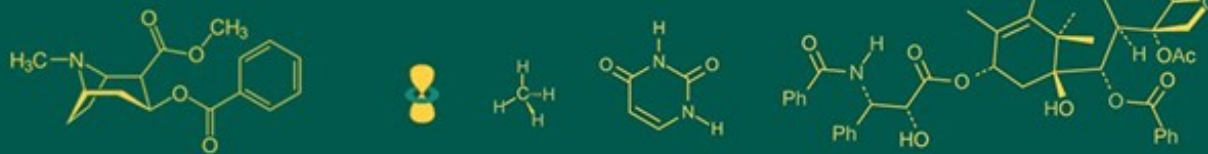


International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
 ISSN Online: 2617-4707
 NAAS Rating (2026): 5.29
 Indexing: Embase
 IJABR 2026; 10(9S): 1972-1980
www.biochemjournal.com
 Received: 05-07-2026
 Accepted: 20-08-2026
 Published: 25-09-2026

Nethravathi Ashok Patil
 Assistant Professor, DSLD
 College of Horticultural
 Engineering and Food
 Technology Devihosur-Haveri,
 University of Horticultural
 Sciences, Bagalkot, Karnataka,
 India

Rajiyabegaum S Hosalli
 DAESI Facilitator, DSLD
 College of Horticultural
 Engineering and Food
 Technology Devihosur-Haveri,
 University of Horticultural
 Sciences, Bagalkot, Karnataka,
 India

Lavanya MN
 Assistant Professor, DSLD
 College of Horticultural
 Engineering and Food
 Technology Devihosur-Haveri,
 University of Horticultural
 Sciences, Bagalkot, Karnataka,
 India

Laxman Kukanoor
 Dean, DSLD College of
 Horticultural Engineering and
 Food Technology Devihosur-
 Haveri, University of
 Horticultural Sciences,
 Bagalkot, Karnataka, India

Corresponding Author:
Nethravathi Ashok Patil
 Assistant Professor, DSLD
 College of Horticultural
 Engineering and Food
 Technology Devihosur-
 Haveri, University of
 Horticultural Sciences,
 Bagalkot, Karnataka, India

Finger millet (Ragi) in India: Production trends, post-harvest losses, processing, value addition, consumer demand and global market opportunities—a critical review

Nethravathi Ashok Patil¹, Rajiyabegaum S Hosalli², Lavanya MN³, Laxman Kukanoor⁴

DOI: <https://www.doi.org/10.33545/26174693.2026.v10.i9Sy.10147>

ABSTRACT

Finger millet (*Eleusine coracana* L.), commonly known as ragi in India, is an important climate-resilient cereal with considerable nutritional, food-processing and commercial potential. India is one of the major global producers of finger millet, with recent estimates indicating approximately 1.18 million ha under cultivation, production of about 1.8 million tonnes and average productivity of approximately 1.6 t ha⁻¹. *Karnataka alone* accounts for nearly 60 per cent of India's finger-millet area, demonstrating the importance of the crop in southern Indian food systems (Chapke *et al.*, 2025). Finger millet is distinguished by its high calcium concentration, dietary fibre, minerals and phenolic compounds, which have increased its relevance in functional, health-oriented and gluten-free food development (Saleh *et al.*, 2013; Anitha *et al.*, 2024). Nevertheless, the crop continues to face constraints associated with labour-intensive harvesting and processing, inadequate post-harvest infrastructure, grain deterioration, limited mechanization, short shelf life of flour and insufficient product diversification. An earlier ICAR-CIPHET assessment estimated total post-harvest losses in ragi at approximately 3.81%, while recent national assessments indicate cereal-level losses of approximately 3.89–5.92%, highlighting the continuing importance of improved post-harvest management (ICAR-CIPHET, 2015; NABCONS, 2022). Processing technologies including cleaning, drying, milling, decortication, germination, malting, fermentation, roasting, popping, extrusion and microwave treatment can improve convenience, digestibility, storage stability and product diversity, although excessive processing may result in nutrient and dry-matter losses (Mahajan *et al.*, 2023; Jindal and Nikhanj, 2023; Anitha *et al.*, 2024). Consumer demand is increasingly influenced by perceptions of nutritional value, health benefits, convenience and sustainability. Studies from India, particularly *Karnataka*, indicate established consumption of ragi and willingness among some consumers to pay premiums for nutritionally enhanced products (Siddiqui *et al.*, 2021). The review critically evaluates the production scenario, post-harvest losses, processing technologies, value-added products, consumer demand and domestic and international market prospects of finger millet. The evidence indicates that the future competitiveness of ragi depends on shifting from raw-grain marketing toward technologically processed, standardized, branded and consumer-oriented products.

Keywords: Finger millet, Ragi, Post-harvest losses, Food processing, Value addition, Consumer demand, Global market

1. Introduction

Finger millet (*Eleusine coracana* L.) is an ancient cereal cultivated predominantly in Africa and South Asia and is one of the most important small millets in India. The crop is locally known as ragi in southern India, mandua or madua in northern India and by several other regional names. It has traditionally been incorporated into porridges, mudde, roti, dosa, malt and fermented foods, particularly in *Karnataka* and other parts of southern India (Singh and Raghuvanshi, 2012).

Interest in finger millet has increased considerably during the last decade because of its combination of nutritional density, climate resilience and processing versatility. Finger millet performs comparatively well under rainfed and low-input conditions and is adapted to environments where major cereal crops can face greater production risks. Its nutritional characteristics, particularly its calcium and dietary-fibre content, have further strengthened its position as a potential component of diversified and nutritious diets (Saleh *et al.*, 2013; Anitha *et al.*, 2024) [1].

The renewed international attention to millets following the declaration of 2023 as the International Year of Millets has further increased research, policy and market interest in millet-based foods (FAO, 2023) [2]. The

emphasis, however, has increasingly shifted from simply increasing millet production to strengthening the entire value chain, including production, post-harvest management, processing, product development, consumer awareness and market access (Jindal and Nikhanj, 2023; Mahajan *et al.*, 2023) [3].

Finger millet is particularly important in this context because a substantial proportion of its potential value is lost between harvesting and consumption. The crop requires appropriate threshing, cleaning, drying, storage and milling before it can be converted into most modern food products. Inadequate post-harvest handling can result in quantitative losses, insect damage, microbial deterioration, nutritional degradation and reduced processing quality (ICAR-CIPHET, 2015; Mahajan *et al.*, 2023) [4].

At the same time, conventional consumption patterns are insufficient to fully exploit the economic potential of the crop. The development of ragi flour, malt, instant mixes, biscuits, bakery products, noodles, pasta, extruded snacks, breakfast cereals, beverages and other products provides opportunities to increase consumption and create higher-value markets (Karki *et al.*, 2020; Jindal and Nikhanj, 2023; Anitha *et al.*, 2024) [5, 3].

The commercial future of ragi is therefore closely linked with the transition from commodity production to value-chain-based commercialization. This review critically examines the production scenario of finger millet in India, nutritional and functional characteristics, post-harvest losses, processing technologies, value-added products, consumer demand and market opportunities, with particular emphasis on the role of post-harvest technology in creating a competitive ragi-based food industry.

Review methodology

The present review was developed through a critical synthesis of peer-reviewed literature, government publications, ICAR reports and international institutional information relating to *et al* consumer behaviour and market development.

Literature published from 2013 to 2026 was prioritized, while earlier studies were retained where they represented foundational research on finger-millet nutrition, processing or consumption. Particular attention was given to recent reviews published between 2021 and 2025 to identify technological advances and research gaps (Yousaf *et al.*, 2021; Mahajan *et al.*, 2023; Jindal and Nikhanj, 2023; Kaur *et al.*, 2024) [6, 7, 3, 8].

The review was organized under the following themes:

1. production and productivity of finger millet in India;
2. nutritional and functional characteristics;
3. post-harvest losses and quality deterioration;
4. need for post-harvest technologies;
5. conventional and modern processing;
6. nutritional consequences of processing;
7. value-added food products;
8. consumer awareness and demand;
9. willingness to pay;
10. domestic market opportunities;
11. global market and export opportunities; and
12. research and policy gaps.

Production scenario of finger millet in India

Importance of India in finger-millet production

Finger millet is one of the most widely cultivated minor cereals in India and is particularly important in Karnataka, Tamil Nadu, Uttarakhand, Maharashtra and Odisha. India remains one of the world's principal finger-millet-producing countries, while eastern African countries such as Ethiopia, Uganda, Kenya and Tanzania are also important producers (Kaur *et al.*, 2024) [8]. Recent ICAR information reported approximately 1.18 million ha under finger millet in India, production of approximately 1.8 million tonnes and productivity of approximately 1,600 kg ha⁻¹ (Chapke *et al.*, 2025) [9]. Karnataka accounted for approximately 60% of the country's finger-millet area, followed by Tamil Nadu, Maharashtra and Uttarakhand (Chapke *et al.*, 2025) [9].

Approximately 90% of India's finger-millet area is cultivated during the kharif season under predominantly rainfed conditions (Chapke *et al.*, 2025) [9]. This characteristic makes ragi important for climate-resilient farming but also exposes production to variability in rainfall and temperature.

Table 1. Recent production profile of finger millet in India

Indicator	Recent estimate
Area	~1.18 million ha
Production	~1.80 million tonnes
Average productivity	~1,600 kg ha ⁻¹
Karnataka's share of area	~60%
Major producing states	Karnataka, Tamil Nadu, Maharashtra, Uttarakhand
Major production season	Kharif
Predominant production system	Rainfed

Source: Chapke *et al.* (2025) [9].

Chapke *et al.* (2025) [9] emphasized that improved varieties and agronomic interventions can substantially increase productivity over traditional production practices. Therefore, future growth in ragi availability is likely to arise from both productivity improvement and more efficient utilization of the harvested crop.

Long-term production trends

Historical government statistics demonstrate considerable fluctuation in the area and production of finger millet.

The Government of India reported that finger-millet area declined from approximately 1.19 million ha in 2013–14 to 1.02 million ha in 2016–17, before increasing again to approximately 1.19 million ha in 2017–18 and subsequently fluctuating (Ministry of Agriculture and Farmers Welfare, 2023) [10].

Values for 2013–21 are based on Government of India statistics; 2021–23 values are based on final DES data; 2023–24 figures should be checked against the latest final DES release before journal submission.

Sources: Ministry of Agriculture and Farmers Welfare (2023) [10]; DES data reported through government agricultural datasets; Chapke *et al.* (2025) [9].

Table 2. Area and production of finger millet in India

Year	Area ('000 ha)	Production ('000 t)	Productivity (kg ha ⁻¹)
2013–14	1,193.64	1,982.94	1,661
2014–15	1,208.06	2,060.91	1,706
2015–16	1,138.25	1,821.89	1,601
2016–17	1,016.11	1,385.11	1,363

(continued on next page)

Year	Area ('000 ha)	Production ('000 t)	Productivity (kg ha ⁻¹)
2017–18	1,194.29	1,985.24	1,662
2018–19	890.94	1,238.70	1,390
2019–20	1,004.46	1,755.06	1,747
2020–21	1,159.40	1,998.36	1,724
2021–22	1,218.40	1,701.10	1,396
2022–23	1,163.30	1,691.40	1,454
2023–24	~1,218.8	~1,537.9	~1,262*

The data indicate that India's finger-millet production has remained broadly within the range of approximately 1.2–2.1 million tonnes over the period examined. Production fluctuations have been influenced by changes in area, yield, rainfall and regional production conditions (Ministry of Agriculture and Farmers Welfare, 2023) [10].

The long-term decline in cultivated area has been discussed by Paramesh (2018) [11], who attributed millet-area changes partly to competition from rice and wheat, changing consumer preferences and economic considerations. More recent research suggests that value-chain development and consumer-oriented product diversification could help reverse this pattern (Jindal *et al.*, 2023) [3].

5. State-wise importance of finger millet

The geographical concentration of production is an important characteristic of India's ragi value chain.

In 2020–21, *Karnataka* produced approximately 1.37 million tonnes, accounting for around two-thirds of India's finger-millet production according to government data (Ministry of Agriculture and Farmers Welfare, 2023) [10]. *Tamil Nadu* was the next important producer, followed by *Uttarakhand* and *Maharashtra*.

Table 3. Major finger-millet-producing states

State	Approximate importance
<i>Karnataka</i>	Largest producer and production base
<i>Tamil Nadu</i>	High productivity and major commercial production
<i>Uttarakhand</i>	Important hill-region production
<i>Maharashtra</i>	Important central/western production
<i>Odisha</i>	Important eastern production
<i>Andhra Pradesh</i>	Important regional production

Karnataka's dominance is particularly significant because it creates an opportunity for regional processing clusters, farmer-producer organizations, millet enterprises and export-oriented value chains (Chapke *et al.*, 2025) [9].

6. Nutritional composition and functional potential

Finger millet has traditionally been recognized as a nutritious cereal, but recent research has expanded understanding of its bioactive and functional components.

According to Saleh *et al.* (2013) [1], finger millet is particularly notable for its calcium content, dietary fibre and polyphenolic com-

pounds. The grain contains substantially more calcium than most major cereals. Chapke *et al.* (2025) [9] reported approximately 7.2% protein, 66.8% carbohydrate, 11.2% dietary fibre and 2.5–3.5% minerals in finger millet. Calcium concentration was reported at approximately 344 mg/100 g, making finger millet one of the richest cereal sources of calcium (Chapke *et al.*, 2025) [9].

Table 4. Selected nutritional characteristics of finger millet

Nutrient/component	Approximate value
Protein	~7.2%
Carbohydrate	~66.8%
Dietary fibre	~11.2%
Calcium	~344 mg/100 g
Fat	~1–2%
Minerals	~2.5–3.5%
Important phenolics	Ferulic acid, <i>p</i> -coumaric acid and other polyphenols

Sources: Saleh *et al.* (2013) [1]; Chapke *et al.* (2025) [9]; Kaur *et al.* (2024) [8].

Kaur *et al.* (2024) [8] reported that finger millet contains substantial phenolic compounds, with important fractions occurring in bound form. These compounds contribute to the antioxidant potential of the grain and increase interest in finger millet as a functional-food ingredient. However, the presence of nutrients does not automatically guarantee high bioavailability. Kaur *et al.* (2021) demonstrated that phytate and other antinutritional components can influence mineral availability. Consequently, processing is a crucial component in converting the nutritional potential of the raw grain into a nutritionally advantageous food.

7. Antinutritional factors and the need for processing

Finger millet contains phytate, tannins and other compounds that may influence mineral bioavailability and protein or starch digestibility. The concentrations of these compounds vary according to genotype, grain colour and growing environment (Saleh *et al.*, 2013; Kaur *et al.*, 2024) [1, 8]. The objective of processing should therefore not simply be to remove the outer layers of the grain. Instead, processing should achieve an appropriate balance between:

nutrient retention + reduction of antinutrients + improved digestibility + sensory acceptability + shelf stability

. Mahajan *et al.* (2023) emphasized that decortication, milling, soaking, germination, malting, fermentation, puffing and related technologies can reduce antinutritional factors while modifying functional properties. Similarly, Yousaf *et al.* (2021) [6] demonstrated that processing substantially modifies nutritional and functional characteristics of millet grains.

Post-harvest losses in finger millet

Post-harvest loss is an important but comparatively under-researched issue in finger millet.

An earlier ICAR-CIPHET assessment reported total ragi post-harvest losses of approximately 3.81%, including losses during threshing, winnowing, transportation and storage (ICAR-CIPHET, 2015) [4].

Table 5. Earlier estimated post-harvest losses in ragi

Post-harvest operation	Estimated loss (%)
Threshing	0.77
Winnowing	0.76
Transportation	0.62
Transport to storage	1.13
Storage	0.53
Total	3.81

Source: ICAR-CIPHET (2015) [4].

However, this figure is a historical estimate and should not be presented as the current national loss percentage. More recent national assessments have reported cereal-level post-harvest losses in the range of approximately 3.89–5.92% across commodities and post-harvest stages (NABCONS, 2022) [12].

This distinction is important because there is currently insufficient evidence to state that the current national ragi loss is exactly 3.81%.

The absence of a recent nationally representative ragi-specific loss assessment covering harvesting, threshing, drying, transport, storage, milling and processing represents a significant research gap.

Nature of post-harvest losses

Post-harvest loss in ragi occurs in several forms.

1 Physical losses: Physical losses occur during : harvesting ; threshing; winnowing; transportation; cleaning; drying; storage; and milling.

ICAR-CIPHET (2015) [4] identified threshing, winnowing, transportation and storage as important points of loss.

Biological losses: Poorly dried or stored grain may be exposed to: insects; rodents; fungi; microbial contamination.

Field-level studies have identified insects, termites, rodents and rain-induced spoilage as important causes of grain deterioration under inadequate storage conditions (Banu *et al.*, 2022) [13].

Qualitative losses: Even when grain quantity is retained, quality can deteriorate through: discolouration; off-flavour; rancidity; nutrient degradation; increased microbial load; reduced germination quality; and reduced processing performance.

Thus, post-harvest loss should be considered in terms of quantity, quality, nutritional value and economic value.

Processing-related nutritional losses

Processing itself can cause nutrient loss. Recent evidence indicates that abrasive decortication can reduce antinutritional factors but excessive processing may simultaneously remove nutrient-rich fractions and increase dry-matter loss. Therefore, the relationship between processing intensity and nutritional quality is not linear.

Kaur *et al.* (2024) [8] emphasized that processing can modify the physicochemical and functional properties of finger millet substantially. Similarly, Mahajan *et al.* (2023) concluded that processing must be optimized because nutrients and bioactive compounds may either become more available or be lost depending on the processing method.

This creates an important food-technology principle:

The best processing technology is not necessarily the technology that removes the greatest quantity of seed coat; it is the technology that produces acceptable food quality with minimum nutritional loss.

Need for Post-Harvest Technologies: The development of post-harvest technology is essential for five reasons

1. **Reducing physical losses:** Mechanized harvesting, threshing, cleaning and grading can reduce avoidable losses and labour requirements (ICAR-CIPHET, 2015) [4].
2. **Improving grain quality:** Scientific drying and moisture management can reduce microbial and storage deterioration (Mahajan *et al.*, 2023).

3. **Extending shelf life:** Milling increases the surface area of grain and can accelerate lipid oxidation and quality deterioration. Therefore, stabilization and appropriate packaging are essential for commercial ragi flour (Yousaf *et al.*, 2021) [6].

4. **Improving nutritional availability:** Germination, malting and fermentation can reduce selected antinutritional factors and improve nutrient accessibility (Kaur *et al.*, 2021; Yousaf *et al.*, 2021) [6].

5. **Creating high-value products:** Processing converts ragi from a bulk cereal into ingredients and finished foods with substantially greater potential for differentiation (Jindal *et al.*, 2023) [3].

Therefore, post-harvest technology should be regarded as an economic-development technology rather than merely a loss-reduction technology.

Primary processing technologies

1 Cleaning and grading: Cleaning removes stones, dust, immature seeds and foreign matter. Grading creates more uniform raw material for milling and processing. Standardization at this stage is important because raw-material variability affects flour colour, particle size, moisture and final product quality (Jindal *et al.*, 2023) [3].

2 Drying: Proper drying is essential before storage. Inadequate drying increases the risk of microbial deterioration, whereas excessive drying can increase energy costs and potentially affect quality. Mahajan *et al.* (2023) identified controlled drying and storage as critical elements of sustainable millet post-harvest management.

3 Storage: Improved storage technologies, including hermetic storage, moisture control and improved packaging, can reduce insect and moisture-related deterioration (Mahajan *et al.*, 2023).

4. Milling and Flour Production: Milling is the most important transformation step because ragi flour forms the basis of many traditional and modern food products. Ragi flour can be used in: dosa and idli mixes; roti, mudde, porridge, biscuits, cookies, cakes, muffins, noodles, pasta, extruded snacks, nutrition bars and beverage mixes. However, milling also creates a major technological challenge: shelf life. Yousaf *et al.* (2021) [6] noted that processing can alter the stability and functional properties of millet flour. The increased surface area after grinding may facilitate oxidation and deterioration. Therefore, commercial ragi flour requires appropriate: moisture control, stabilization, packaging, storage temperature, oxygen management and shelf-life testing.

5. Germination and Malting: Germination is among the most promising technologies for nutritional enhancement. During germination, enzymatic activity increases and modifies starch, proteins and other components. Phytate and tannin concentrations can decline, while digestibility and nutrient availability can improve (Yousaf *et al.*, 2021; Kaur *et al.*, 2024) [6, 8]. Malting further extends the application of germinated grain by producing a stable ingredient suitable for: malt beverages, instant porridge, complementary foods, breakfast drinks, nutrition mixes, bakery products. Simran *et al.* (2024) [14] identified malting, fermentation and extrusion as promising technologies for improving the utilization and value addition of finger millet.

6. Fermentation: Fermentation is a traditional but technologically important method of improving cereal foods. According to Yousaf *et al.* (2021) [6], fermentation can influence, digestibility, phytate, tannins, flavour acidity, mineral availability, microbial quality. Fermented ragi can be used in dosa, idli, porridge, beverages, sourdough, probiotic formulations. Controlled fermentation represents an opportunity to combine traditional knowledge with modern food biotechnology.

7. Roasting, Popping and Puffing: Roasting can improve flavour and reduce moisture, making roasted ragi suitable for instant beverage and porridge formulations. Popping and puffing produce lightweight, crisp products with greater convenience and consumer appeal. These technologies can be used to develop: breakfast cereals, snack products, cereal mixes, energy bars and confectionery products. Jindal *et al.* (2023) [3] emphasized that modern processing technologies can significantly expand the range of millet-based commercial products.

8. **Extrusion Technology:** Extrusion is one of the most promising technologies for large-scale commercialization. Extrusion allows ragi to be converted into: expanded snacks, breakfast cereals, noodles. Pasta, pellets; instant foods. Extrusion provides advantages in terms of continuous production, product standardization and control of texture. Karki *et al.* (2020) [5] and Jindal *et al.* (2023) [3] identified extrusion as an important modern technology for millet-based product development. However, processing parameters such as moisture, temperature, screw speed and formulation need optimization to achieve desirable texture and nutritional retention.

9. **Novel Processing Technologies:** Recent research has expanded beyond conventional processing toward microwave, hydrothermal, ul-

trasound and other technologies. Kaur *et al.* (2024) [8] reported that physical modifications such as hydrothermal treatment, microwave treatment and ultrasonication can alter starch structure, digestibility and functional properties. Microwave treatment is particularly promising for improving flour stability because it can modify enzyme activity and reduce deterioration during storage. These technologies remain at different stages of laboratory and commercial development, and their economic feasibility requires further investigation.

Value addition of finger millet

The greatest opportunity for increasing the economic value of ragi lies in product diversification.

Table 6. Major value-added ragi products and potential markets

Product	Processing route	Target consumer
Ragi flour	Cleaning + milling	Household
Germinated ragi flour	Germination + drying + milling	Health-conscious consumers
Ragi malt	Germination + malting	Children/adults
Instant porridge	Milling + formulation	Urban households
Dosa/idli mix	Milling + formulation	Convenience market
Biscuits	Composite flour + baking	Children/adults
Cookies	Flour + baking	Premium snack market
Cake/muffins	Composite flour + baking	Urban consumers
Noodles	Extrusion	Youth/urban consumers
Pasta	Extrusion	Convenience market
Breakfast cereal	Popping/extrusion	Families
Extruded snacks	Extrusion	Children/youth
Nutrition bars	Flour/malt + binding	Fitness market
Malt beverage	Malt + formulation	Health market
Ragi-milk beverage	Ragi + dairy formulation	Dairy/functional market
Gluten-free foods	Ragi flour + specialized processing	Gluten-free consumers

The diversity of potential products demonstrates that the commercial potential of ragi extends far beyond traditional foods.

Ragi in Bakery Product: Bakery products are among the easiest routes for introducing ragi to consumers who do not traditionally consume millet. Ragi flour can be incorporated into: biscuits, cookies, bread, cakes, muffins, crackers, pizza bases. However, finger millet does not contain gluten, and high substitution levels can affect dough elasticity, volume and texture in wheat-based products. Kaur *et al.* (2024) emphasized the importance of formulation and processing optimization when incorporating finger millet into modern food systems. Therefore, product development should focus on identifying the optimum level of ragi incorporation rather than maximizing ragi percentage

Ragi Noodles, Pasta and Convenience Foods: Changing lifestyles have increased demand for convenience foods. Jindal and Nikhanj (2023) reported that millet processing technologies have enabled development of noodles, pasta, extruded foods and other ready-to-eat or ready-to-cook products. This is particularly relevant to younger consumers who may not prefer traditional foods such as ragi mudde or porridge but may accept ragi when incorporated into familiar food formats. Therefore

Traditional grain + modern format = expanded consumer market. This principle should become a central strategy for ragi commercialization

Ragi and Dairy-Based Products: The combination of ragi with dairy ingredients represents an underexplored opportunity for food and dairy researchers. Potential products in-

clude: ragi-milk beverages; ragi malt drinks; ragi yoghurt; ragi-based fermented dairy beverages; ragi pudding; ragi kheer; ragi ice cream; ragi dairy desserts. The combination can provide both cereal-derived dietary fibre and micronutrients and dairy-derived protein and calcium. However, formulation challenges include sedimentation, viscosity, mouthfeel, flavour compatibility, microbial stability and consumer acceptance. These issues require product-specific experimental research before commercial-scale adoption

Consumer Awareness and Demand: Consumer demand is the key determinant of whether increased production and processing capacity can be converted into economic returns. Siddiqui *et al.* (2021) reported high awareness of millets among urban Indian consumers, but awareness did not always translate into frequent consumption. This indicates that the major challenge is not simply awareness creation but conversion of awareness into repeated purchase and consumption behaviour. Consumer motivation for millet consumption has commonly been associated with: perceived nutritional value, health benefits, traditional familiarity, weight management; dietary diversification, environmental sustainability. Banu *et al.* (2021) emphasized that consumer preferences vary according to geography, demographic characteristics and familiarity with specific millet products

Consumer Demand for Ragi in Karnataka: Karnataka represents a particularly important market because ragi has been

traditionally integrated into the state's food culture, Studies of millet consumption in Karnataka have consistently identified finger millet as one of the most frequently consumed millet species. Consumer preference is supported by familiarity with traditional products such as ragi mudde, dosa, roti and malt. The challenge is therefore not primarily to introduce ragi to Karnataka consumers but to increase frequency, convenience and product diversification. Modern products such as: ragi cookies, instant dosa, ragi pasta, ragi noodles, breakfast cereal, ragi malt beverages; nutrition bars can increase consumption among urban consumers and younger generations

Willingness to pay for nutritionally enhanced ragi

One of the most important findings for commercialization comes from consumer willingness-to-pay research. Studies on iron-biofortified finger millet in Karnataka found strong consumer interest in nutritionally improved ragi. reported that approximately 98% of participants placed a positive bid for iron-biofortified finger millet, with average willingness to pay showing a premium over conventional grain. The study further demonstrated that nutrition information could increase consumer valuation. This finding has major implications for value addition

Nutritional differentiation can create economic differentiation.

Therefore, producers may potentially obtain higher prices when scientifically validated nutritional characteristics are combined with certification traceability appropriate labelling, attractive packaging and consumer education.

However, all health and nutrition claims must comply with applicable food regulations.

Consumer barriers to ragi consumption

Despite increasing awareness, several barriers remain.

- **Traditional image:** Millets have historically been associated in some contexts with low-income or rural diets. Paramesh (2018) [11] identified social perception and changing food preferences as factors contributing to reduced millet consumption.
- **Taste and texture:** The characteristic flavour, colour and texture of ragi may limit acceptance among consumers unfamiliar with the grain.

Preparation time: Traditional ragi foods can require preparation skills and time.

Product availability: Consumers are more likely to purchase ragi if products are readily available through modern retail and online

channels.

Price: Premium processing and packaging can increase retail prices. This creates a challenge because ragi has traditionally been considered an affordable cereal. Consequently, future market development must balance:

nutrition + convenience + sensory quality + affordability.

Global market opportunities

The global market environment for millets has become increasingly favourable.

FAO (2023) [2] emphasized the importance of millets for sustainable food systems, nutrition and climate resilience. The International Year of Millets 2023 significantly increased international visibility of millet-based foods.

Kaur et al. (2024) [8] identified increasing industrial demand for finger millet because of its nutritional, functional and climate-resilience characteristics.

However, a critical limitation must be recognized: global commercial market reports frequently aggregate finger millet with pearl millet, sorghum and other millets.

Therefore, a reported "global millet market size" should not automatically be presented as the market size of finger millet.

This is a major research gap.

Potential international markets for ragi

Ragi has potential in several international market segments.

Indian diaspora markets: Consumers familiar with Indian foods represent a natural initial market for ragi flour and traditional mixes.

Gluten-free markets: naturally gluten-free nature of finger millet creates opportunities in gluten-free food categories, although cross-contact control is essential for products carrying gluten-free claims.

Health-food market: Consumers seeking high-fibre and nutrient-rich foods may represent a premium market.

Functional beverages: Ragi malt and ragi-based beverages can be positioned within functional and nutrition beverage categories.

Breakfast cereals: Extruded and puffed ragi products can compete in breakfast cereal markets.

Plant-based foods: Ragi ingredients can potentially be incorporated into plant-based food formulations.

Jindal et al. (2023) [3] and Kaur et al. (2024) [8] emphasized the importance of developing modern food applications rather than limiting millet commercialization to traditional products.

Export strategy: Grain versus value-added products

The international commercialization strategy should move progressively from:

Raw grain → cleaned grain → flour → specialized ingredients → finished products

The economic value generally increases as additional processing, quality assurance, packaging and branding are incorporated.

Potential export products include:

cleaned ragi grain; organic ragi; ragi flour; germinated ragi flour; ragi malt; instant porridge; dosa mixes; gluten-free bakery products; noodles; pasta; breakfast cereals; extruded snacks; nutrition bars; and functional beverages.

Thus, export development should focus increasingly on processed and branded products rather than bulk grain alone.

Ragi value chain and economic opportunity

The ragi value chain can be represented as:

Farmer

↓

Aggregation

↓

Cleaning and grading

↓

Scientific drying

↓

Storage

↓

Primary processing

↓

Milling / germination / malting / fermentation

↓

Food formulation

↓

Quality testing

↓

Packaging

↓

Branding

↓

Domestic market / Export market

At present, much of the economic value is concentrated in the later stages of the chain. Farmers often participate primarily at the raw-grain stage.

Value addition creates opportunities for:

- farmer-producer organizations;
- women self-help groups;
- rural enterprises;
- food-processing companies;
- dairy enterprises;
- start-ups;
- institutional food processors.

Mahajan *et al.* (2023) emphasized that sustainable post-harvest processing and product development can strengthen both food security and economic opportunities.

Role of women and rural enterprises

- a. Ragi processing has considerable potential for decentralized entrepreneurship because several value-added products can be produced using relatively small-scale equipment.
- b. Women-led enterprises can develop: ragi flour; malt; instant mixes; biscuits; cookies; ladoos; nutrition bars; snacks; beverages.
- c. The opportunity is particularly relevant in *Karnataka* because of the strong production base and cultural familiarity with ragi.
- d. The transition from farmer → raw grain seller to farmer → processor/entrepreneur could potentially increase value realization within rural communities.

Major Challenges: Despite its potential, several challenges constrain commercialization

Inadequate processing infrastructure: Small producers often lack modern milling, germination, malting and packaging equipment.

Labour-intensive operations: Traditional processing can be time-consuming and expensive.

Raw-material variability: Genotype, grain colour, moisture and cultivation environment influence processing quality (Kaur *et al.*, 2024) [8].

Short shelf life of flour: Milling increases susceptibility to quality deterioration.

Nutritional losses during processing: Excessive decortication can remove nutrient-rich fractions.

Sensory limitations: High ragi incorporation may affect colour, flavour and texture.

Lack of standardization: Commercialization requires standardized processing conditions, formulations and quality specifications.

Weak market intelligence: Reliable, species-specific data on ragi consumption, processing, exports and international demand remain limited.

Research gaps

The review identifies several important research gaps.

1) Ragi-specific post-harvest loss assessment: The commonly cited 3.81% loss estimate is based on an older assessment (ICAR-CIPHET, 2015) [4]. A new nationwide study is required.

The study should measure: harvesting loss, threshing loss, cleaning loss, drying loss, transport loss, storage loss, milling loss, processing loss.

2) Standardization of processing: Optimum processing conditions need to be established for different varieties and end products.

3) Nutrient retention: Future studies should quantify nutrient retention at every processing stage.

4) Shelf-life extension: Research should investigate: microwave stabilization; thermal stabilization; vacuum packaging; modified-atmosphere packaging, hermetic storage, natural antioxidants.

5) Consumer segmentation: Consumer studies should separately examine children, youth, women, elderly, fitness consumers, urban households, rural households and gluten-free consumers.

6) Willingness to pay for processed ragi products: More research is needed on willingness to pay for: germinated flour, malt, organic ragi, fortified ragi, ragi beverages, ragi snacks and ragi-dairy products.

7) *International market data*: Dedicated databases are needed for: ragi export volume, ragi export value, importing countries, processed ragi products, export prices, consumer preferences.

8) Future market opportunities

The future market for ragi can be divided into five major categories.

Traditional market: Flour, mudde mix, dosa mix and malt.

Health market: Germinated flour, nutrition mixes and fortified products.

Convenience market: Instant porridge, noodles, pasta, breakfast cereals and ready-to-cook products.

Premium market: Organic, biofortified, specialty and traceable ragi products.

Global market: Gluten-free products, functional foods, beverages and packaged ethnic foods. The highest potential for value creation is likely to occur where these categories overlap.

For example: Organic + germinated + gluten-free + ready-to-cook ragi product has considerably greater differentiation than ordinary ragi grain.

9) Strategic framework for ragi commercialization

The evidence reviewed suggests that ragi commercialization should follow an integrated strategy.

Stage 1: Production: Increase productivity using improved varieties and agronomic practices (Chapke *et al.*, 2025) [9].

Stage 2: Post-harvest management: Reduce harvesting, threshing, drying, transport and storage losses (ICAR-CIPHET, 2015) [4].

Stage 3: Processing: Introduce efficient milling, germination, malting, fermentation and extrusion technologies (Mahajan *et al.*, 2023; Jindal and Nikhanj, 2023) [3].

Stage 4: Product development: Develop convenient, nutritious and sensory-acceptable products (Kaur *et al.*, 2024) [8].

Stage 5: Consumer research: Identify product preferences, price sensitivity and willingness to pay (Siddiqui *et al.*, 2021).

Stage 6: Branding: Promote scientifically supported attributes such as: high calcium, dietary fibre, whole grain, gluten-free, germinated, climate-resilient crop.

Stage 7: Market expansion: Link farmer groups and processors with modern retail, e-commerce and export markets.

Conclusion

Finger millet represents one of India's most promising cereals for linking climate-resilient agriculture, nutritional security, post-harvest technology, food processing and rural entrepreneurship. Recent ICAR evidence indicates that India cultivates approximately 1.18 million ha of finger millet and produces around 1.8 million tonnes annually, with *Karnataka* accounting for approximately 60% of the cultivated area (Chapke *et al.*, 2025) [9].

The historical production data indicate substantial year-to-year fluctuations in area and productivity. These variations emphasize the importance of improving productivity while simultaneously strengthening the post-harvest and marketing systems (Ministry of Agriculture and Farmers Welfare, 2023) [10].

Nutritionally, finger millet is distinguished by its high calcium content, dietary fibre, minerals and phenolic compounds (Saleh *et al.*, 2013; Kaur *et al.*, 2024) [1, 8]. However, the nutritional potential of the raw grain can be influenced by phytate, tannins and processing losses. Germination, malting, fermentation and other appropriate processing methods can improve nutrient availability and functionality (Kaur *et al.*, 2021; Yousaf *et al.*, 2021) [6].

Post-harvest management is a critical but insufficiently studied component of the ragi value chain. An earlier ICAR-CIPHET estimate reported 3.81% total losses, but this should be regarded as a historical benchmark rather than a current national figure (ICAR-CIPHET,

2015) [4]. The lack of updated, ragi-specific national loss data represents an important research gap.

The future of ragi therefore depends strongly on post-harvest technologies. Improved drying, storage, milling, stabilization, germination, malting, fermentation, extrusion and packaging can simultaneously reduce losses, improve nutritional quality, extend shelf life and create new products (Mahajan *et al.*, 2023; Jindal and Nikhanj, 2023) [3].

Consumer demand provides encouraging evidence for commercialization. Ragi already has strong traditional acceptance in *Karnataka* and other southern Indian regions. Increasing awareness of nutrition, functional foods, gluten-free diets and climate-resilient foods creates additional opportunities (Siddiqui *et al.*, 2021; Kaur *et al.*, 2024) [8].

Nevertheless, consumer awareness must be converted into repeat purchase, convenience and willingness to pay. Product development should therefore focus on sensory quality, affordability, attractive packaging and convenient formats rather than relying only on nutritional claims.

The global opportunity for ragi is significant, but it should be approached carefully. Global millet market estimates generally combine several millet species and cannot automatically be interpreted as finger-millet market estimates. Dedicated ragi trade and consumption statistics are therefore urgently required.

The strongest market opportunity lies in shifting from raw-grain commercialization to value-added product commercialization. Germinated flour, malt, instant mixes, bakery products, noodles, pasta, extruded snacks, breakfast cereals, nutrition bars, beverages and ragi-dairy products provide multiple opportunities for product diversification.

Overall, the evidence supports a transition from:

“Ragi as a traditional cereal”

to

“Ragi as a scientifically processed, nutritionally differentiated and globally marketable food ingredient.”

Such a transition requires coordinated action among farmers, farmer-producer organizations, food technologists, researchers, processors, entrepreneurs, retailers and policymakers. Strengthening post-harvest infrastructure, standardizing processing, improving product quality, understanding consumer preferences and generating reliable market intelligence will be essential for converting India's production advantage into sustained economic value.

Future research priorities

Based on the reviewed evidence, the following research priorities are proposed:

1. Nationwide assessment of current ragi post-harvest losses.
2. Development of low-loss mechanized threshing and cleaning systems.
3. Optimization of ragi decortication to maximize nutrient retention.
4. Development of shelf-stable ragi flour.
5. Standardization of germination and malting conditions.
6. Development of ragi-based functional beverages.
7. Development of ragi-dairy products.
8. Development of gluten-free convenience foods.
9. Consumer willingness-to-pay studies for specific ragi products.
10. Species-specific global ragi market and trade database.
11. Life-cycle and economic analysis of ragi processing technologies.
12. Development of export-oriented ragi products.

These priorities can help move future research from laboratory-level product development toward commercially viable and farmer-oriented value chains.

References

1. Saleh ASM, Zhang Q, Chen J, Shen Q. Millet grains: Nutritional quality, processing and potential health benefits. *Comprehensive Reviews in Food Science and Food Safety*. 2013;12:281–295.
2. FAO. International Year of Millets 2023. Food and Agriculture Organization of the United Nations, Rome; 2023.
3. Jindal P, Nikhanj P. A review on processing technologies for value added millet products. *Journal of Food Process Engineering*. 2023;46:e14419.
4. ICAR-CIPHET. Assessment of quantitative harvest and post-harvest losses of major crops and commodities in India. ICAR-Central Institute of Post-Harvest Engineering and Technology, Ludhiana; 2015.
5. Karki S, Kharel K, others. Processing and value addition of finger millet and other millet-based foods. 2020.
6. Yousaf L, Hou D, Liaqat H, Shen Q. Millet: A review of its nutritional and functional changes during processing. *Food Research International*. 2021;142:110197.
7. Mahajan M, Singla P, Sharma S. Sustainable postharvest processing methods for millets: A review on its value-added products. *Journal of Food Process Engineering*. 2024;47(1):e14313.
8. Kaur S, Kumari A, Seem K, Kaur G, Kumar D, Verma S, Singh N, Kumar A, Kumar M, Jaiswal S, Bhardwaj R, Riar A, Singh BK. Finger millet (*Eleusine coracana* L.): from staple to superfood—a comprehensive review on nutritional, bioactive, industrial, and climate resilience potential. *Planta*. 2024;260:75.
9. Chapke RR, Srinivas A, Anuradha N, Swarna R, Sreeleela Y, Laxmiprasanna P. Empowering farmers with improved finger millet production technologies for higher productivity. *Indian Farming*. 2025;75(10):18–22.
10. Ministry of Agriculture and Farmers Welfare. State-wise estimates of area and production of ragi. Government of India, New Delhi; 2023.
11. Paramesh V. Sustainability of millets and changing production and consumption patterns in India. *Agriculture*. 2018;8:131.
12. NABCONS. Study to determine post-harvest losses of Agriproducts in India MOFPI. 2022.
13. Banu Arjuman, Ganapathy MS, Govinda Gowda V, Siddayya MR, Girish, Begum S, Mohan Kumar TL. Value Chain Analysis of Minor Millets for improving Economic Status of Farmers in Tumakuru District of *Karnataka*. *Mysore Journal of Agricultural Sciences*. 2022;56(4):51–60.
14. Simran, Chaudhary S, Avinash H, Dubey N. Nutritional advantages and opportunities for its processing of finger millet (*Eleusine coracana* L.): A comprehensive review. *Journal of Advances in Biology & Biotechnology*. 2024;27:605–617.
15. Grovermann C, Umesh KB, Quédeville S, Ganesh Kumar B, Sakamma S, Moakes S. The Economic Reality of Underutilised Crops for Climate Resilience, Food Security and Nutrition: Assessing Finger Millet Productivity in India. *Agriculture*. 2018;8:131.
16. Dwivedi N, Rathore V, Sharma K. A Review of Millet Crops for Agricultural Sustainability in India. *Asian Journal of Agricultural Extension, Economics & Sociology*. 2023;41(10):216–224.
17. Kumar G, Sharma V, Rutika, Shalini K. Cultivation and Commercialization of Millets for Nutritional Security and Sustainable Livelihoods in Hamirpur District of Himachal Pradesh, India. *International Journal of Research and Analytical Reviews*. 2026;13(1):282–288.
18. Anitha S, Givens DI, Botha R, Kane-Potaka J, Sulaiman NLB, Tsusaka TW, Subramaniam K, Rajendran A, Parasannanavar DJ, Bhandari RK. Calcium from Finger Millet—A Systematic Review and Meta-Analysis on Calcium Retention, Bone Resorption, and In Vitro Bioavailability. *Sustainability*. 2021;13:8677.

19. Kane-Potaka J, Anitha, Takuji WS, Botha T, Rosemary, Muralidhar B, Shweta U, Parkavi K, Karuna M, Raghavendra H, Ashok Kumar J, Swamikannu N. Assessing millets and sorghum consumption behavior in urban India: A large-scale survey. *Frontiers in Sustainable Food Systems*. 2021;5:10.3389/fsufs.2021.680777.

How to cite this article: Patil NA, Hosalli RS, MN L, Kukanoor L. Finger millet (Ragi) in India: Production trends, post-harvest losses, processing, value addition, consumer demand and global market opportunities—a critical review. *International Journal of Advanced Biochemistry Research*. 2026;10(9S):1972-1980. doi: <https://www.doi.org/10.33545/26174693.2026.v10.i9Sy.10147>