RECENT ADVANCES IN MILLET PROCESSING AND VALUE ADDITION

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The introduction to millets as smart cereals encompasses their growing importance in a global context, responding to the need for sustainable and nutritious food sources. This chapter begins by delineating the increasing demand for resilient foods worldwide, setting the stage for an exploration of millets' historical and contemporary significance in India's dietary landscape. It then delves into the taxonomy, structure, and unique traits that make millets intelligent crops, capable of thriving in diverse and challenging environments. The processing journey of millets, from field to table, is outlined, encompassing primary and secondary processing techniques that enhance their quality and shelf-life. The chapter also highlights the advancement of value-enhanced goods and the establishment of rigorous quality benchmarks, ensuring their nutritional integrity and safety. Lastly, the chapter underscores millets' potential in nutraceutical and functional foods, presenting them as versatile ingredients rich in bioactive compounds and nutrients that can contribute to holistic well-being.

Keywords: Millets, International Year of Millets, Value Addition, Functional Food, Nutraceuticals

**1. Introduction**

# The term 'millet' has its roots in the French word "mille," meaning thousand, a reference to the remarkable fact that a small quantity of millet can encompass up to a thousand grains. Belonging to the Poaceae family, millets are a collection of small-seeded grasses that have a long history of cultivation, initially in Asia and Africa, before spreading globally to become essential food sources for various civilizations. With a cultivation history dating back to 2600 BC, millets were among the earliest crops to be domesticated and utilized for various purposes, including animal feed. However, over time, the prevalence of cereal crops such as rice and wheat gained prominence, particularly during the post-green revolution period of the 1960s, causing millets to gradually lose ground. The shift was influenced by factors like changing dietary preferences, modernization of agriculture, and limited awareness about the health benefits of millets, leading to a decrease in their consumption. Today, millets are primarily grown in arid regions of India and Africa by marginalized farmers.

# The agricultural benefits of millets are noteworthy, as they thrive in marginal and low-input farming conditions due to their C4 photosynthetic pathway and resilience to environmental stress. Their nutritional richness, including proteins, vitamins (A and B), calcium, and iron, positions them as a potential solution to prevalent health issues like diabetes, obesity, and cardiovascular diseases. Despite their remarkable attributes, millet production and consumption have declined in many countries, limiting their potential to address food and nutritional security. As the emphasis on nutritious diets and sustainable practices grows, it becomes imperative to raise awareness about the nutritional and ecological advantages of millets among consumers, producers, and policymakers alike. Initiatives like India's inclusion of millets in its National Food Security Act and the proposed International Year of Millets (2023) endorsed by the FAO and the UN General Assembly are vital steps toward revitalizing millet cultivation, enhancing food security, and promoting the health benefits of these remarkable grains.

# 2. Global area and production of millets

As of 2022, the global millet cultivation spanned across 71.70 million hectares. The worldwide millet yield reached 90.65 million metric tons in the same year, displaying a decade-long growth trend (2012-2022) from 88.31 million metric tons in 2012. India held the foremost position in millet production in 2022, contributing 17.60 million metric tons, which accounts for 19.42% of the overall global production. Following India are Nigeria (9.00 million metric tons; 10.01%), Sudan (6.50 million metric tons; 7.23%), the United States (6.21 million metric tons; 6.91%), and China (5.70 million metric tons; 6.34%). In terms of millet categorization, the global sorghum acreage encompassed 40.44 million hectares in 2022, constituting 56% of the total. Concurrently, the area allocated to other millet types amounted to 31.28 million hectares (44%). Among these, sorghum contributed approximately 66% (60.13 million metric tons) to the total global millet production, while the remaining 34% (30.52 million metric tons) came from other millet variants such as small millets, finger millets, and pearl millets, as reported by FAO and USDA sources.

**3. Indian area and production of millets**

In 2022, India's millet production reached 17.60 million metric tons, comprising 4.40 million metric tons of sorghum and 13.20 million metric tons of other millets. From 2012 to 2022, there has been a notable increase in millet production, rising from 16.03 to 17.60 million metric tons. Interestingly, this growth has occurred alongside a decrease in millet cultivation area, which went down from 15.40 to 14.00 million hectares. Despite this reduction in cultivated land, millet productivity demonstrated a significant rise, increasing from 1.04 to 1.26 metric tons per hectare, as indicated by USDA data.

Within India, Rajasthan emerged as the primary millet producer, yielding 5.15 million metric tons in the 2020-21 period, constituting 28.61% of the national output. Karnataka followed closely as the second-largest contributor, generating 2.56 million metric tons, equivalent to 14.26% of the national production. Other significant millet-producing states encompassed Maharashtra (2.51 million metric tons; 13.95%), Uttar Pradesh (2.29 million metric tons; 12.75%), Haryana (1.36 million metric tons; 7.58%), and Gujarat (1.09 million metric tons; 6.06%). Together, these leading six states collectively accounted for over 80% of India's millet production during the 2020-21 period.

**3.1. Trade:** Being the largest millet producer, India holds a crucial position in the global millets trade. In 2021, India's millet exports amounted to USD 65.10 million, contributing 1.66% to the global trade. In terms of volume, India exported 168,000 metric tons (0.45% of global trade). Over the years, India's exports grew from USD 55.22 million in 2011 to USD 65.10 million in 2021, reflecting a Compound Annual Growth Rate (CAGR) of 1.66%. However, in volume terms, exports experienced a negative decline of 0.52%, dropping from 176,000 metric tons in 2011 to 168,000 metric tons in 2021.

The leading export destinations for Indian millets in 2021 included UAE, Saudi Arabia, Nepal, USA, Kenya, and Bangladesh. In terms of value during 2021, the leading export destinations for India were as follows: UAE with USD 13.16 million (20.22%), Saudi Arabia with USD 6.29 million (9.67%), Nepal with USD 6.28 million (9.65%), USA with USD 4.19 million (6.44%), and Kenya with USD 3.23 million (4.96%). In volume terms, the top five export destinations for the same year were UAE with 37.88 thousand metric tons (22.58%), Nepal with 22.42 thousand metric tons (13.36%), Saudi Arabia with 20.15 thousand metric tons (12.01%), Kenya with 10.60 thousand metric tons (6.32%), and Bangladesh with 7.73 thousand metric tons (4.61%).

**4. Types of millets**

Millets can be classified into two distinct groups based on their seed size and intended use. The major millets group includes sorghum (Sorghum bicolor), pearl millet (Pennisetum glaucum), and finger millet (Eleusine carocana). In contrast, the minor millets group comprises proso millet (Panicum miliaceum), kodo millet (Paspalum scrobiculatum), foxtail millet (Setaria italica), little millet (Panicum sumatrense), barnyard millet (Echinochloa crusgalli), and browntop millet (Brachiaria ramose) (Chandrashekar and Shahidi, 2012). The Table 1 lists the vernacular names of millets along with their origins, while Table 2 provides an overview of the distinctive characteristics of these diverse millet varieties (Yousaf *et al.,* 2022)

# Table 1. Types of millets grown in India (Dayakar *et al.,* 2017)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Scientific name** | **English** | **ಕನ್ನಡ** |  | **Origin** |
| *Sorghum bicolor* | Sorghum | ಜೋಳ | जोवार | India |
| *Pennisetum glaucum* | Pearl millet | ಸಜ್ಜೆ | बजरा | Africa |
| *Eleusine carocana* | Finger millet | ರಾಗಿ | रागी | Africa |
| *Panicum miliaceum* | Proso millet | ಬರಗು | छेना | Eastern Asia |
| *Paspalum scrobiculatum* | Kodo millet | ಹರಕ | कोडों | India |
| *Setaria italica* | Foxtail millet | ನವಣೆ | काकुन | Eastern Asia |
| *Panicum sumatrense* | Little millet | ಸಾಮೆ | कुटक | Southeast Asia |
| *Echinochloa crusgalli* | Barnyard millet | ಊದಲು | साँवा | Japan |
| *Brachiaria ramose* | Browntop millet | ಕೊರಲೆ | छोटी कंगनी | South East Asia |

# Table 2. Characteristics of different millet (Yousaf *et al.,* 2022)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Millet** | **Seed type** | **Size** | **Shape** | **Colour** |
| Sorghum | Caryopsis | 3 to 4 mm  ø | Round | White, yellow, red or brown |
| Pearl millet | Caryopsis | 3 to 4 mm  length | Oval | White, grey, slate blue or purple |
| Finger millet | Utricle | 1 to 2 mm ø | Round | Yellow, white, red, brown or violet |
| Proso millet | Utricle | 2 to 3 mm length | Oval | Cream, yellow or orange |
| Kodo millet | Caryopsis | 1 to 2 mm length | Oval | Blackish brown to dark brown |
| Barnyard millet | Caryopsis | 3 to 4 mm  length | Oval | Straw white, grey to dull white |
| Little millet | Caryopsis | 1.8 to 1.9 mm in length | Round | Grey to straw white |
| Foxtail millet | Utricle | 2 to 3 mm length | Oval | Red, black, white or yellow |
| Browntop millet | Caryopsis | 2 mm long | Ellip-soid | Pale brown |

# 5. Millets are smart cereals

ICRISAT introduced the concept of "Smart Food," which refers to food that meets specific criteria: "Good for you," containing a protein content ranging from 7% to 12%, fat content between 2% and 5%, carbohydrates making up 65% to 75% of their composition, a substantial 15% to 20% dietary fiber content, and serving as a valuable source of essential nutrients such as iron, zinc, calcium, and various others, addressing issues of malnutrition and anemia in India. A comparative analysis of millets' nutritional value is presented in Table 3 and Table 4. "Good for the planet," millets exhibit a low carbon footprint, functioning as a strategy for climate change mitigation and adaptation. "Good for the small farmer," millets are adaptable to high temperatures, require minimal water, possess climate resilience, and offer multifaceted benefits (food, fodder, biofuel) ([www.icrisat.org](http://www.icrisat.org)).

# Table 3. Nutrient compositions of millets compared to wheat and rice

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Grains | Carbohydrates  (%) | Protein (%) | Fat (%) | Crude fibre (%) | Ash (%) | Energy (kcal) | Amino acids (g/100 g of protein) | |
| Methionine | Cystine |
| **Rice** | **78.2** | **6.8** | **0.5** | **0.2** | **0.6** | **345** | **0.12** | **0.05** |
| **Wheat** | **71.2** | **11.8** | **1.5** | **1.2** | **1.5** | **346** | **0.18** | **0.23** |
| Sorghum | 72.6 | 10.4 | 1.9 | 1.6 | 1.6 | **349** | 1.52 | 0.06 |
| Pearl millet | 67.5 | 11.6 | **5.0** | 1.2 | 2.3 | **361** | 2.11 | **0.80** |
| Foxtail millet | 60.9 | **12.3** | **4.3** | **8.0** | **3.3** | 331 | **3.06** | **0.45** |
| Finger millet | 72.0 | 7.3 | 1.3 | 3.6 | 2.7 | 328 | **2.74** | **0.27** |
| Barnyard | 65.5 | 6.2 | 2.2 | **9.8** | **4.4** | 307 | 2.20 | 0.10 |
| Proso millet | 70.4 | **12.6** | 1.1 | 2.2 | 1.9 | 341 | 2.21 | 0.25 |
| Kodo millet | 65.9 | 8.3 | 1.4 | **9.0** | 2.6 | 309 | 2.69 | 0.19 |
| Little millet | 67.0 | 7.7 | **4.7** | 7.6 | 1.5 | 341 | 2.21 | 0.04 |
| Browntop millet | 66.6 | 11.1 | 1.9 | 8.4 | 4.2 | 338 | 1.01 | 0.13 |

**Source: Nutritive value of Indian foods, NIN 2007**

# Table 4. Comparison of the mineral profiles of millets, wheat, and rice per 100 grams:

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Grains** | **Ca** | **P** | **Fe** | **Mg** | **K** | **Cu** | **Mn** | **Zn** |
| **Rice** | **10** | **160** | **0.7** | **90** | **-** | **0.14** | **0.59** | **1.4** |
| **Wheat** | **41** | **306** | **5.3** | **130** | **204** | **0.08** | **2.29** | **2.7** |
| **Sorghum** | 25 | 222 | 4.1 | **171** | 131 | 0.46 | 0.78 | 1.6 |
| **Pearl millet** | 42 | **296** | **8.0** | **137** | **307** | 1.00 | **1.15** | **3.1** |
| **Foxtail millet** | 31 | **290** | 2.8 | 81 | 250 | 1.40 | 0.60 | **2.4** |
| **Finger millet** | **344** | 283 | 3.9 | **137** | **408** | 0.47 | **5.49** | **2.3** |
| **Barnyard** | 20 | 280 | 5.0 | 82 | - | 0.60 | 0.96 | 3.0 |
| **Proso millet** | 14 | 206 | 0.8 | **153** | 113 | **1.60** | 0.60 | 1.4 |
| **Kodo millet** | 27 | 188 | 0.5 | **147** | 144 | **1.60** | **1.10** | 0.7 |
| **Little millet** | 17 | 220 | **9.3** | **133** | 129 | 1.00 | 0.68 | **3.7** |
| **Browntop millet** | 27 | 276 | **8.9** | 94.5 | 60 | 1.23 | **1.99** | **2.5** |

**Source: Nutritive value of Indian foods, NIN 2007**

**6. Health benefits**

* Millet functions as a prebiotic, providing nourishment to the beneficial microflora residing within your internal ecosystem.
* It effectively contributes to lowering blood pressure.
* Millet addresses issues like constipation, excessive gas, bloating, and cramping.
* Its consumption aids in preventing type 2 diabetes.
* Millet reduces the risks associated with gastrointestinal conditions such as gastric ulcers and colon cancer.
* It plays a preventive role against breast cancer.
* Millet supports the optimal functioning of kidneys, liver, and the immune system.
* Niacin (vitamin B3) found in millet can assist in reducing cholesterol levels.
* Manages respiratory conditions like asthma.
* Millets aid in body detoxification.

# 7. Millet processing

Millets are characterized by relatively challenging digestibility, limited mineral bio-availability, and short processed shelf-life. Consequently, a combination of both traditional and innovative processing methods is imperative to enhance their dietary, sensory, and shelf-life attributes while reducing anti-nutritional factors. Millet processing involves the conversion of transforming raw materials into usable or cookable forms that offer extended shelf life, unique flavors, improved textures, and enhanced taste.

The process can be classified into primary and secondary stages. Primary millet processing involves activities at the farm or producer level, encompassing tasks like cleaning, dehulling, sorting, polishing, and grading. Secondary processing occurs after primary steps, converting millet grains into consumable products. This includes traditional techniques such as milling, roasting, germination, and fermentation, yielding primary products like millet rice, semi-polished rice, semolina, dehusked flour, and composite flour. Additionally, secondary products like porridge, gruel, weaning food, and supplementary nourishment are produced.

Advanced secondary food processing technologies like malting, extrusion, baking, spray drying, and popping are harnessed to create instant mixes, convenient ready-to-eat (RTE), and ready-to-cook (RTC) products, further diversifying the millet product range (Ramashia *et al.,* 2019).

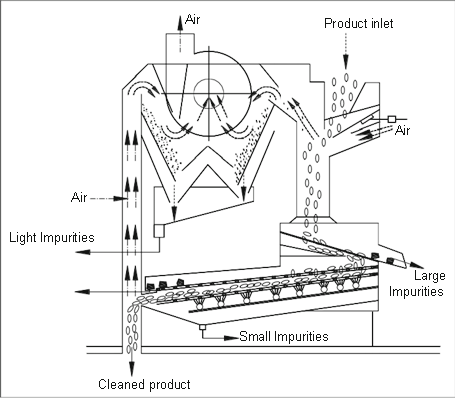
# 7.1 Primary processing operations

# 7.1.1 Cleaning

In this stage, the initial grains undergo a purification process aimed at removing impurities, commonly known as foreign matter. These impurities can take the form of dust, sticks, straw, sand, stones, as well as ferrous and non-ferrous particles. The separation process relies on differences in size, shape, terminal velocity, and magnetic properties of these elements (Srinivas, 2022).

# 7.1.1.1 Cleaner

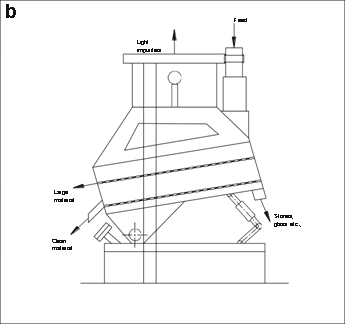
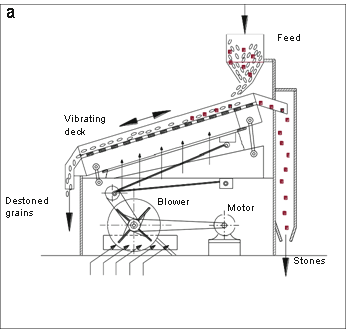
The grain processing industry offers a variety of cleaners, each tailored by manufacturers to suit specific grains. To account for varying impurity levels and Material Other than Grain (MOG), the selection of a cleaner should involve manufacturer-tested samples. Impurities, distinct in size, shape, and weight from the grain, necessitate customized cleaning strategies. A typical cleaner setup, as depicted in Figure 1, involves feeding grains through an upper opening. A fan-powered air suction system pulls air through the bed of millets, effectively isolating and removing lightweight impurities. The millets then descend onto a vibrating sieve with larger perforations, effectively eliminating significant impurities like straw and sticks. Subsequently, a sieve with finer perforations is employed to separate smaller impurities from the millets. Additional air aspiration is used to eliminate any remaining lightweight impurities and dust from the final grain output. When acquiring a cleaner, it is crucial to communicate with the manufacturer to ensure the provision of screens suitable for different millet types. These screens, easily replaceable, are designed to accommodate various grain sizes. Adjusting the air volume passing through the grain stream proves instrumental in selectively removing lighter impurities (Srinivas, 2022).



**Fig. 1. Schematic diagram of a cleaner**

# 7.1.1.2 Destoner

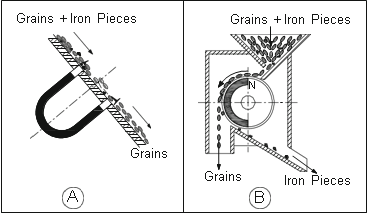
A destoner is employed to separate grains from stones based on their differing densities. It incorporates a layer of air, which can either be blown from beneath the reciprocating screen or drawn from above. When air is blown from below, it is known as a pressure-type destoner, and when air is drawn from above, it is termed a vacuum destoner. Both types of destoners utilize an air cushion on the vibrating platform, which is adjusted to allow only grains to float, while heavier impurities such as stones, glass, and non-ferrous materials settle on the platform. The inertia of the platform discharges these impurities at the higher end, while the lighter grains are expelled at the lower end. The separation process can be fine-tuned by regulating the feed rate, air volume, and the inclination of the sieve (Fig.2) (Srinivas, 2022).



**Fig. 2. Schematic diagram of (a) Pressure destoner and (b) Vacuum destoner**

# 7.1.1.3 Magnetic separator

Magnetic separators are highly effective in removing magnetic (ferrous) impurities from the grain supply. Type A magnetic separators employ a permanent magnet that makes direct contact with grains containing magnetic impurities. These ferrous particles are drawn towards a plate positioned above the magnet and necessitate periodic cleaning. To address this issue, a more efficient approach is illustrated in Figure 3 (Type B) magnetic separators. This design incorporates a semicircular magnet encased within a rotating cylinder made of non-ferrous material. In this configuration, as the mixture of grains and ferrous impurities is introduced, gravity causes the grains to flow past the magnet. Simultaneously, the magnetic impurities adhere to the non-ferrous drum due to the stationary magnet's magnetic pull. The impurities are automatically discharged when they reach a non-magnetic zone. This system operates autonomously and requires minimal inspection, ensuring both effective and efficient cleaning (Srinivas, 2022).



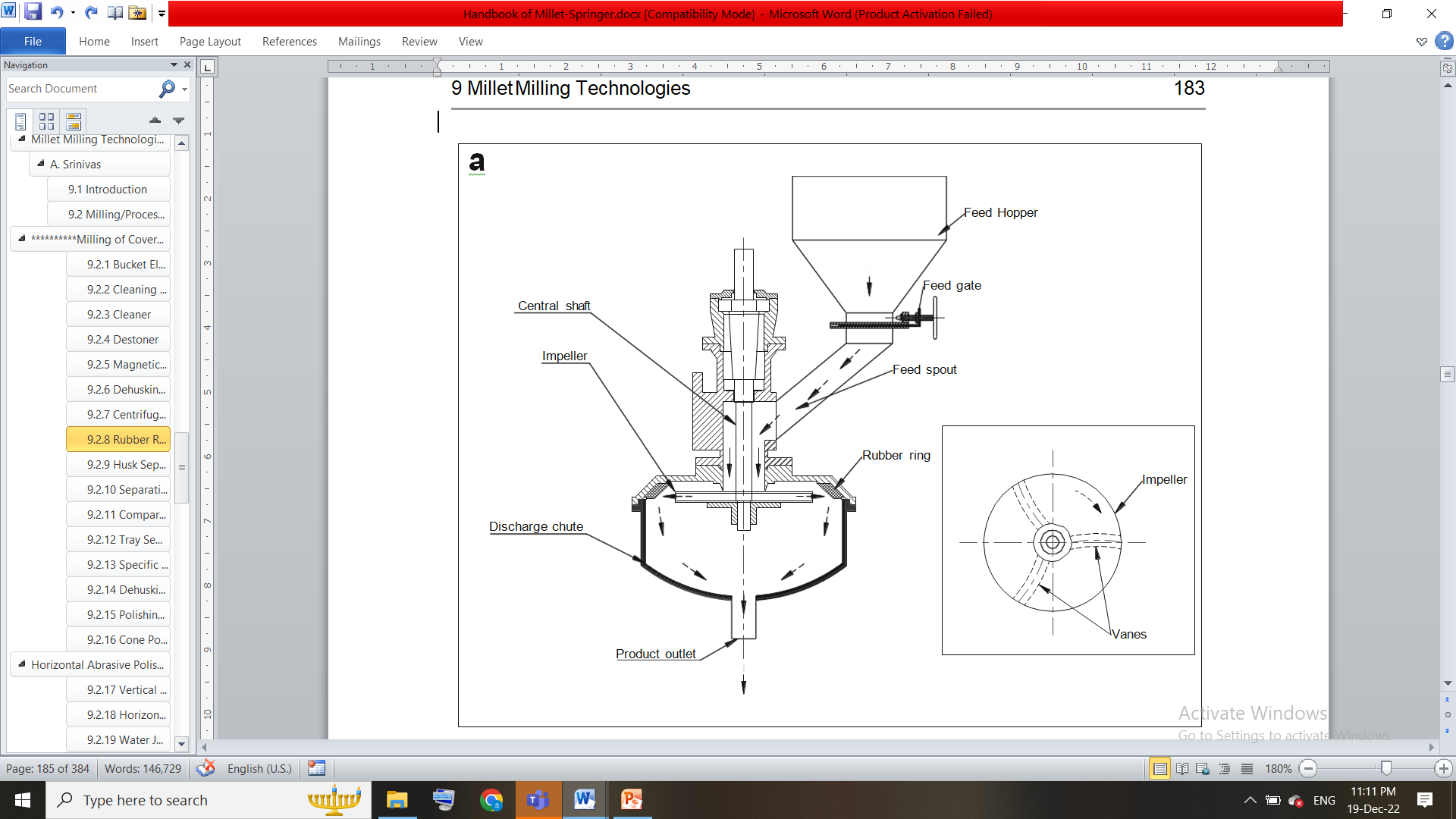
**Fig. 3. Schematic diagram of magnetic separator**

# 7.1.2 Dehusking

During this phase, the cleaned millet grains undergo husk removal to make them suitable for consumption. Because of the variation in husk content and the number of layers among different millet grains, the dehusking process requires precise milling techniques and the selection of appropriate machinery. Two primary methods are employed for dehusking millets: centrifugal shellers and rubber roll shellers. Centrifugal shellers are suitable for smaller capacities, typically up to 1 ton per hour. They are known for their ease of operation, low maintenance requirements, and reduced need for operator expertise. However, due to their reliance on friction and impact, they carry a higher risk of damaging the inner cotyledon of the millet grains. On the other hand, rubber roll shellers use compression and shear forces to remove husks and are favored by millers who aim to maximize head grain recovery. However, this type of sheller requires continuous supervision during processing and the involvement of a skilled operator to ensure optimal results. It spans a wider range of milling capacities compared to centrifugal shellers, making it a versatile choice for larger operations. (Srinivas, 2022).

# 7.1.2.1 Centrifugal sheller

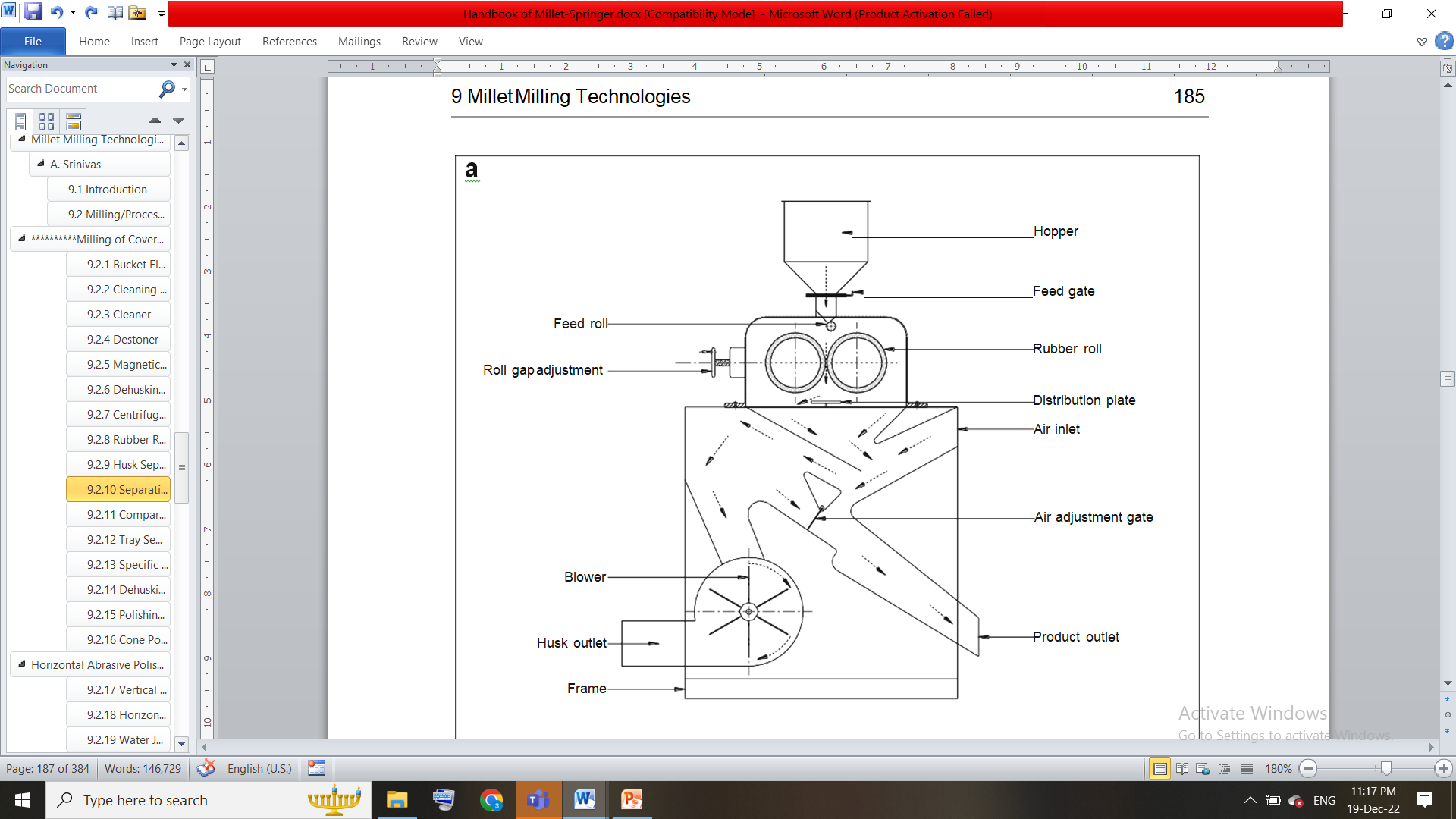
The centrifugal sheller operates by rotating millets with impellers or rotating blades, generating radial acceleration through centrifugal force. This rotational movement, assisted by pressure mechanisms like the Coriolis force, friction from the blades, or the impact force upon colliding with the blades and the peripheral surface, effectively removes the husk. The grains, influenced by inertial (centrifugal) force in the radial direction, are propelled outward. In horizontal centrifugal shellers, a feed screw is used to guide the grains toward the center of the impeller. Conversely, in vertical configurations, gravitational forces guide the grains for the same purpose. After dehusking, the husk fan functions as a disperser, propelling the husked material towards the outlet of the husk separator (Fig. 4).



**Fig. 4. Schematic diagram of vertical centrifugal sheller**

# 7.1.2.2 Rubber roll sheller

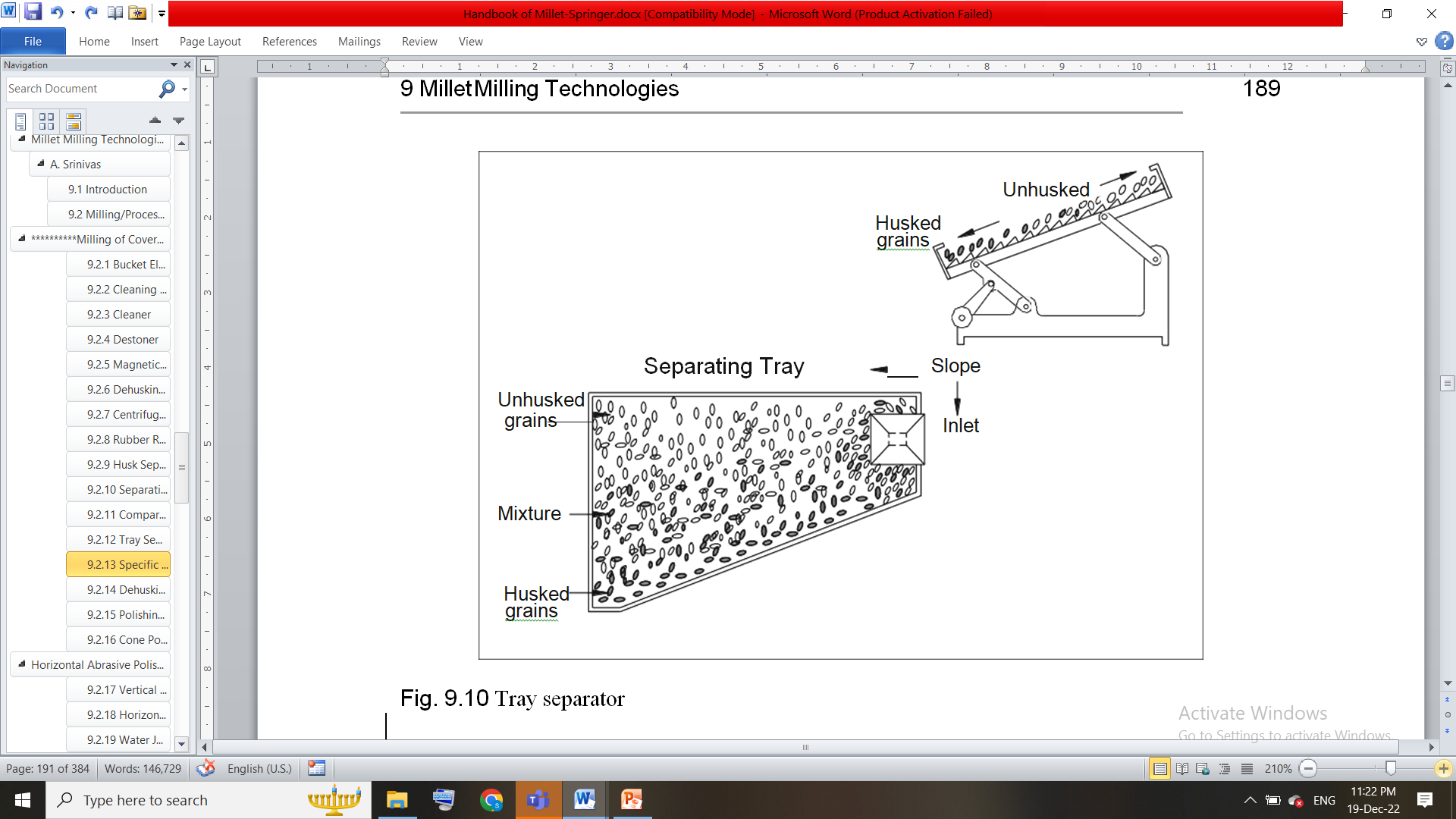
The rubber roll sheller utilizes a pair of rubber rolls rotating in opposite directions, ensuring that their point of contact with the grains is directed downward. Dehusking is accomplished through compression and shear forces. Compression is achieved by narrowing the gap between the two rubber rolls, which is done by fixing one roll in place while laterally adjusting the position of the other. The fixed roll typically rotates about 20-25% faster than the movable roll. The interaction of varying peripheral speeds, coupled with controlled inter-roll pressure, subjects the grains entering the nip of the rollers to compression and shear forces, effectively removing the husk. Essentially, the portion of husk in contact with the faster roll moves more swiftly than the other half, facilitating dehusking. Friction generated during this process produces heat, which can have a detrimental effect on the hardness of the rubber. Extended exposure to heat can soften the rubber, leading to accelerated wear and a reduced operational lifespan of the rubber rolls. To counteract this, air is blown onto the surface of the rolls to cool them during continuous operation. Due to the difference in roll speeds, wear is not uniform. The faster roll experiences more rapid wear, eventually resulting in the elimination of the speed difference between the rolls. In this scenario, the required shear forces for husk removal become negligible, and grains are simply compressed and discharged. Figure 5 provides a schematic diagram of a rubber roll sheller with an integrated aspirator.



**Fig. 5 Schematic diagram of rubber roll sheller**

# 7.1.2.3 Specific gravity separator

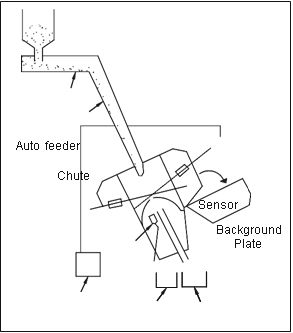
The specific gravity separator functions based on differences in size, shape, and specific gravity among grains that necessitate separation. This machine consists of two integral steps facilitated by a porous table through which air is blown. The separation process occurs in two stages: vertical separation, characterized by grain stratification induced by the air, followed by horizontal separation driven by the motion of the table and gravity. Importantly, for effective separation during the subsequent table motion, grains must first be stratified. This concept can be likened to placing a mixture of straw and sand of the same size into a glass of water, where the straw floats on top of the water, and the sand sinks. The machine's table has a dual inclination, sloping downward in both the X and Y directions. The grain mixture feed is introduced at the highest point of the table. This design allows lighter grains to float in the air and move downhill due to gravity, while heavier materials remain in contact with the table and are discharged slightly uphill. The configuration of the specific gravity separator ensures that not all areas of the table receive the same amount of air. This variation is due to differences in bed depth and grain weight across the table. The highest amount of air is supplied to the feed zone, where the grain depth is at its maximum. In contrast, the least amount of air is directed to the point where light grains are discharged, not only because of their lightness but also because of the shallower grain depth in this zone. Additionally, the area where heavy grains are discharged requires a significant amount of air. Key adjustable parameters in a specific gravity separator include the feed rate, the airflow rate through the table, and the inclination of the table in both the X and Y directions (see Fig. 6).



**Fig. 6. Schematic diagram of speciﬁc gravity separator**

# 7.1.2.4 Color Sorter

The color sorter operates as a photoelectric particle separator, utilizing a solenoid air valve (ejector) connected to a sensor through electrical means. This sensor relies on reflected light to distinguish between the background and the grains, which descend from a chute shaped like a conduit. When any grains display discoloration, the ejector expels them. The grains are individually guided to pass through a channel and are compared against a predefined standard. If a rice grain's color deviates from the set shade, the ejector releases a burst of air, propelling the discolored grain away from the bulk. The color can be adjusted to achieve a consistent hue throughout the sorted rice. Currently, color sorters equipped with CCD cameras are widely used. The process involves placing the selected material into the machine hopper. A vibratory feeder ensures even distribution across channels or feed distribution channels. Singular grains pass through the observation cabinet located between the monitor (camera) and a background plate. Using appropriate lighting, an optoelectronic sensor receives light from the material, triggering the system to generate an output signal for the ejectors. These ejectors, which function as nozzles connected to an air compressor, are controlled by solenoid valves. These valves expel the "rejected" grain into a separate waste compartment, while the "accepted" grain continues its descent into the "good" product area. Subsequently, the accepted grain is weighed and packaged (Fig. 7).



# Fig. 7. Schematic diagram of colour sorter

# 7.2 Secondary processing operations

Secondary processing of millets involves a range of value-added procedures, which include milling and sieving millet grains to produce flours. It also encompasses processes such as germination or malting, fermentation, and techniques like roasting, popping, or puffing millets. Moreover, millets can be utilized as a source of biofuels, contribute to the extraction or preparation of innovative nano-biochemical compounds, and play a significant role in advancing nanotechnologies.

# 7.2.1 Milling

Milling is the process of reducing cereal grains into fine flour through various size reduction methods. In millet processing, technologies from both wheat and rice milling are currently employed. Traditional mills utilize plate mills, roll mills (utilizing shear and crushing), and hammer mills (employing impact and pulverization), all operating on principles of abrasion. These techniques are still utilized in small-scale processing units. However, conventional milling methods have certain limitations:

1. Conventional milling techniques frequently struggle to attain a fine particle size below 400 μm.

2. Elevated moisture levels in the raw material can impede milling efficiency.

3. The milling process often leads to the contamination of the operational area with dust and flour particles, which can extend to the surrounding environment. This poses health risks to human operators' respiratory health and contributes to environmental pollution in the vicinity.

The following section explores innovative approaches and improvements applied to various milling techniques to address the previously mentioned drawbacks.

Given the prevalence of hammer mills, multiple experiments have been conducted to tackle the mentioned issues. The results revealed that a hammer mill equipped with an end suction lift mechanism could operate continuously without clogging. This led to higher milling percentages and the production of particles smaller than 400 μm, suitable for composite and basic flour used in various food preparations. This design involved the removal of sieves and the introduction of a mechanism to ensure efficient reprocessing of larger particles (using mechanical separators) for improved milling. Sedimentation chambers were also introduced to prevent flour or dust particles from escaping into the environment.

In this process, cereal grains enter the feed hopper of the hammer mill. The raw material flows unidirectionally into the milling chamber through the hopper. Inside the milling chamber, hammers pulverize the material to the desired particle size, aided by mechanical separators rotating at the same speed as the shaft. A fan induces a mixture of air and particles, which is then vented through overhead ducts. These ducts are designed to enhance the movement of dust-carrying air, minimizing particle sedimentation. As the air passes through a cyclone, the velocity of particles decreases, causing fine particles to fall, which are then collected and bagged.

Air jet milling presents an alternative method to achieve the desired particle size reduction in millet flours. This method is based on the fluid energy impact milling principle, enabling the production of particles no larger than 40 μm. By accelerating materials to high-velocity air, super-fine powders are generated through inter-particle impact or collisions, leading to size reduction. Air jet milling shows promise as a milling technology to be further explored, especially for obtaining millet flours with enhanced physicochemical and functional properties. This method can produce final particle sizes of around 1000 nm, depending on the processed material, presenting an opportunity for improved flour quality.

# 7.2.2 Germination and Malting of Millets

Germination is a biochemical transformation process (Chauhan and Sarita, 2018) that transitions seeds from a dormant to an active state. This progression enhances the nutritional value of grains by reducing anti-nutrients and improving the bioavailability of nutrients. Malting consists of three stages: steeping, germination, and drying. During steeping, grains are soaked in water until they absorb sufficient moisture to initiate the metabolic processes required for germination. Controlled conditions of temperature (typically between 25–30°C), moisture content, and a specific germination period (lasting 2–6 days) are maintained during the germination phase. Following germination, drying (known as kilning) serves as the final step in malting. This process reduces the moisture content and water activity, resulting in a stable product enriched with active enzymes and heightened nutritional attributes. The malted grains can then be finely ground into malted flour, yielding a highly nutritious product.

Drying temperatures during kilning usually range between 50 and 60°C and are maintained for approximately 24 hours or longer, depending on the chosen drying method.

# 7.2.3 Germination and Fermentation of Millets

Recent advancements and research have explored innovative approaches that involve germination and fermentation as alternatives to conventional malting processes, with the aim of maximizing the benefits from millet grains. A study conducted by Inyang and Zakari in 2008 focused on the nutritional and sensory assessment of "Fura," a millet-based food product. This process involved germinating pearl millet grains by soaking them for 12 hours, followed by sprouting for 48 hours. Subsequently, natural fermentation was carried out for 48 hours at room temperature. The results of the study revealed a significant reduction in phytic acid levels compared to the control. Specifically, the phytic acid levels were recorded at 416 mg/100 g for the traditional Fura (TF) control, 230 mg/100 g for germinated Fura (GF), 266 mg/100 g for fermented Fura (FF), and 220 mg/100 g for germinated and fermented Fura (GFF). This innovative approach highlighted the potential of germination and fermentation in enhancing the nutritional profile of millet-based products.

# 7.2.4 Popping or Puffing of Millets

When grains are exposed to high temperatures for a short duration, the starch inside them undergoes gelatinization and expansion, leading to a phenomenon known as "Popping." In this process, the grain is rapidly cooked, and the endosperm expands suddenly, causing the outer skin to rupture due to the release of superheated vapor. Similarly, controlled expansion is achieved in a process called "Puffing." These techniques are employed to create oil-free snacks with a desirable taste and texture. Popping and puffing can be achieved through various methods. Conventional methods include using sand and salt for heat transfer, dry heat, and gun puffing. In recent times, innovative technologies like high-temperature short time (HTST) and microwave puffing have gained popularity. These techniques offer alternatives for producing expanded snacks with improved sensory qualities and enhanced nutritional attributes (Mishra et al., 2014).

# 7.2.5 High Temperature Short Time (HTST) Popping of Millets

High Temperature Short Time (HTST) is a process in which grains are exposed to elevated temperatures, typically ranging from 230 to 270°C, for a very brief duration. In a study conducted by Kumari et al. in 2018, various varieties of pearl millet were subjected to popping to examine their nutritional and popping characteristics. The process began with cleaning pearl millet grains, followed by conditioning them by increasing their moisture content to 18% through the addition of water and allowing them to condition for 6 hours. Subsequently, these conditioned grains were popped at a temperature of 230°C using a grain popper.

The study revealed that the popping percentage achieved ranged from 43.0% to 85.0%, depending on the specific pearl millet varieties used. A greater volume of popped grains corresponded to a higher puffing index, which ranged from 5.27 to 9.29, depending on the varieties. Furthermore, the study observed a reduction in the content of phytic acid in popped millet compared to raw millet. These findings highlight the potential of popping pearl millet as an ingredient for producing nutritious and wholesome snacks (Kumari et al., 2018).

# 8. Value-Addition of Millets

Value-addition involves enhancing raw commodities into higher quality products, meeting consumer preferences. Despite minor global cereal consumption (2%), millets are crucial in arid regions due to nutritional prowess, gluten-free protein, low glycemic index, and bioactive compounds.

Over time, millets have served both culinary and medicinal roles, showcasing their historical consumption. Recent studies on millet processing and enhancement have unveiled promising avenues, broadening their presence in traditional and convenient health foods. This has led to the innovation of various millet products, encompassing flakes, pops, puffs, and extrudates, alongside roller-dried variations. Furthermore, fermentation and malting techniques have enabled the production of composite flours and infant food formulations. These advancements underscore millets' increasing potential as adaptable and nourishing ingredients (Mishra et al., 2014).

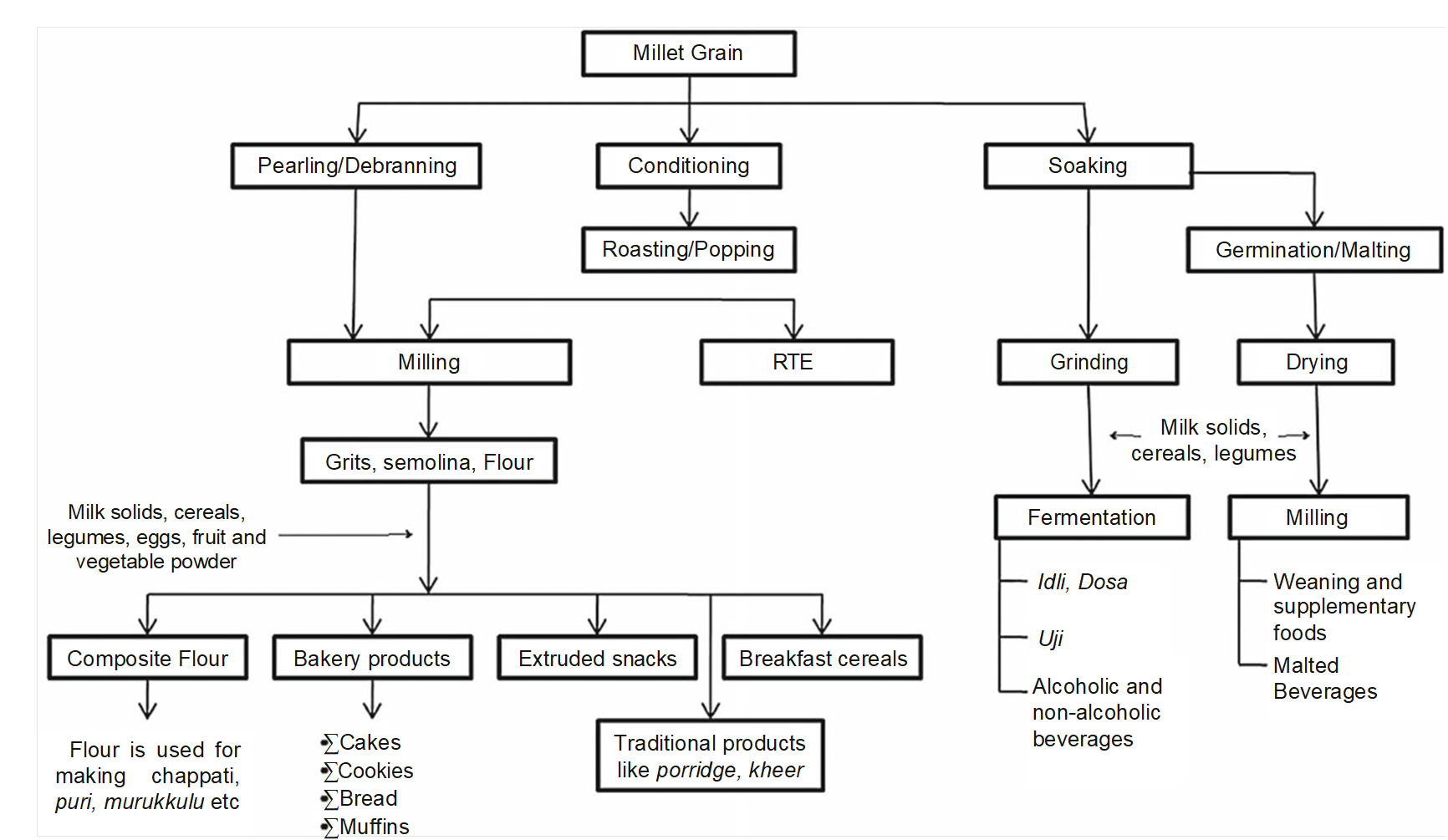
# 8.1 Millet rice

Millets are characterized by their mild flavor, which lends itself well to blending with various other food products. To enhance their flavor, millets are frequently combined with different grains and subjected to roasting before cooking. This approach helps to bring out the inherent taste of millets and create a harmonious blend with other ingredients. Notably, the addition of millets to food formulations has yielded promising outcomes. Researchers, as evidenced by Ronda et al. (2015), observed a significant increase in the dietary fiber, mineral, protein, and antioxidant content of the final product upon incorporating millets into the formulation. This highlights the potential of millets to contribute not only to taste but also to the nutritional profile of food products.

# 8.2 Millet ﬂour

Millets are processed into either coarse or fine flour, finding application in the preparation of chapatis and bakery products, as highlighted by Collar (2016). The inclusion of millet flour in baked goods not only improves their texture but also imparts enhanced flavor and heightened nutritional value. Moreover, millets serve as a versatile ingredient for the creation of leavened pancakes, commonly known as dosa, as well as thin, unleavened roti.

Millets have found their way into diverse segments of the food processing industry, including biscuits, confectionery, beverages, weaning foods, and even fermented products like beer, as noted by Laminu et al. (2011). Interestingly, a trend has emerged where sorghum, maize, and wheat composites are employed for soft biscuits and cookies, while millets are being utilized for cakes and non-wheat bread, yielding positive outcomes, as documented by Hama (2012). Despite their immense potential, progress in the infant weaning food sector has been somewhat sluggish, partly attributed to limitations in industrial malting capacity. A generalized process flowchart depicting the production of composite food products using millets is presented in Figure 8.



# Fig. 8. Schematic diagram for developing millet-based food products (Source: Kumar *et al.,* 2018).

# 8.3 Millet foods in India

Indeed, traditional foods are a cornerstone of Indian cuisine and play a vital role in the diets of both rural and urban households. In rural areas especially, a wide assortment of traditional snacks is crafted from millets like ragi and other small millets. Milled versions of these small millets, including ragi, panivaragu, kuthiraivali, thinai, varagu, and saamai, exhibit cooking properties similar to rice. This similarity allows them to be used in the preparation of various food items, contributing to the rich culinary diversity of Indian cuisine. These small millets have found their way into numerous dishes, offering a range of flavors, textures, and nutritional benefits. From breakfast to dinner and everything in between, millets are utilized in an array of culinary creations that cater to both taste and nourishment. This culinary versatility extends from simple porridges and flatbreads to complex snacks and traditional sweets, showcasing the adaptability of millets in meeting the dietary preferences and cultural practices of the Indian population. The cooking style of these small millets in India are bhat, kheer (sweetened thin porridge), roti/chapatti (unleavened bread), gruel (thin porridge), mudde (stiff porridge), dosa (fermented pancake), shavige (noodles), hurihittu (popped grain ﬂour), sattu, pappad (deep fried or roasted), halwa (cooked sweet product), malted beverage and fermented beverages. Many other traditional foods are made from popped ragi ﬂour mixed with sugar or jaggery or ghee or milk or butter milk and salt. In south India traditional millet products namely, koozh-porridge also called kanji (made from ragi, bajra) puttu (jowar, maize, ragi), kali (ragi, bajra), adai/roti (ragi, bajra, varagu) are more popular (Hema *et al.,* 2022).

Traditional Indian millet products like koozh (porridge), puttu (steamed cake), and kali (porridge) are particularly popular in South India. Indian flatbreads or chapattis, a staple in North India, can be prepared using millet flour or composite blends with wheat flour to create softer chapattis with improved shelf stability. These gluten-free alternatives are suitable for individuals with celiac disease or those sensitive to gluten-associated health risks.

Rice derived from decorticated saamai, thinai, and ragi is also widely consumed. Local sweet products like hurakki holige and halubai, as well as savory offerings like chakkali and hurihittu, hold cultural significance. Fermented and malted millet beverages are also popular choices.

Ragi, for instance, is commonly consumed in the form of flour-based foods such as roti (unleavened pancake), mudde (stiff porridge), and ambli (thin porridge), each offering distinct characteristics. Ambli is typically mildly fermented by mixing millet flour with water and a small amount of buttermilk, then allowing it to ferment overnight for a soothing summer beverage.

Millet-based alternatives to conventionally rice-based dishes like idli and dosa have also gained traction. These include dosa made from batter prepared by soaking, grinding, and fermenting varagu grains, black gram dal, and methi seeds. Idli prepared by soaking kodo millet and black gram in specific ratios is soft and well-received. Additionally, ready-to-use mixes for idli and dosa made from ragi are now available in the market, showcasing the nutritional value and versatility of millets in traditional Indian cuisine.

# 8.4 Breakfast Cereals and Expanded Millet

Breakfast cereals are indeed a popular choice for ready-to-eat meals, and cereal flakes constitute a prominent category within this segment. While corn and oats have been the primary sources for cereal flakes, there's a growing interest in utilizing millets for the preparation of ready-to-eat cereals as well. Various processing techniques are employed in the production of these cereals from millets, including extrusion, flaking, puffing, and granule formation. These processes aim to create convenient and nutritious breakfast options from millet grains. One innovative product arising from millets is the expanded grain. This novel creation holds great potential as a food item that can appeal to a wider audience, including those who might not be familiar with traditional millet consumption. The expanded millet possesses a porous and crisp texture, with the seed coat removed. This feature opens up the possibility of seasoning the expanded millet with various spices, condiments, or even coating it with complementary ingredients to create a delightful snack. These adaptations not only enhance the taste but also make expanded millets a versatile and convenient snack option for different consumer preferences (Desikachar, 1975 and Malleshi, 2007).

|  |  |
| --- | --- |
| Finger millet flour (200 g), pearl millet flour (120 g) and wheat flour (300 g)  ↓  Pasta mixer-extruder  ↓  34 ml/ 100 g of water to composite flour  ↓  Cold extrusion  ↓  Extruded pasta dried at 60°C for 3- 4 h to attain moisture content to about 9% (db)  **Fig. 16. Flowchart for preparation of for millet pasta**  (Gull *et al.,* 2015) | Browntop millet  ↓  Cleaning  ↓  Grinding and sieving (80 mesh)  ↓  Extrude at 150 °C, 360 rpm and 20% (feed moisture)  ↓  Browntop millet extrudates  **Fig. 17. Flowchart for preparation of for browntop millet extrudates**  (Sirisha *et al.,* 2022) |

|  |  |
| --- | --- |
| Sorghum (100 g), kodo millet (100 g), rice (100 g), dhal (100 g), green gram whole (100 g), soya bean (100 g)  ↓  Cleaning, washing, drying, grinding  ↓  Sieving  ↓  Mixing  ↓  salt (20 g)  ↓  Mixing well  ↓  Instant adai or crepe mix (kind of dosa)  **Fig. 18. Flowchart for preparation of for instant adai or crepe mix**  (Balasasirekha and Santhoshini, 2016) | Finger millet flour (600 g), black gram flour (300 g)  ↓  Adding papad khar (seasoning) 25 g  ↓  Adding coarsely pounded cumin, pepper and red chilli (5 g) and salt (50 g)  ↓  Making dough with hot water and kneading with oil (30 min)  ↓  Dividing the dough into balls  ↓  Pressing papad press and drying in sun/shade  ↓  Deep frying/ roasting finger millet papads  **Fig. 19. Flowchart for preparation of for finger millet papad** (Prabhakar *et al.,* 2016) |

|  |  |
| --- | --- |
| Foxtail millet flour (50 %) +wheat flour (50% )  ↓  Mixing thoroughly with water (35%), guar gum (1%) and edible oil (1%)  ↓  Cold extrusion  ↓  Tray drying at 50ºC for 3 h  ↓  Foxtail Millet Enriched Rice Analogue Fig. 20. Flowchart for preparation of for foxtail Millet rice analogue | 600 g millet flour +400 g refined flour+ 100 g sugar  ↓  Mixing thoroughly with 700 ml of water and 100 ml of oil for 10 min  ↓  Shaping 180 g of mixed material into a pizza shape  ↓  Proofing for 15-20 min and baking at 160ºC  ↓  Millet pizza base Fig. 21. Flowchart for preparation of for millet Pizza Base |

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# 8.5 Weaning and Supplementary Foods

"Malted Weaning Food" (MWF) is a popular and nutritious option for introducing infants to solid foods during the weaning period. This food is prepared by blending two parts of malted millet with one part of malted green gram. Malted millet and green gram have complementary nutritional profiles that enhance the overall nutritional quality of the food. The resulting MWF offers superior nutritional content and desirable textural properties.

When MWF is reconstituted with water and heated to boiling, it forms a nutrient-dense slurry with a relatively low bulk. Compared to roller-dried weaning foods, MWF contains twice the amount of nutrients under similar consistency. This makes MWF an excellent choice for providing essential nutrients to infants during their transition from a solely milk-based diet to solid foods. It's crucial to select locally available and cost-effective food sources for weaning food formulations. Ragi, a type of millet, is often considered an ideal choice due to its nutritional benefits, ease of availability, and affordability. The nutrient content of MWF is tailored to address the nutritional needs of infants and young children during their critical growth phases. Supplementary foods like MWF play a vital role in ensuring that infants and young children receive adequate nutrition as they transition to consuming a variety of foods beyond breast milk or breast milk substitutes. These foods are specifically designed to address nutrient deficiencies that might exist in the base staple foods, ensuring optimal growth and development during this important stage of life (Mal *et al.* 2010).

|  |  |
| --- | --- |
| Ragi grain (70%) + wheat (15%) + green gram (15%)  ↓  Soaking (12-16 h)  ↓  Sprouting green gram (24 h), wheat and ragi (48 h)  ↓  Oven drying at 60°C  ↓  Conditioning (5% moisture, 10 min)  ↓  Milling and sieving (60 mesh)  ↓  **Ragi malt**  **Fig. 22. Flowchart for preparation of ragi malt**  (Sarkar *et al.,* 2015) | Ragi grain  ↓  Soaking (8-12 h)  ↓  Grounding in a colloidal ball mill and filtering to get millet milk  ↓  Maltodextrin (30%)  ↓  Spray drying at feed rate of 0.4 kg/h, 120°C inlet temperature and outlet air temperature of 95°C  ↓  **Ragi milk powder**  **Fig. 23. Flowchart for preparation of ragi milk powder**  (Anitha and Sellamuthu, 2021) |

|  |  |
| --- | --- |
| Kodo millet (400g)  ↓  Cleaning, washing and sun drying (2 h)  ↓  Roasting (110°C for 3 min), powdering and sieving  ↓  Adding raw rice flour (400 g ) and black gram flour (200 g) and salt (0.75 g)  ↓  Adding water (50 ml)  ↓  Adding thick batter to boiling water (200 mL)  ↓  Cooking for 5 min  ↓  Millet gruel mix  **Fig. 24. Instant gruel mix**  (Thirumangaimannan and Gurumurthy, 2013) | Pearl millet (1 kg)  ↓  Cleaning and pearling  ↓  Roasting (90°C for 5 min)  ↓  Sieving  ↓  Adding sugar (½ kg), pepper (10g), dry ginger with cardamom (5g)  ↓  Pulverizing  ↓  *Sathu maavu*  **Fig. 25. Instant health mix**  (Vijayakumar and Mohankumar, 2009) |

# 10. Millet processing technologies and millet-based value added products developed in the department of processing and food engineering, CAE, Raichur

* Fractionation and characterization of foxtail millet and its applicability in extruded products
* Development of rubber roll dehusker cum grader for foxtail millet
* Milllet enriched rice analogues
* Effects of different retail and wholesale packaging materials on the shelf life of dehusked foxtail millet
* Effect of gamma irradiation on nutritional quality parameters of dehusked foxtail millet (*Setaria italica* (L.) Beauv.)
* Studies on enhancing the shelf life of foxtail millet flour
* Millet processing unit ( 1 TPH)
* The University of agricultural Sciences Raichur and NABARD organized a “Millet Conclave” on 26 and 27 August 2022 at Raichur.
* Finance Minister Nirmala Sitharaman announced providing Rs 25 crore under the NABARD’s rural infrastructure development fund UAS, Raichur, Karnataka, for establishment of incubation centre for processing and value addition for promotion of millets.

# 11. CFTRI, Mysuru millet based value added products

|  |  |
| --- | --- |
| * Bread (Ragi & Bajra) * Convenience Flour for Mudde * Cookies (Ragi & Bajra) * Decorticated Ragi * Expanded Bajra * Ragi Snack * Expanded Ragi * Flaked Jowar RTE * Germinated Ragi Drink Mix * Ragi Vermicelli * Multigrain Pasta * Multigrain Sweet Mix (Halva) | * Ragi Pappad * Ragi Roti * Ragi Rusk * Instant Beverage from Ragi * Instant Ragi Semolina/Porridge * Jowar Flakes * Malted Ragi Flour-Enzyme Rich * Millet based Upma & Halwa Mix * Millet Semolina (Coarse & Fine) * Multigrain Drink Mix * Shelf Stable Bajra Flour * Shelf Stable Jowar Flour |

# 12. NIFTEM-IIFPT patented millet based value added products

|  |  |
| --- | --- |
| * Arka Mushoom * Millet Cookies * Cookies from Kodo and Kutki Millets * Fermented, Functional Food Product * Gluten Free Chapatti Mix * Gluten Free Potato-millet Cookies * Gluten-Free Breads * Idli and Dosa Dry Mix * Kodo Kheer and Halwa Mix | * Millet Flaking Machine * Millet Milk Powder * Millet Edible Film * Multi-Grain Flour with Low Glycemic * Multi-grain Semolina, Gluten Free Cookies and RTE Extruded Snack * Non-Dairy Millet Ice Cream * Sprouted Pearl Millet and Green Gram Pasta * Value Added Sorghum and Millets Products |

# 13. A centre of excellence on small millets, UAS Bangalore millet-based products

|  |  |
| --- | --- |
| * Foxtail millet butter biscuit * Small millet churmuri * Little millet phulka * Foxtail millet burfi * Proso millet rava idli mix * Little millet idli * Little millet ohmo biscuit * Foxtail millet puliogare mix * Proso millet vangibath * Foxtail millet pulav * Little millet upma mix * Kodo millet curd rice * Foxtail millet rotti * Small millet pasta * Foxtail millet flakes | * Foxtail millet melting moments * Proso millet rava idli mix * Barnyard millet rusk * Foxtail millet vaemicelli * Little millet onion pakoda * Little millet flakes * Little millet rusk * Kodo millet rusk * Barnyard millet doughnut * Barnyard millet dosa mix * Instant proso millet dosa mix * Instant little millet dosa mix * Instant kodo millet dosa mix * Instant foxtail millet dosa mix * Instant barnyard millet dosa mix |

# 14. ICAR-Indian Institute of Millets Research (IIMR), Hyderabad millet – based value added product technologies developed

|  |  |
| --- | --- |
| * Pearl millet flakes (thin) * Jowar extruded snack * Jowar Lassi * Jowar cake * Ragi cake * Ragi based energy bar * Ragi pizza base * Zinc rich jowar vermicelli * Zinc rich jowar pasta * Zinc rich jowar cookies * Iron rich jowar pasta * Iron rich jowar vermicelli | * Ragi Bread * Jowar muffins * Jowar bread * Almond based Jowar cookies * Jeera based jowar cookies * Ragi muffins * Foxtail millet vermicelli * Foxtail millet pasta * Jowar khakha * Multi millet bread * Jowar choco chip cookies * Jowar instant khichidi mix |

# 15. Codex alimentarius international standards for millet

# Table 5. Codex alimentarius international standards for pearl millet grains

|  |  |  |
| --- | --- | --- |
| **Factor/description** | **Limit** | **Method of analysis** |
| **Appearance** | Buyer preference | Visual examination |
| Brown, white or green |
| **1000 kernel weight** |  | None defined |
| * + Whole millet grains | 5.0 to 10.0 g |  |
| * + Decorticated millet grains | 4.0 to 8.0 g |
| **1 litre weight** | 750 to 820 g | None defined |
| **Ash** | 0.8 to 1.0% on a dry matter basis | AOAC 923.03 |
| * + Decorticated millet grains |
| **Protein** (N x 5.7) | 8.0% on a dry matter basis | AOAC 920.87 |
| **Decortication** | Max: 20% | None defined |
| **Crude fibre** |  | ISO 5498:1981 |
| * + Whole millet grains | 3.0 to 4.5% on a dry matter basis |
| * + Decorticated millet grains | Max: 2.0% on a dry matter basis |
| **Fat** |  | AOAC 945.38f; 920.39c  ISO 5986:1983 |
| * + Whole millet grains | 3.5 to 6.0% on a dry matter basis |
| * + Decorticated millet grains | 2.0 to 4.0% on a dry matter basis |

Source: www.fao.org/fao-who-codexalimentarius/en

# 16. Use of millets in nutraceutical and functional food

The term "nutraceutical" is a combination of "nutrient" (a nourishing food component) and "pharmaceutical" (a medical drug). Coined in 1989 by the Foundation for Innovation in Medicine, it refers to any substance that is derived from food and offers potential medical or health benefits, including disease prevention and treatment. Nutraceuticals can encompass a wide range of compounds found in foods that contribute to health and well-being. Health Canada defines a nutraceutical as a product created from foods but sold in forms like pills, powders, or other medicinal formats not commonly associated with regular foods. Examples include phytochemicals, vitamins, minerals, amino acids, and bioflavonoids.

On the other hand, the American Dietetic Association defines "functional food" as any food or food ingredient that has been modified to offer health benefits beyond the conventional nutrients it contains. These foods are typically part of a regular diet and are believed to have positive effects on health. While functional foods may help reduce the risk of certain diseases or alleviate their symptoms, they are generally not considered a guarantee for disease prevention. They may also contribute to improved physical performance.

Both nutraceuticals and functional foods underline the connection between nutrition and health, focusing on the potential benefits that certain foods or food components can provide beyond basic nourishment.

# Table 6. Disorders and nutraceuticals

|  |  |  |
| --- | --- | --- |
| **Disorder** | **Nutraceutical** | **Reference** |
| Cardiovascular disorder | Antioxidants, dietary fibers, omega-3 polyunsaturated fatty acids (N-3 pufas), polyphenols , α-lipoic acid, magnesium, vitamin B6 (pyridoxine), vitamin C, nacetyl cysteine, Mg, K and lignin. | Garg *et al.* (2001) and Shukla and Singh (2009) |
| Obesity | Chitosan, vitamin C, linoleic acid, capsaicin and psyllium fiber | Li and Zhang (2001) and Bell and Goodrick (2002) |
| Diabetes | Phytoestrogens, isoflavones, omega-3 fatty acids, docosahexaenoic acid, lipoic acid, dietary fibers from psyllium.  Magnesium, chomium picolinate, calcium and vitamin D | McCarty (2005) |
| Cancer | Phyto-estrogens, carotenoids, retinoids, saponins, proanthocyanidins, ellagic acid, ferulic, caffeic, gallic acids and limonene | Gulcin *et al.* (2006) |

# Table 7. Food type and nutraceuticals

|  |  |  |
| --- | --- | --- |
| **Food type** | **Nutraceutical** | **Reference** |
| Immune boosters | Sulphides/thiols, phyto-estrogens, isoflavones | (Chanda *et al.,* 2019) |
| Pregnant women | Β-carotene, vitamin A, thiomin, riboflavin, niacin, vitamin C, fiber, vitamin E, thiamine, niacin, riboflavin, pantothenic acid and pyridoxine. Minerals like magnesium, manganese, iron, calcium and phosphorous | (Wassells *et al.,* 2019) |
| Malnutrition | Calcium, phosphorus, potassium, iron, magnesium, thiamine, niacin and riboflavin, fibers, polyphenols, valine, methionine, tryptophan and cysteine | (Charalampopoulos *et al*., 2002 ) |
| Weaning food | Calcium and zinc | (Usman *et al.,* 2016) |
| Anameic | Essential fatty acids, vitamin D, K, B12 , Fe, iodine and flouride | (Pandey *et al.,* 2010) |
| Sports | Whey proteins, branched chain amino acids, n omega-3 polyunsaturated fatty acid, calcium and vitamin D, iron, zinc, magnesium, β-carotene and selenium, conjugated linoleic acid*,* β-hydroxy β-methylbutyrate, methoxy-isolavone | (D’Angelo and Tafuri, 2020) |

**Table 8. Nutraceuticals and sources (Varma *et al.,* 2016)**

|  |  |
| --- | --- |
| **Chemical constituents** | **Source** |
| **Carotenoids** | |
| Lemonene | Guava, papaya, watermelon,tomato |
| β-Carotene | Vegetables, fruits, oats, Carrots |
| Lutein | Spinach, corn, avocado, egg yolk |
| Tocotrienol | Palm oil, different grains |
| Saponins | Beans like soya beans, chickpeas |
| **Polyphenolic Compounds** | |
| Flavonones | All citrus fruits |
| Flavones | Fruits, soyabean, vegetables |
| Flavonols | Broccoli, tea, onions, fruits |
| Curcumin | Turmeric root |
| Resveratrol | Grapes, raisins, berries, peanuts |
| Glucosinolates | Cruciferous |
| Limonoids | Citrus fruits |
| **Prebiotics/ Probiotics** | *Lactobacilli, bifidobacteria* |
| **Phytoestrogens** | |
| Isoflavones | Legumes, beans like soy beans |
| Lignans | Vegetables, rye and flaxseed |
| **Dietary fibre** | |
| Soluble fibre | Legumes, cereals |
| Insoluble fibre | Whole grain, corn bran, nuts foods |
| Sulphides/Thiols | Cruciferous vegetables |
| **Fatty Acids** | |
| Omega 3 fatty acids | Fish and flax seed |
| Monosaturated acids fatty | Present in tree nuts |
| Minerals like Zn, Ca, cu, K | Food |
| Polyols sugar alcohols | Food |

# Table 9. Some commercially marketed nutraceuticals (Sachdeva *et al.,* 2020)

|  |  |  |  |
| --- | --- | --- | --- |
| **Category** | **Product** | **Claim** | **Manufacturer** |
| Calcium supplement | Coral Calcium | Calcium and trace minerals | Nature's answer, Hauppauge, NY, USA |
| Calcirol D-3 | Calcium and vitamins | Cadilla healthcare limited, Ahmedabad, India |
| Immune Booster and immuno modulator | Celestial Healthtone | Dry fruit extract | Celestial Biolabs Ltd., India |
| Chyawanprash | Amla, Ashwagandha, Pippali | Dabur India Ltd., India |
| Amiriprash (Gold) | Chyawanprash Avaleha, Swarnabhasma and RasSindur | UAP Pharma Pvt. Ltd., India |
| Immulina | Bioactive microalgae complex | Nordic Phytopharma Group, Havdrup, Denmark |
| Emergen-C | Vitamin | Alacer Corp. California |
| Ester C | Vitamin | Ester-C, Bohemia, NY |
| Prebiotics | Cereals, drink mixes and cereal bars | Fiber | Kashi Company, La Jolla, CA, USA |
| Ensure Fiber | Fiber, digestive health | Abbott Nutrition, Columbus, OH, USA |
| Builder's Bar | Fiber | Clif Bar Inc., Berkeley, CA, USA |
| Helios Nutrition's Organic Kefir | Bifidogenesis, calcium absorption | Lifeway Foods, Morton Grove, IL, USA |
| Low-fat ice cream sandwiches | Fiber | Skinny Cow, Nestle SA, Vevey, Switzerland |
| Probiotics | DanActive® | *L casei* DN114001 | Danone Inc., Paris, France |
| Nutritional supplement | Weight smart™ | Vitamins and trace elements | Bayercooperation, Morristown, NL, USA |
| GRD® | Proteins, vitamins, minerals and carbohydrates | Zydus Cadila Ltd., Ahmedabad, India |
| Proplus® | Soy proteins | Campbell soup company, Camden, NJ, USA |
| Physical health and immune supplement | Nutricafe -Organic performance coffee | Cordyceps and Ganoderma | EnerHealth Botanicals, Longmont, CO, USA |
| Dietary supplement | Olivenol™ | Natural antioxidant hydroxytyrosol | Cre Agri, Hayward, CA, USA |
| Neuropathic pain supplement | PNer plus™ | Vitamin and other natural supplement | NeuroHelp, San Antonio, Texas, USA |
| Protein supplements | Theptin® Diskettes | Proteina and Vitamin | Raptakos, Brett and Co. Ltd., Mumbai, India |
| Proteinex® | Carbohydrates, minerals, proteins and vitamins. | Pfizer Ltd., Mumbai, India |
| Energy drink | Rox® | Caffeine, glucuronolactone and taurine. | Rox America, Spartanburg, SA, USA |
| Meal replacement beverage | Snapple-a-day™ | Vitamins and minerals | Snapple beverage group, White Plains, NY, USA |
| Amino acid supplement | WelLife® | Granulated-L-glutamine | DaesangAmerica Inc., Hackensach, NJ, USA |
| Neurotonic | Biovinca™ | Vinpocetine | Cyvex nutrition, Irvine, CA, USA |
| Anti-depressant | Pure Red Reishi | *G. Lucidum* | Terrasoul Superfoods, Fort Worth, TX, USA |
| Physical health supplement | Shiitake Gold | *L edodes* | Aloha Medicinals Inc., Carson City, NV, USA |
| Immunity supplement | Immune Assistcomplete | Blend of A. blazei, Coriolusversicolor, *L. edodes,* *Grifola frondosa and G. lucidum.* | Aloha Medicinals Inc., Carson City, NV, USA |

# Table 10. Functional properties of millets

|  |  |  |  |
| --- | --- | --- | --- |
| **Millet** | **Functional component** | **Potential health** | **Reference** |
| Pearl millet | Phytonutrient – lignin, flavonoid, apigenin, myricetin, ferulic acid and catechin | Prevent hormone-dependent cancer and cardiac arrests, anti-fungal, anti-ulcerative properties | Bora *et al.* (2019) |
| Finger millet | Gallocatechin, epicatechin, epigallocatechin, taxifolin, vitexin, tricin, myricetin, leuteolin, quercetin, apigenin, kempherol, diadzein, pyrocyanidin B1 and B2, ferulic acid and catechin | Anti-turmogenic, anti-diabetic, anti- microbial and antioxidant properties | Chandrasekara and Shahidi (2011) |
| Foxtail millet | Catechin,quercetin, apigenin, kempherol, ferulic acid, chlorogenic acid, caffeic acid, p-coumaric acid, syringic acid, xanthophylls, zeaxanthin, ferulic and p-coumaric | Body detoxication, antioxidant property and anti-proliferative activity | Zhang and Liu (2015) and Pradeep and  Sreerama (2018) |
| Kodo millet | Apigenin, kempherol, vitexin, isovitexin, leutolin, quercetin, ferulic acid and catechin, naringin, taxifolin | Antithombotic,  anti-allergic, antimicrobial,  anti-inﬂammatory, antiviral, anticarcinogenic | Bora *et al.* (2019) |
| Barnyard millet | Luteolin, tricin, n-(p-coumaroyl) serotonin, p-coumaric and chlorogenic acids | Anti-diabetic,  anti- cancerous | Anis and Sreerama (2020) |
| Porso millet | Apigenin, kempherol,myricetin, ferulic acid and catechin | Anti-diabetic,  anti-rheumatic,  anti- cancerous | Chandrasekara and Shahidi (2011) |
| Little millet | Apigenin, ferulic and *p-*coumaric, ferulic acid and catechin | Anti-diabetic, anti-rheumatic, anti-cancerous | Pradeep and  Sreerama (2018) |

# Table 11. Composition of millet by-products generated by processing industries

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **By-product** | **Variety** | **Composition** | **Application** | **References** |
| **Seed coat matter** | Finger millet | Dietary ﬁber, calcium , iron and zinc | Potential cereal food product development to enhance physical and functional properties | Amritha *et al.* (2018) |
| **Bran** | Foxtail millet | Oil, fermentable sugars, protein, dietary ﬁber and vitamin | Food packaging, healthcare and synthesis of chemicals | Chu *et al*. (2019) |
| **Husk** | All | Cellulose and ash | Concrete industries | Bheel *et al.* (2021) |
| **Broken grains** | All | Same as raw millet | Feed, millet analogues, fortification | Hanna and Wright (1995) |

**17. Conclusion**

The absence of suitable primary processing techniques for producing Ready-to-Cook (RTC) products and secondary processing methods for creating Ready-to-Eat (RTE) value-added products has been a major constraint in realizing the full potential of millets in diversified food applications and enhancing economic viability. Despite the challenges posed by the complex processing of millet grains, there are significant opportunities driven by consumer demand for healthier food options. This demand provides a platform for the development of appropriate processing technologies and the creation of innovative products, while also encouraging the mechanization of processing procedures. Promoting the diverse nutritional and ecological advantages of millets to various stakeholders, including consumers, producers, value chain participants, and policymakers, is a timely effort that can strengthen the connections within the food sector. In line with these considerations, a proposal for an International Year of Millets in 2023 was initiated by the Government of India. This proposal gained support from members of the Food and Agriculture Organization (FAO) Governing Bodies and was endorsed by the 75th Session of the United Nations General Assembly. The International Year of Millets serves as an important opportunity to raise awareness about the benefits of millets, encourage research and innovation, and foster collaboration across nations to advance millet-related initiatives.

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