.

**Keywords:** Millets ● Processing ● Finger millet ● Phenolic compounds ● Value-added products

## Introduction

The global population faces a grave threat from nutritional insecurity and malnutrition especially affecting those mostly consume cereal-based diets that is deficient in vital micronutrients. National growth is affected by the hunger and improper nutrition of native people of the country. To address this concerns, conventional and primitive agricultural cereal crops can be cultivated in certain places, which are currently being displaced by non-commercial food crops, is one of the possibly effective ways to improve food security (Singh & Raghuvanshi, 2012). Millets are getting in trended globally due to their nutritional content, gluten-free nature, and ecological sustainability. According to the National Academy of Agricultural Sciences, millets are small-grained cereals that are divided into major and minor categories as per their grain size. *Pennisetum glaucum*, *Sorghum bicolor*, are major millets, while *Eleusine coracana*, *Echinochloa frumentacea*, *Setaria italica*, *Panicum miliaceum*, and *Panicum sumatrense* were minor millets. Millets are the primarily domesticated crops to be farmed by human civilization. The grains of all millets (Poaceae) have diverse size, shape, colour, high in dietary fibre, protein, vitamins, minerals etc. are an important part of a healthy diet (Bora et al., 2019). The crop is pathogen tolerant and can cultivated on marginal field where other cereals can't be produced (Gull et al., 2014). These cereals crops can survive at unfavourable climatic conditions i.e., climatic fluctuations, droughts, and low soil productivity (Bommy & Maheswari, 2016). Hence, familiar as "climate resilient or wonder crops. By the potential utilization of these "wonder crops" with the appropriate efforts, partnerships, and policies, we can create the way for a healthier and more sustainable future for everyone (Kanojia et al., 2024).

Amidst these wonder cereals, "Ragi" *Eleusine coracana* (L.) Gaertn) known for their health role in human development. It is herbaceous annual millet crop species widely cultivated about 25 countries in Africa and Asia like India, Ceylon, Malaysia, China and Japan. Finger millet is the member of Poaceae family and originated from Africa, hence, grown in South Asia and Africa with diverse agro-climatic environment (Karuppasamy et al., 2013). Around 5000 BC it was domesticated in various region, popularly known as "Mandua" or "Ragi" in India (Ambati & Sucharitha, 2019). The grain has naked-caryopsis with reddish-brown seed coat, which is significance for preparation of conventional food like flatbread (roti), light porridge (ambali) and dumplings (mudde) (Devi et al., 2014). In South-east-Asia and East-Africa these minor millets server as primary dietary stable for large communities with low-income (Vagdevi et al., 2023). Africa and Asia, finger millets positioned fourth in millets production after the sorghum, pearl millet and foxtail millets (Antony et al., 2018). In India and Africa annual production of finger millet is 4.5 million tons, out of these, 1.2 million and 2.5 million tons of the crop produced in India and Africa respectively (Ramashia et al., 2019). Whole grains are rich Calcium and contain about 0.34% Calcium (Ca), that is relatively high percentage as compared to remaining grains, which is the essential macronutrient for child growth, pregnant lady and the adults for good tissue and cells growth, with the well development of teeth and bones (Kumar et al., 2016). *Eleusine coracana* stands as crucial genotype against the food insecurity of communities from infertile, dry, and marginal lands of Eastern-Africa. It is the most suitable crop to unfavourable agro-environmental conditions with low essential agricultural inputs such as fertilizer, fungicides, and weedicides. In spite of this, Ragi grain is a gluten-free with high nutraceutical properties and low glycaemic index important for diabetic patients. Therefore, including millets in our daily diet, help to eliminate nutrient deficiencies and improve our overall nutritional health (Tripathi et al., 2023). Despite of ragi being important in essential nutrients, which makes it potential crop for large-scale production and the creation of various value-added food items, it remains largely ignored and underutilized as a crop. The present review was aimed to examine the effects of processing methods (traditional as well as modern methods) on the nutrient composition, and anti-nutritional content of finger millet seeds. Despite of its useful characters, health empowerment properties, here is a few research and studies on effects of processing on finger millets quality.

**Phytochemical composition**

The phytochemicals or biological active substances are chemical compounds produced by plant species, generally to resist the bacteria, fungi, plant virus infections, and herbivores. It has positive therapeutic health effects. Finger millet gain popularity as a functional food because of its elevated level of dietary fibre and polyphenol content. In comparison to primary stable cereals like wheat and rice, it has the highest levels of bioactive and nutritious compounds. The research has revealed that finger millet contains a diverse range of phenolics, however it's evident that phenolic acids and flavonoids have been effectively extracted and utilized rather than phenolics. Chandrasekara & Shahidi, (2011) reported that the seed coat of finger millet has a higher amount of phenolic compounds at 0.8% as compared to whole flour (6.2%). The polyphenol tannins and phenolics are higher, while flavonoids are smaller amount. The gallic acid, vanillic acid, protocatechuic acid, salicylic acid, syringic, ferulic acid, etc are analysed for its health advantages (Udeh et al., 2017). Due to the high percentage of tannins present in finger millets serves as a barrier against the fungal infection and enable the grain to withstand with fungus infestation. The important flavonoids identified in finger millets are condensed tannins, quercetin, gallo-catechin, epigallocatechin, catechin, epicatechin, and proanthocyanidins (Chandrasekara & Shahidi, 2011; Udeh et al., 2017). The study of Xiang et al. (2019) revealed that p-coumaric acid and ferulic acid mostly found in the bound form, whereas epicatechin and catechin dominated in the free fraction.

 DOI: https://doi.org/10.51220/jmr.v19-i2.6

## Millet's Processing

The processing involves transformation of raw materials in the final consumable by products following different treatments using traditional as well as modern techniques. In order to increase the productivity, nutritional content, quality, food processing techniques are evolved and strongly supported by Singh & Raghuvanshi, (2012). Before entering in the processing procedure, each grain necessarily goes through a number of preliminary procedures to remove undesired materials, including cleaning (stones, chaffs soil particles, stalks, and piece of other grain crops, grading, size reduction and separation (Ambre et al., 2020). Finger millet in India, commonly grind into a fine powder and use the whole flour to make traditional dishes like roti (flatbreads), kazhi (*Eleusine coracana* balls), and less concentrated porridge (kanji) (Shobana et al., 2009). Apart from these customary foods, malted, fermented, and popped items are also made from finger millet. Considering its nutritional potential, different millet-based food products i.e., bakery, fermented, snack, weaning, and health foods can be made (Bhatt et al., 2022).

## Methods of Processing

### 1. Physical processing treatments

**1. (a) Soaking:** Soaking is a pre-treatment method for millets that increases their nutritional value and digestibility. Millets are soaked with distilled water and then left it at 30-60°C overnight (Saleh et al., 2013). The grains are immersed in lukewarm or hot water, after that dried in an oven (hot air) for 90 minutes to enhance zinc bioavailability (Ramashia et al., 2018). Soaking reduces the level of antinutritional chemicals such as phytic acid, and improving mineral absorption (Table 1.)

### 1. (b) Milling/decortications

Milling is a crucial phase in the processing of millets, because it includes reducing the size and removing the seed coat or coarse bran, which makes up a substantial percentage of millets and must be dehusked and debraned before use (Singh & Raghuvanshi, 2012). The milling process comprises stages such as sorting, cleansing, hulling, removing bran, and kilning to prepare for subsequent processing (Rasane et al., 2015). Flour is created from unbroken seeds and kernels with delicate endosperm, this makes it hard to cook and polish like rice or cereals. Flour is prepared by milling or pulverizing it and replacing the hard husk with 10% water. Milling eliminates antinutrients and increases iron bioavailability. Finger millets significantly reduced 74.7% polyphenolics and 39.8% phytate phosphorus following the milling step (Ramashia et al., 2019). The milling methods comprise of the implements of modern and traditional equipment, primitive stone mills, ball mills, burr mills and hammer mills. The milling method produces fine flour for chapatti, but coarse flour is utilized for mudde and pez, which are compact balls and thin porridge (Patel & Verma, 2015).

**Table 1. Studies showing the effects of soaking on the Finger millets**

| S. N. | Processing effects | References |
|---|---|---|
| 1. | Soaking at 25°C for 1-2 days decreases polyphenols, phytate, saponins, oxalates, and trypsin inhibitors, hence increasing mineral bioavailability and nutritional quality. | Hotz & Gibson, (2007) |
| 2. | Several antinutritional factors are effectively inactivated due to the absorbed water during soaking and enhances the heat transfer during cooking. | Wang et al. (2022) |
| 3. | Soaking with NaOH solution or water for about 8 hours, the tannins compounds of ragi is recorded low. | Syeunda et al. (2021) |
| 4. | The phytic acid content dropped significantly after soaking about 12 hours. | Shigihalli et al. (2018) |
| 5. | Finger millets pressure cooking reduces total phenolic content, bio-accessible polyphenols, flavonoids, and tannin while increasing polyphenol and flavonoid bioavailability. | Hithamani & Srinivasan, (2014) |

| | | |
|---|---|---|
| 6. | Finger millets hydrothermal treatment increases the digestion of carbs from 61 to 73g/100g and proteins from 79 to 91g/100g. | Dharmaraj & Malleshi, (2011) |
| 7. | Boiling water or steam cooking, like soaking, can deactivate thermal-labile anti-nutrients in *Eleusine coracana* | Kakade & Hathan, (2015) |
| 8. | Zinc bioavailability was increased by soaking then finger millets in lukewarm water and after that drying in an oven (hot air) at 60°C for 1 and half hours. | Ramashia et al. (2019) |

## 2. Biochemical processing treatments

### 2. (a) Germination

Germination is a traditional step of millets processing, where whole unhusked grains are soaked for 2-24 hrs and then spread on a damp cloth for up to 24-48 hrs (Shimray et al., 2012). Germination is less-expensive process without use of high-cost instruments and an adaptable processing method. From centuries, it is used to soothe the seed coat and enhance the nutritional content and percentage of carbohydrates, essential amino acids, vitamins, and minerals. Subsequently, enhances the useful characters of the millet or cereals (Pushparaj & Urooj, 2011). Germination improves seed nutritional content and functional qualities by needing moisture, oxygen, and ideal temperature, maintaining the majority of minerals, vitamins, and lowering the phenolics of finger millets (Syeunda et al., 2021; Abioye et al., 2022). It involves the shifting of seed from resting to active states (Ghavidel & Prakash, 2007). The germination rise the protein content of finger millets due to enzyme development and amino acid synthesis, resulting in increased digestibility and lower anti-nutritional content, hence increasing important mineral bioavailability (Nguyen et al., 2022) (Table 2.).

**Table 2. Showing the various effects of germination on the Finger millets**

| S.N. | Treatment Germination | References |
|---|---|---|
| 1. | The total phenolic content of finger millets is expected to fall by around 33.5% upon germination. | Hithamani & Srinivasan, (2014) |
| 2. | During the germination phase, the oxalic acid level falls due to the washing out of oxalate. | Suma & Asna, (2017) |
| 3. | The alkaloid content of finger millets also experienced augmentation. | Antony et al. (2018) |
| 4. | The phytic acid levels dropped from 676.77 mg/100g to 587.20 mg/100g. | Patel & Dutta, (2018) |
| 5. | Germination lowers pH and raises total titrable acidity in finger millets, which is necessary for catabolic process of compound. | Owheruo et al. (2019) |
| 6. | After germination, the reduced anti-nutritional content, reduced trypsin inhibitor activity, tannins and phytic acid content was observed | Rathore et al. (2019) |
| 7. | A reduction about (42.63%–38.46%) in the total phenols and (61.66%–33.33%) in tannins recorded, while antioxidant activity (26.66%–33.33%) and flavonoid content (48.30–51.13%). | Syeunda et al. (2021) |
| 8. | Improving the bio-accessibility of essential minerals, with the increase in enzymatic activity and decrease in anti-nutrients. | Nguyen et al. (2022) |

### 2. (b) Fermentation

The fermentation process (metabolic process) has been used conventionally as well as modern processing methods for the preparing the fermented foods products and drinks in homes, rural areas and in small-scale industries (Osungbaro, 2009). Finger millets grains work as the base material for the growth of microorganism and these microbes evolved the chemical changes in grains due to the enzymatic actions. *Lactobacillus salivarius*, an important yeast for fermentation processing of finger millet, enhanced the amino acid tryptophan and lysine level (Rathore et al., 2019). In fermentation food processing and production involves changes the polysaccharides into the monosaccharides with the presence of some enzymes. Microbial activity transforms food and beverages in beneficial ways. Fermented foods like porridges, pancakes, and beverages have long been enjoyed, thanks to this natural process, which is a crucial stage in their preparation (Singh & Raghuvanshi, 2012). Michaelsen et al. (2008) suggested that fermentation stands as the most ancient and efficient means of the preserving foods by the processing step. Fermentation diminished the antinutrient elements in millets as well increase nutritional content.

## 3. Thermal/Hydrothermal processing treatments

### 3. (a) Popping/Roasting

Roasting, a conventional step, has been practiced for age-long time in rural areas as part of the processing of finger millet. Popping treatments aid the transformation of raw cereal or millet grain into fine flour. Popping reduces the moisture content and hardens the seed coat and, which then facilitates the efficient removal of endosperm for flour, consequently extending the shelf life. It is an intense thermal treatment (70 to 80°C) provided to seeds and the causing the endosperm burst out from the grain in an irregular or distorted shape. Roasting can significantly decrease poisonous substances such as alkaloids, goitrogenic substances, cyanides and saponins. Additionally, result also revealed that roasting also enhance the starch and nitrogen digestion in laboratory conditions. Heating affects the protein digestibility, making them more prone to hydrolysis (Chandrasekara & Shahidi, 2011) (Table 3.).

### 3. (b) Parboiling

Parboiling or partial boiling is a hydrothermal treatment technique, which is efficient in rice processing and also used for the millets. There are 3 major steps of parboiling: steeping, steaming and then drying (Saleh et al., 2013). Steeping performed at around 70°C for 10 to 24 hours allows for complete water absorption, resulted the reduction in phytic acid content. Extending the steeping time may further reduces the phytic acid levels 25% to 30% (Sene et al., 2018). After steeping, steaming process ensues, in which starch of the endosperm undergoes gelatinization at elevated temperature, either the use of steamer or autoclave. Ultimately, an open-air drying method is employed to decrease the retaining moisture content to an acceptable level (10%). This process is important as it can increase the nutrient availability and digestibility of the grains, with minimum breakage in milling and improve the grain texture. Parboiling facilitates the endosperm separation from grain (with husk) or bran and increase the nutrition absorption from seed outer coat upon soaking. This process increases the residual starch and decreases the glycemic index of millets (Kaushik et al., 2021) (Table 4).

### 3. (c) Extrusion

Extrusion of finger millets is one of the popular innovative approaches for converting ingredients into the value-added by products. It works on the fundamental of cooperative efforts of shear force along with intense heat and pressure, resulted to alter the starch profile (Nikmaram et al., 2017). Ready to eat food products of millets with various shape, size, fragrance, taste and texture was obtained from the extrusion process (Dhurve et al., 2015). Additional advantages of extrusion include low inputs, higher productivity with quality, products developed with minimal wastage, enhances protein digestibility, offers versatility with distinct by products and contributing in energy efficiency (Manjula et al., 2015). It is widely used in industrial products such as noodles, snacks, macaroni, baby foods, spaghetti and pasta preferred by young generation (Thapliyal & Singh, 2015; Masli et al., 2018). Rathore et al. (2019) suggested such finger millets flour with moisture content about 16-18% can undergo extrusion (with a temperature 100-120 °C) resulted the remarkable expansion in upgraded porosity, smoother texture and crunchiness. Extrusion cooking usually stimulates several changes including, protein denaturation, starch gelatinization, increased mineral absorption and break down of anti-nutrients (Kaur & Prasad, 2021

**Table 3. Studies on the roasting effects on the Finger millets**

| S.N. | Roasting treatment | References |
|---|---|---|
| 1. | The roasting step increased digestibility with preserving most of the valuable nutrients. | Krantz, (1983) |
| 2. | Roasting helps in prolonging the shelf life of foods and enhancing its storage duration. | Huffman &Martin, (1994) |
| 3. | Some phenolic components reduced with the roasting of finger millets. | Hegde & Chandra, (2005) |
| 4. | There is the significant alteration in fatty acid composition, when finger millets varieties were conditioned with 20% moisture content and roasted at temperatures ranging from 220 to 230°C for 2 hours. | Wadikar et al. (2007) |
| 5. | The finger millets flour has reduced viscosity by 55-60% with the grain roasting at different temperature and time. | Auko, (2009) |
| 6. | An increase in enzymatic digestion, when starch becomes more digestible, because of the gelatinization and liberation of the granules of starch. | Singh & Raghuvanshi, (2012) |
| 7. | Roasting leads to a rise in release of phenolics from the grain, consequently enhancing their bio-accessibility. | Hithamani & Srinivasan, (2014) |
| 8. | Roasted finger millets items have the pleasant aroma, high advanced texture and quality of grains by non-functioning the microbes. | Thapliyal & Singh, (2015) |

**Table 4. Studies on the effect of parboiling on the Finger millets**

| S.N. | Parboiling effects | References |
|---|---|---|
| 1. | Parboiling before decortication enhanced the phenolic content while decortication without parboiling reduces the total phenolic content due to the destruction of outer layer. | Saleh et al. (2013) |
| 2.. | Research suggested that the yield of finger millets significantly increased, almost double upon parboiling. | Ayamdoo et al. (2013); Sene et al. (2018) |
| 3. | Advanced the resistance of grains withstand tension and pressure applied during the milling step due to the low breakage during parboiling. | Vikrant et al. (2018) |
| 4. | As compare to raw millets products, parboiled led to raise the starch content and reduces the glycemic index of the millets. | Bora, (2014) |
| 5. | Upon parboiling finger millets endosperm hardened, making it easier to remove seed coat or husk. | Dharmaraj et al. (2015) |
| 6. | Parboiling leads to changes such as protein decomposition and the gelatinization of starch granules due to the endosperm surface cracking and facilitating easier husk removal. | Vikrant et al. (2018) |
| 7. | Parboiling resulted in the enhanced yield of proso millets by 24% and pearl millets by 18-57%, depending according to the duration of milling process. | Bora et al. (2019) |

## Conclusion

The observation from the current review concluded that the finger millets (Eleusine coracana) is a nutritious crop have rich nutrient profile, including essential amino acids, minerals, and dietary fibres, making it valuable for food security, nutrient deficiency and malnutrition. The processing methods like germination, fermentation, and parboiling enhance its bioavailability of nutrients. In 2023, the Food and Agricultural Organization declared the "International Year of Millets" to boost global millet productivity. However, in India, many challenges like low farmer prices, limited processing technology, and poor marketing hinder the sector's growth and global recognition. Despite of its wide-ranging benefits, further research work is needed to explore the whole therapeutic potential of *Eleusine coracana*, particularly through clinical trials. Additionally, optimizing its processing techniques can enhance its commercial value and global utilization. Overall, this review underscores significant nutritional and medicinal value, offering positioning finger millet as a key crop for global sustainability.

## Acknowledgements

Authors are grateful to the University Grant Commission (UGC) for their research funding.

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