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Review Article

# Recent advances in post-harvest processing technologies & value addition in millets- A Review

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## Abstract

**Background**: Being one of the oldest commodities still in existence, millets are thought to have been the world's first grain crop. The sixth-most significant grain crop in the world, these plants are classified as a category of small-seeded annual fodder grasses. One of the extremely nutrient-dense foods that has a significant beneficial impact on one's health is millet. Due to their lack of gluten, they are regarded as effective wheat replacements and a great source of protein and fiber. In most of the world's semi-arid and dry regions, where there is little or no yearly rainfall, these crops are the primary energy source. The supply and consumption of all these grains are steadily declining, even in regions where millet farming is relatively popular. The leading cause of this decline is the laboriousness of processing these grains using conventional techniques because there aren't enough post-harvest innovations adapted to make it easier for people to consume them. By drastically reducing labor-intensive tasks and processing time, mechanical processing might encourage growers to boost millet and millet-based food production, consumption, and profitability. **Conclusion:** This review provides an overview of the use of adaptive equipment for millet processing in remote areas of developing and industrialized countries, opening the door to the development of innovative technological innovations that have little to no negative impact on the nutrient content of millet during handling

**Keywords:** Millet, travail, industrialization, conventional methods of handling, post-harvest technologies, and nutritional benefits.

## Introduction

Millets are a diverse genus of small-seeded grasses cultivated worldwide as cereal crops or grains for human and animal consumption. They belong predominantly to the Paniceae tribe, although some millets are classified under other taxonomic groups (Vetriventhan & Azevedo, 2020). Millets have a long history of cultivation and consumption, predating the domestication of major staple crops. They have been integral to traditional diets across many cultures (Bhullar & Jenner, 1985).

The global popularity and cultivation of millets have declined over time due to the adoption of alternative agricultural practices favoring high-yielding and economically lucrative cereal varieties (Padulosi, Bergamini, & Lawrence, 2013). Consequently, even in regions where millets once served as staple crops, their cultivation has significantly diminished.

Millets offer nutritional benefits and resilience in diverse ecological conditions, making them a valuable resource in sustainable agriculture and food security efforts. Their adaptability to marginal lands and lower water requirements positions millets as crucial components in climate-resilient farming strategies. Despite their declining cultivation trends, renewed interest in millets is emerging globally due to their nutritional richness, gluten-free nature, and potential in diversified cropping systems.

### Agricultural production of millets

The anticipated global millet yield for 2016 is 30.5 million tons, with India as the leading producer with a supply of 17.96 million tons for 2020–21 **(FAO, 2018).** The eating of millets has typically been limited to the world's socially deprived population, despite the remarkable output and accessibility of millets **(Bharucha & Pretty, 2010).** Since the increased production and utilization of working capital crops like rice and wheat at a lower cost as well as the lack of fully prepared millet-based packaged foods, its use as a staple food has begun to wane even in regions like Asia and Africa where they are permanent on a large scale by the low-income members of society **(Gopalan & Rama Sastri, 2019).** Though equipment made for other cereals like corn might be employed, there is a rising desire for mechanizing millet manufacturing to alleviate labor-intensive handling and counteract nutrient losses that occur during conventional processing **(Chandrashekhar & Narsing Rao, 2016).**

Varieties of millets have fallen out of favor as a crop for human consumption due to these factors. In the previous 18 years, millet innovation has resulted in the development of a number of unique ready-to-eat/ready-to-use commodities with palatable aromas and higher consumer attractiveness, particularly in the bread sector, which may encourage excess uptake **(Padulosi & Ng, 2019; Rai & Singh, 2016; Krishnan & Radhakrishnan, 2016; United Nations Food and Agriculture Organization [FAO], 2017).**

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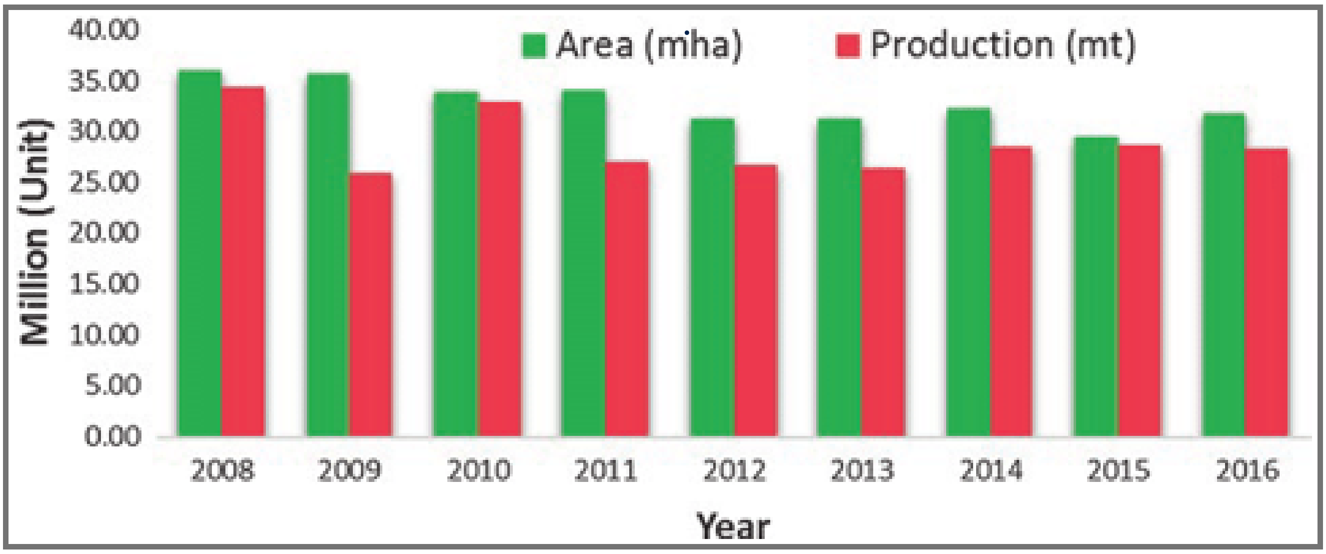


**Emerging countries' use of millets**

Millets have traditionally seemed to be the principal food commodity consumed daily, enabling energy and food sovereignty for a huge number, particularly the impoverished dwelling in the parched and quasi regions of developing countries **(Bhullar & Bhullar, 2018).** Africa (44.7%) and Asia (54.3%), which as of 2016 contributed one of the most significantly to manufacturing, are the two regions that cultivate various grain products most frequently. But not every kind is developed in these areas with similar value **(FAO, 2017).** In contrast, beyond the eastern highlands, pearl millet is the most common variety of millet grown throughout Africa, whereas foxtail millet is not grown at all (De Wet, 2015).

Typically, millets are eaten as whole kernels or as flour, depending on how they are processed. Porridges, alcoholic and non-alcoholic drinks **(such as togwa, oskikundu),** flatbreads that have been metabolised or not (such as injera and kisra), as well as dumplings, have all been typically made from millets (popped millets) **(Gopalan & Rama Sastri, 2019).** Such nourishing grains, nevertheless, have historically been disregarded because there isn't enough processing equipment and technology available in communities and townships **(Belton & Mather, 2018; Padulosi & Ng, 2019).**

**Millets in industrialized countries**

The growth of millet is uncommon in industrialized nations like the USA and Canada, compared to the other largest agricultural kinds. The Americans provide only 1.150 percent of the world's total millet production, and only a very small portion of this percentage is consumed by humans (National Research Council, 1996). The fact that grains are not readily available in the form of ready-to-eat or ready-to-use items, as well as the lack of information and understanding about these crops as significant food grains for their hygiene and cleanliness, are the main causes of this scenario (Padulosi & Ng, 2019).

The most widely grown millet variety on the American continent is the proso variety. Proso millet, however, is primarily planted as a crop for pastures and as a component of bird seed mixes, livestock, and pet food **(Baltensperger, 2018; Boyles, 2016).** The majority of many other types, however, are typically seen as invaders **(Ceylon & Toker, 2017; Guèye & Haefele, 2019; Sidaoui & Mokhtar, 2018).**

**Need for automation**

Millets must go through a number of post-harvest processes before being further processed for consumer use, including gathering, conveyance, threshing, cleaning, drying, milling, and warehousing **(Chandra Jena, n.d.; Macauley & Ramadjita, 2015).** This preserves the grain's keeping quality and keeps pest infestation out of the grain until it is processed **(Mazar Ali, 2016),** where the consumable kernels are segregated from the bran and husk **(Kumar et al., 2021; Mazar Ali, 2016).** The outermost husk must be removed because it contains compounds that are anti-nutritional **(Macauley & Ramadjita, 2015; Zhang et al., 2022)** and has sensory properties unsatisfactory, rendering the grains unfit for human eating **(Mazar Ali, 2016).**

The outermost husk must be removed because it contains substances that are anti-nutritional and sensory properties unsatisfactory, rendering the grains unfit for human eating **(Mazar Ali, 2016)**. As a result, there is a good need to create processing plants that are affordable and can be used at the village level to facilitate millet processing **(Joshi et al., n.d.; Zhang et al., 2022).** This will ultimately enable the manufacture of increased millet food products on a commercial basis that can be made available for utilization by urban populations **(Chandra Jena, n.d.; Mazar Ali, 2016).**

This review paper emphasizes the diversity of equipment like threshers, rotary mills, dehullers, etc., to handle different millets and their impact on millet grain quality while also taking into account the relevance of equipment in remote regions and the need for extensive studies to ease millet grain processing **(Buerkert & Haake, 2015; Jideani & Jideani, 2011; Kumar et al., 2020; Kothari et al., 2019; Mubaiwa & Fogliano, 2019; Olatunde et al., 2016; Omueti et al., 2018).**

**Problems encountered during processing**

Milling millets involves adequate post-harvest procedures since they are vulnerable to infection. Threshing, decorticating, and crushing the millet grains into powder/flour are the first steps in post-harvest processing. From harvesting to flour manufacture and quality enhancement, women, in particular, play a critical role in the on- and off-farm processing of millets **(International Development Research Centre [IDRC], 2015).**

Millets are typically harvested and processed by hitting the plants bearing the grains on the ground, striking them with clubs, or stepping on them with bulls or humans **(International Crops Research Institute for the Semi-Arid Tropics [ICRISAT], 2013).** The issue with the conventional method of chopping is the buildup of dust, tiny stones, and external contaminants, which not only reduced seed yield but also lengthen computation cost by necessitating a cleaning or preparatory stage **(Sehgal, Ranjan, & Raju, 2019).**

The preponderance of millet consumers and manufacturers struggle with the labor-intensive practice of manually dehulling and grinding their grain prior to making millet meals **(Shrestha, Dhakal, & Shrestha, 2015).** With the exception of pearl millet, which can be eaten both whole and decorticated, other minor millets must be dehulled before preparation. By pressing these whole seeds in a pestle or mortar or crushing the grains between two stones, dehulling and milling are accomplished. However, regional variations exist in this practice **(ICRISAT, 2013).**

Institutions like the International Development Research Centre **(IDRC),** Canadian International Development Agency **(CIDA),** International Crops Research Institute for the Semi-Arid Tropics **(ICRISAT),** Development of Human Action **(DHAN)** foundation, etc., and several other research institutions have concentrated R&D to address the challenges faced during the customary millet processing and finally meet the need for analyzing machines and tools in the industrialized regions **(Bellon, Hodson, & Hellin, 2011; Padulosi & Ocampo, 2013; Sehgal et al., 2019; Yiridoe, Bonti-Ankomah, & Martin, 2010).**

**Specialized post-harvest equipment for primary processing of millets**

A crucial stage in the initial processing of millets is acquiring grain rice and in the subsequent processing of grains for human use. Sorghum, pearl, and finger millet are examples of naked grains that are simple to process. However, handling millets with husks, such as small, proso, kodo, barnyard, foxtail, and brown top millets, is more challenging **(Kumar & Singh, 2017).** These must have the inedible husk removed after processing. The small size of the grains, variations in the raw materials due to variety, cultivation practices, and microclimate across production regions and across the years, variations across the crops, and low shelf life of the processed rice and grits due to pests and diseases and rancidity are the main challenges in processing small millets **(Prakash, 2018).**

Graders, shakers, destoners, air classifiers, aspirators, and hullers are the types of machinery now utilized for handling small millets on a small to medium scale. Three various dehulling technologies are currently in use: the emery mill, which operates on the abrasion basis; the rubber roller mill, which operates on the impact concept; and the centrifugal type **(Bhavani, Bhagavatula, Sarveshwaran, & Patil, 2016).** The majority of this treatment equipment are adapted versions of paddy treatment technologies. Because there hasn't been much scientific input into the design and production of mini millet production machinery through systematic technology transfer, equipment makers mostly develop and manufacture them based on their practical experience (the trial-and-error technique) **(Gopalan & Rama Sastri, 2019).** Contrarily, a small number of clever players in the market have mastered the processing of little millet through numerous iterations, collecting operating expertise that is "tacit" in nature. The standardization of processing technologies as a process line has only received a small amount of formal investigation **(Pushpa, Krishnan, & Vanaja, 2018).**

The collaboration and exchange of information among research organizations, suppliers of equipment, and end users, as well as the documentation of learning within each organization's sector, have not been supported by any efficient working mechanisms or learning platforms. The few hulling technologies that have been established are not tested in processing units employing high-throughput sequencing volumes to determine their functionality. The yield quality and hulling effectiveness (measured as the proportion of millet rice kernels to the total grain processed) have been subpar **(Ravi & Alagusundaram, 2016).** The clients' struggle with unhulled grains in millet rice is a significant one. The high processing costs required to produce rice of acceptable quality have an adverse effect on the processor's ability to sell as much tiny millet rice **(Rao & Seetharama, 2018).**

The crucial bridge in the short grain supply chain connecting production and consumption is processing, therefore challenges and inefficiencies there pose a significant barrier to the expansion of markets for small millet food items. In order to increase output quantity and quality as well as user-friendliness, it is necessary to fine-tune the tiny millet processing machinery now in use **(Upadhyaya & Kumar, 2016).**

**Pre-Cleaners**

A machine's induction system includes a device called a grain pre-cleaner, which is installed before the air cleaner. For extra-large contaminants like huge stones, soil clods, hemp rope, and straw, pre-cleaner is employed on unprocessed paddy. This is done to increase the product quality that has to be cleaned and to maximize the grain's ability to store **(Tiwari & Gupta, 2016).** Most impurities and grime from the entering air are removed by filtering. Pre-cleaners efficiently get rid of bigger dirt and water flecks. Furthermore, it is a machine that cleans wheat and rye grains of dust, dirt, and other debris **(Khattak & Rehman, 2018).** Additionally, it strips some of the nuts and berry coverings from grains of cognitive responses crops including oats, millet, and barley. Utilization of this is both efficient and affordable **(Smith, 2015).**

The apparatus is made up of a great physique, frame, centrifugal fan, development chambers, magnetic separator, and screening assembly. Before the grains enter the cleaning system, the magnetic separator cleans them of ferrous contaminants like nails, pins, screws, etc. **(Singh, 2013).** Dust, chaff, immature grains, and any other light contaminants are eliminated from the grain by the centrifugal compressor. The adolescent grains are gathered by an aspiration box and delivered to a sealed gate flap for bagging **(Brennan & Grandison, 2009).**

Dual aspiration at the unit's entry and exit enables good scrubbing and a dust-free environment in the working area **(Dhaliwal & Arora, 2016).** Pebbles, clay chunks, straw, leaves, sand, and other contaminants are taken out of grain using the quintuple sieving process. A beater-style cleaning tool keeps sieve efficiency high and prevents clogging. These sieves can be changed out and chosen depending on the type of grain **(Ratti, 2001).**

**Grain Cleaner-Destoner**

Using variations in specific gravity with or without the air-recycling device known as a destoner, it is possible to reliably remove high-density contaminants like stones, metal shavings, and glass from a continuous product stream. A dispenser, which also serves as an air seal for the equipment, spreads the grain that is gravitational pull across its whole breadth. The air flows through the products from bottom to top while the preparatory screen oscillates, stratifying the product stream according to its specific gravity. The heavier, including the stones, particles settle in the bottom, while the lighter ones accumulate at the top **(Yadav, 2017).**

The bottom destoning screen's last separation zone receives the uppermost flow of the lower layer of heavy particles. A versatile correspondence of air is responsible for the final separation of the stones from the grain. The two screens' stone-free product streams run slowly in the direction of the product outlet while floating on air cushions. Squeeze valves made of rubber control the discharge **(Kader, 2002).**

Depending on how the equipment is being operated, one or two vibrators force the sieve box to oscillate while it is being held by hollow rubber springs **(Gupta & Das, 2018)**. To attain the ideal level of separation, each of the three variables—air volume, screen inclination, and ultimate separation—can be independently adjusted. A single screen deck is used with the equipment for throughput under 6 to 7 t/h **(Tiwari & Gupta, 2016).**

Slight modification involves knowing that the mass of the particles in the equipment at any given time seems to be not more than 5 kg, the reinforced metal material employed for the frame makes the grader's reciprocating action an exceedingly inefficient use of energy **(Singh, 2013).** The hefty chassis of this equipment requires more energy to move than it does to sustain the grain as it travels through the various-sized mesh of the screen, wasting well over 90% of the energy used to operate it. You can experiment with a grader that has decks arranged in a zig-zag pattern rather than parallel. On the reciprocating mechanism, this will balance out how the loans are distributed. To increase grading efficiency, try using a grader with a feature that allows the grains to be continuously stretched vertically **(Brennan & Grandison, 2009).**

Integrating the processes for convenience of use, it is necessary to identify and designate the destoner's bed angle and fan box adjustment for the various materials, kinds, and grades that are separated throughout the pre-and post-hulling stages. The machine will be simpler to clean and more efficient if a cyclic blower is used to supply the fluidizing air. The categorization of grains, stones, and pollutants will be more

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precise if the fluidizing airflow rate is controlled. The initial maintenance of grains before separating and dehulling can be done with the same regenerative blower. It is currently very difficult to separate unhulled grains from de-hulled grains, but the destoner machine can be improved to do this **(Ratti, 2001).**

**Millet rice polisher**

The millet rice huller polisher is a specialized machine designed to hull and polish millet rice. Similar to a traditional rice huller, it includes a polishing unit. The process starts with feeding unpolished millet rice into the hulling machine through a hopper. The hulling unit consists of a unique rotor with longitudinal and helical ribs operating inside an enclosed cylinder **(Bhavani et al., 2016).**

In the hulling unit, the metal disc moves inside a metal-plated cylinder, creating friction that forces the grain particles against a copper screen and each other. This action removes the bran layer from the grain by shear stresses formed between the grains and the metal screen surface **(Gopalan & Rama Sastri, 2019).** The emery roller polishing device, located beneath the huller, then produces clean, polished rice. This polisher operates with a rotor featuring lengthwise and spiral ribs within an enclosed cylinder, enhancing the hulling process **(Kumar & Singh, 2017).**

The diagonal design and whitener of friction polishers are essential. By exerting pressure on the grain during the whitening process, heat is produced, which can cause certain grains to crack and break. The friction whitener, with an iron disc moving within a metal-plated cylinder, forces the grain particles against the copper barrier and each other, effectively removing the outer layer from the grain by shear stresses **(Mathur & Kapoor, 2017).**

To optimize the efficiency and minimize grain breakage, it is crucial to manage the pressure and heat generated during the polishing process. Adjustments in the design, such as using a diagonal layout for the whitener and controlling the pressure applied to the grains, can help in reducing the risk of grain fracture **(Padulosi & Gaur, 2019).**

**Centrifugal Impact Dehuller**

In a centrifugal impact huller, grains are thrown off a revolving component and strike a stationary platform at a specific range with as regular a force as possible. As a result of the collision, the millet rice kernel's husk separates and cracks open. The husk from the rice and broken kernels are removed by a connected extraction unit that is an aspirator **(Bhavani et al., 2016; Gopalan & Rama Sastri, 2019).**

Moderate and major modification involves for both the closed loop system and a double chamber hulling machine, rpm customization is required for various little millets as well as for various varieties of the same millet. Once the appropriate rpm has been determined, a step pulley with the appropriate-sized steps can be used to hull various millets, types, and grades with the least amount of energy. To assist in hulling various small millets using the same dehuller, variable frequency drives (VFD) are to be investigated as an additional product feature. A minimum speed of rotation of 3000 to

3750 rpm is required to obtain good milling results, according to initial data from tests utilizing small and foxtail millets **(Kumar & Singh, 2017)**

The calorie content of each kilogram of dehulled grain ought to be the next step in this machine's evaluation. The aspirator's design should prevent grain fractions from amassing during treatment over time and make it simple to remove any built-up debris. The amount of beginning torque required increases when moving power from a big aperture pulley to a smaller diameter pulley. The motor starting assembly will probably get damaged as a result of this.

The hulled substance stagnates in the rotary chambers where the outflow blathers are parallel to the grain route. The ratio of broken material produced during milling and the machine's power consumption are both impacted by this standstill. To solve this issue, a more thorough analysis can be carried out in order to redesign the chamber in accordance with the typical blower casing scroll arrangement used in models **(Mathur & Kapoor, 2017).**

When millets are being hulled, power pulled from the designs does not change, indicating that the machine is mostly responsible for the burden on the generator and not the millets themselves. It is critical to understand the power requirements for the aspirator fan and prime centrifugal impeller shaft in the dehusking compartment for both the single- and double-chamber hulling machines in order to prevent overdriving and save on energy expenses **(Prakash, 2018).**

**Grader/sorter**

Graders are crucial tools used in the pre- and post-hulling phases of the production of tiny millet because they segregate material according to size **(Bhavani et al., 2016; Gopalan & Rama Sastri, 2019).** The market currently offers two- and three-deck graders. There are three variants available: just a grader, a grader with an aspirator, and a grader with a destoner.

The pre-hulling process entails clearing the millet grains of dust, light components other than kernels, and large and small foreign components like stones, mud balls, straw, etc. It also involves separating a batch's larger grains from its smaller grains **(Kumar & Singh, 2017).** Following hulling, grains are separated into un-hulled fractions, broken rice kernels of various sizes, millet husk, husk-rich flour, and un-hulled grains.

Moderate modification required a significant chunk of the sieve's length is unused after the particles from the hopper drop onto it about a quarter of the way down its length to the dead zone. The grain exit port must be constructed so that the grains: (a) glide off of it as opposed to falling off; and (b) drop a minimum distance from the exit port to the surface of the sieve bed. Both of these characteristics aid in the direction of the grains and lessen their initial velocity **(Mathur & Kapoor, 2017).**

Several types have exhaust spouts that are quite close to the ground. These need to be raised in altitude so that at least 15-20 kg of materials may be collected in a tub. Additionally, large overhang loads on pillow blocks can cause early bearing failure. In terms of sieve size and type, the grader needs to be standardized for the cleaning and grading procedures required during the pre- and post-hulling phases for all tiny millet crops **(Prakash, 2018).**

Knowing that the mass of the particles in the equipment at any given time seems to be not more than 5 kg, the reinforced metal material employed for the frame makes the grader's reciprocating action an exceedingly inefficient use of energy. The hefty chassis of this equipment requires more energy to move than it does to sustain the grain as it travels through the various-sized mesh of the screen, wasting well over 90% of the energy used to operate it. You can experiment with a grader that has decks arranged in a zigzag pattern rather than parallel. On the reciprocating mechanism, this will balance out how the loads are distributed. To increase grading efficiency, try using a grader with a feature that allows the grains to be continuously stretched vertically **(Padulosi & Gaur**, **2019; Pushpa et al., 2018).**

**Separator**

As per particle density, a gravity separator sorts dry, granular, freely moving materials. In operations including seed and grain, minerals, and recycling, the unit is often utilized to enhance service quality **(Bhavani et al., 2016).** The repudiate seed, which is lighter, can be distinguished from the excellent seed, which is heavier, bypassing the grain through a gravity separator. As a result, a higher proportion of the seed will germinate, improving the seed's overall quality **(Gopalan & Rama Sastri, 2019).** Nevertheless, not all millet can be successfully separated in a gravity separator, and in some situations, buying and operating one or more gravity separators may not be cost-effective.

As the material travels a considerable distance with these gravity separators' rectangle decks, light and heavy particles are separated more thoroughly, and the proportion of middling's is reduced. The material stratifies according to its specific weight as it runs over the oscillating deck through which compressed air is pumped **(Kumar & Singh, 2017).** The lighter particles move to the lower level of the deck while the heavier particles move to the upper level. The pressurized air supply must be precisely controlled in order to achieve effective separation by specific weight, and this is done by using individually adjustable air fans to regulate the amount of air distribution at various points on the vibratory deck **(Mathur & Kapoor, 2017).** There is a vibrator positioned underneath the deck, often an electric eccentric-weight device. Typically, there is a fan under the deck. The operator can adjust the tilt and vibration levels of the deck using a set of manual control levers or an automatic switching panel located close to the deck **(Padulosi & Gaur, 2019).**

When the machine is in operation, the substance exits the surge bin and moves through the conveyor before being discharged onto the deck. While the fan pushes air uphill through the mesh apertures in the deck, the vibrator shakes it side to side at a frequency of 200 to 600 cycles per minute, usually 490 to 525 cycles per minute **(Pushpa et al., 2018).** The entire material bed is lifted and stretched out by the vibration and airflow, which causes it to expand and fluidize as it descends **(Prakash, 2018).**

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The materials become stratified as a result, with the light particles landing on top of the heavy ones and the heavy ones sinking straight to the deck. Between the riffles, where the particles frequently gather, a constant bed depth can be built and maintained **(Rai & Singh, 2016).** The heavily loaded particles are moved by the vibration of the deck uphill along the deck, between the riffles, and in the direction of the customizable gates on the high side of the deck. The heavy particles exit the deck through the adjustable gates, which direct them down along the side of the deck in the direction of the heavy particle outflow at the lower end of the deck **(Sehgal et al., 2019)**. The heavier particles and riffles are crossed by the lighter particles as they move in opposite directions toward the light particle discharge at the bottom of the deck **(Shrestha et al., 2015).**

**Color sorter**

The production process of products like coffee, almonds, and oil crops uses color sorters. In the present day, it is also observed in the millet industry. The objective is the separation of materials that are discolored, poisonous (like ergot), not as ripe as necessary, or still contain hull after dehulling, minor millets like Kodo, little, foxtail, barnyard, and brown top millets **(Taylor & Belton, 2002).**

The console's individual unit hopper is where the raw material enters. The raw material travels rapidly via the channel into the monitoring zone of the sorting cabinet through the agitation of the vibrator device, passing between the sensor and the backing plate **(Sharma et al., 2017).** Under the influence of the LED light source, the recognized material continues to sink into the finished product cavity of the acceptance outlet hopper as the maximum power of the mechanism is driven to drive the solenoid valve in response to the intensity and color change of the light to accomplish the goal of color sorting **(Bhise & Pawar, 2017).**

The feed hopper, oscillating feeder, chute, beam splitter, backdrop plate, CCD lens, output hopper, nozzle, blower, air tank, and sift are the color sorter's primary parts. Other important parts include an air tank and filter **(Upadhyaya & Reddy, 2007).** It is made up of a serving hopper, an oscillating feeder, and a chute. Feedstock enters the pulsing feeder from the feeding hopper. Vibration and a guiding mechanism dynamically organize the material into a series of uninterrupted current lines, and after the chute has accelerated it, the material falls to a detecting zone at a constant speed to verify that the materials are undeniably in the sorted container **(Haripriya & Vasavi, 2015).**

The significant aspect of the color sorting machine is the optoelectronic system, which is primarily composed of an LED light source, a background plate, a CCD lens, and supporting evidence components. The background plate and the item being examined are evenly and steadily illuminated by the beam of light **(Prabhakar & Sudha, 2017).** The sortation system includes add ons like a sorting cabinet, nozzles, and an air supply. It has been demonstrated through experimentation that the number and spacing of nozzles are two of the most important variables impacting the color sorter's accuracy **(Hulse et al., 1980).** Multi-color sorting modes are pre-set for patrons on the large-screen wide-angle touch screen. And create a warm human-machine interface that makes reacting to the unique circumstances of the materials simple and rapid

**For secondary processing**

**Extruders**

Extruders are devices that force ingredients through a specific kind of aperture or die to give the extruded a different design. A thermodynamic processing unit is an extruder. The raw material that has been treated is transferred by a revolving screw to an aperture or die that gives the finished product its new shape. When ingredients enter through the screw, a new procedure is carried out, such as heating, combining, and delivering pre-grounded and conditioned ingredients **(Zuidam & Nedović, 2010).**

The product exits the extruder device over a kick bucket, where it typically puffs and changes surface in response to the entry of the steam and regular forces **(Smith, 2001).**

**Cold Extrusion:**

The millet sample is heated during cold extrusion to a maximum of 100 degrees Celsius. When food is shaped and mixed, including processed products and pasta, cold extrusion is utilized to keep the food's temperature constant. The reduced extrusion process can also be carried out at temperatures lower than 100 degrees Celsius. The retention of cold-extruded goods can also be accomplished using baking, chilling, or drying techniques. Cold extruders are appropriate for both home use and small-scale enterprise **(Schoenlechner & Zannini, 2017).**

Cold extruders are mostly used to make pasta, while related equipment is also used to frame and roll dough into different shapes. The mixture created with durum wheat flour is used to construct a variety of pasta using a pasta extruder. By using a mixture created using millet flour and eggs, a pasta extruder is used to create a variety of pasta **(Kaushik & Sharma, 2017).**

The pasta extruder has a variety of components, including a die, a conveying screw, an extruder barrel, and a mixing chamber, which are used to produce pasta in a precise shape. Many businesses that manufacture equipment use bronze as their preferred material for the die because they guarantee that it creates the pasta a rough surface that keeps sauce better than pasta created using any other method **(Lorusso et al., 2018)**. Pasta can be stored for up to five to six months in addition to being promptly cooked, dried, and sold in retail stores **(BeMiller & Huber, 2018).**

**Hot extrusion technology**

Extrusion cooking, another name for hot extrusion, involves heating food to temperatures greater than 100 degrees Celsius. The temperatures can be raised quickly by using frictional heating and other heating methods. The food is transferred to barrel sections with a small flight after it has been heated; this feature serves to increase the shear and pressure. Following its final shaping, the food is quickly chilled to remove any food is quickly chilled to remove any remaining moisture, which was present as steam, before being forced under pressure through the die **(Smith, 2001; Kokini & Ho, 2018).**

**Twin screw extruder**

A twin screw extruder contains two revolving parallel screws with the same dimensions inside the barrel. Despite being more complicated than single screw extruders, twin screw extruders offer significantly better control and greater versatility. For an equivalent capacity, twin-screw extruders are often more expensive than single-screw machines. Positive pumping of the screw flights ensures that the product flow is uniform throughout the barrel **(Bhattacharya et al., 2018).**

**Flaking**

A significant millet product made from millet is flaked rice. According to antiquity, it is made from soaked millet grain that has undergone thermal treatment and is immediately flattened with a flaking machine (an edge runner). One or two large steel or granite rollers set on a horizontal shaft and rotated around a central vertical shaft make up an edge runner mill, often referred to as a Chilean mill or a roller stone mill. The rollers rest on a bed of steel or granite. Scrub brushes are used to keep the material that needs to be ground in the runner's path. The weight of the stones and their pressure contribute to some of the diminutions, but friction between the runners' and the bed stone's contact surfaces contributes more **(Mustapa Kamal & Abdullah, 2013).**

Parboiled rice is used to create flakes. To soften the kernel, the millet grain is immersed in water for two to three days. Next, the water is heated to a boil for a short period of time, and then the water is removed. The millet is cooked until the husks split open in a shallow clay vessel or iron pan. The husk and kernel are removed after being flattened by a hardwood pestle. By winnowing, the husk is separated. Rice that has been flaked is white and paper-thin **(Krokida & Oreopoulou, 2001).**

Millet grains are used to make millet rice flakes, which are delicious flakes. When making millet rice flakes, the millet rice is parboiled before the grains are flattened to form solid flakes. Asian cuisine uses a variety of rice flakes dishes. In Western nations, cereals and various snacks frequently contain rice flakes. After being cooked until tender, the rice is rolled and then flattened. Depending on how much pressure is used, the flattened rice will have a different thickness. The flattened rice is then given time to thoroughly dry when the mixture has reached the proper thickness. The dry sheets are then subjected to one more rolling procedure to produce straightforward flakes. The millet rice flakes can now be packaged for use as dry cereal, used as a component in recipes for a side dish, or even utilized to make cakes, cookies, muffins, or any other snack foods **(Panesar & Panesar, 2016).**

**Baking**

Baking is a fundamental process in producing bakery goods, involving complex physiological, colloidal, microbiological, and biochemical changes within the dough

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influenced by heat and moisture. During baking, the dough ingredients transform, creating new materials suitable for consumption. This process is influenced by the loaf's size and type, as well as two critical variables: baking temperature and baking time **(Cauvain & Young, 2009).**

In the initial stage of baking, the dough volume increases rapidly due to gas cell expansion, known as oven spring. When the temperature reaches 60˚C, the yeast is killed, and protein coagulation begins. The yeast is highly active initially, and the starches undergo gelatinization.

Crust formation and browning occur as the process continues **(Pyler & Gorton, 2010).** Drying signals the start of baking. Steam must be introduced into the baking chamber to prevent the product from crumbling due to rapid drying. The burners operate at atmospheric pressure, causing the oven's dew point to reach up to 100˚C, facilitating the dough's instant dewatering at lower temperatures and providing significant heat **(Figoni, 2017).**

The dough's internal temperature rises gradually through four stages. Between 30˚C and 40˚C, yeast gas production, bacterial acid production, and enzymatic reactions increase, continuing the dough's maturation. At 40˚C to 60˚C, yeast gas production ceases, cells die, and enzyme activity declines, except for amylase, which negatively impacts the process (Suas, 2008).

Baking methods include High-Temperature Short Time (HTST) and Low-Temperature Long Time (LTLT). HTST baking, if done too quickly, results in suboptimal crumb structure.

LTLT baking produces a thicker, more rigid crust that doesn't brown. The baking temperature varies depending on the product type, typically ranging from 200˚C to 245˚C for exquisite bread goods and 175˚C to 200˚C for high-sugar products **(Weibiao & Houyuan, 2012).**

Baking ovens must suit the task, ensuring the proper formation of crust and crumb. The dew point parameter is crucial, requiring a temperature of at least 95˚C to prevent condensation and initiate drying. Suitable baking ovens can adjust baking temperature, replace heat continuously, humidify the oven temperature, and specify baking time. Types of ovens include ribbon ovens, automatic ovens, extruded ovens, tunnel ovens (for large-scale production), and rotating carriage ovens (common in small businesses) **(Hui, 2017).**

**Popping and puffing**

Popping and puffing have been used traditionally for a long time as the simplest, least expensive, and fastest way to apply dry heat to the production of ready-to-eat snacks and weaning meal formulas **(Guha & Ali, 2017).** An extremely common and well-known technique is explosion puffing, which involves the quick release and expansion of water vapor. Popping and puffing give the goods a passable flavor and appealing scent. As a well-before, ready-to-eat substance, popped or puffed grain can be used to create supplementary foods, gourmet foods, and snacks. Popping is a form of starch cooking in which grains are briefly heated to high temperatures. When kernels are heated, the interior moisture swells and pops through the outer shell of the kernel, a process known as popping. While during the puffing phase, the pre-gelatinized kernel expands, and water vapor is abruptly released. Contrarily, because the products are uniformly exposed to the heating medium during the high-temperature short time **(HTST)** fluidized bed air puffing, the puffing effectiveness is higher. Electromagnetic waves like microwaves are currently used because they offer superior energy efficiency in a relatively short amount of time, overcoming the constraints of traditional popping and puffing techniques (Rao, **2007).** Modern society uses microwave energy everywhere. Puffing and Popping techniques can be done using dry heat, such as sand roasting, salt roasting, gun puffing, hot oil frying, utilizing a heating medium such as hot air or microwave radiation, or the most popular method is puffing in hot sand (around 250˚C) or oil (200–220˚C). Three methods for puffing and popping are described below: Sand roasting, gun puffing, microwave popping, and puffing. In an oven or on a grill, roasting is dry-heat cooking with the application of fat or oil. When employing a split, radiation heat is used to cook; convection and radiation heat are combined to roast food in an oven. Sand that is heated to roughly 250˚C is used in the sand roasting method to cook pre-gelatinized grains. A dramatic heat gradient causes the moisture in the grains to evaporate and attempt to escape through the microspores, growing the size of the starchy endosperm in the process.

### Parboiling

Parboiling is a crucial hydrothermal treatment applied to paddy before milling, aimed at enhancing millet rice quality and increasing milling yield (Juliano, 1985). The process involves several key steps conducted under controlled conditions to optimize results. Initially, whole millet grains are soaked in water at temperatures ranging from 60 to 90˚C for four hours using a kettle **(Englehardt, 2000)**. After soaking, the grains are allowed to cool to room temperature while covered. Subsequently, the grains undergo pre-drying, where they are boiled and then sun-dried for about an hour to remove excess water and facilitate gelatinization **(Chakraborty & Puri, 2016).** Following this, the grains are dried further in the shade for three days until their moisture content reaches between 10% and 12%, measured using a moisture meter **(Oshodi & Ekundayo, 1994).**

The effectiveness of the parboiling process hinges on specific conditions: soaking temperatures of 60 or 70˚C for four hours, and a steaming period of 900 seconds. These parameters have been determined to enhance millet yield and reduce the incidence of broken grains, as indicated by physicochemical analyses **(Bhattacharya et al., 2002).** This optimized parboiling technique not only improves milling efficiency but also helps mitigate nutrient losses during subsequent grain processing.

### Fermentation

Fermentation, one of the oldest and most widely used traditional food processing techniques, stands in contrast to methods aimed at improving nutrient quality and extending shelf life. It plays a crucial role in enhancing the nutritional composition of millet grains, significantly increasing their nutrient content **(Steinkraus, 1996)**. Additionally, fermentation induces favorable physiological and chemical changes in the final food product, facilitating enhanced digestion of proteins and carbohydrates **(Holzapfel, 2002).** Furthermore, fermentation has been found effective in reducing the anti-nutrient content of millets, thereby enhancing their overall nutritional availability **(Nielsen et al., 2010).** In regions where sorghum and millets are staples, fermentation is commonly employed with microorganisms like lactic acid bacteria (LAB) or in combination with yeasts to produce sourdoughs and traditional fermented beverages (**FAO/WHO, 2002).** This integration of fermentation with other processing methods underscores its role in optimizing nutrient utilization beyond what can be achieved through fermentation alone.

### Malting and germination

A time-honored technique for handling grains called "germination" or "malting" is known to improve their nutritive benefits by undergoing specific biochemical changes **(Singh, Singh, & Singh, 2010),** hence encouraging their use in a variety of dishes **(Shobana et al., 2013)**. Millets' digestibility is improved by germination, according to studies, which demonstrate this **(Malleshi & Desikachar, 1986; Oghbaei & Prakash, 2016).** The bio-accessibility and in-vitro extraction rate of micronutrients (iron and calcium) were shown to rise during the germination of finger and pearl millet **(Abdalla, El Tinay**, M**ohamed, & Abdalla, 2008),** whereas the phytic acid level was observed to decrease **(Ijarotimi & Adeoti, 2012).** Additionally, germination of finger millet for 48 hours at 30 degrees Celsius increased the in-vitro protein digestibility by 17% **(Singh et al., 2010)**, whereas germination of pearl millet increased the absorption of iron in-vitro by a factor of two **(Abdalla et al., 2008).** The millet quality suffers a little bit as a result of millet grain germination**(Oghbaei & Prakash, 2016).** The breakdown of low molecular weight nitrogenous substances, the hydrolysis of lipids, and the oxidation of fatty acids during germination may be the cause of, for instance, the observed decreased crude protein and fat content of foxtail millets **(Singh et al., 2010).** However, three days of germination and milling of millets, such as foxtail, into flour greatly boosted their amylase activity, 2, 2-diphenyl-1-picryl-hydrazyl-hydrate scavenging activity, and mineral concentration **(Oghbaei & Prakash, 2016).** The nutritious value of millets was also stated to be enhanced when germination was combined with other conventional techniques like fermenting, soaking, etc. **(Malleshi & Desikachar, 1986; Saleh et al., 2013).** It has been claimed that pearl millet's germination and fermentation, which followed, significantly altered its chemical makeup and enhanced its nutritional content **(Abdalla et al., 2008)**. It also resulted in the removal of anti-nutritional elements **(Ijarotimi & Adeoti, 2012).**

The grain's germination increases the food's nutrient and energy densities **(Shobana et al., 2013).** It dramatically decreased the amount of phytic acid when combined with fermentation **(Ijarotimi & Adeoti, 2012).** Combinations of food made from pearl millet that was first fermented with probiotic organisms had higher levels of thiamin, niacin, total lysine, protein fractions, sugars, soluble dietary fiber, and calcium, iron, and zinc that were available in vitro **(Shobana et al., 2013; Saleh et al., 2013).**

## Method of preparation of Conventional and Non- Conventional Value-added products in Millets

| Products | Procedure | Reference |
|---|---|---|
| Chapatti (unleavened bread) | Millet flour is combined with lukewarm water to gradually gelatinize the starch that gives dough its binding qualities. The dough was rolled out thinly and cooked on a hot metal frame. | Akubor, P. I., & Ukwuru, M. U. (2003). |
| Mudde | Hot water and millet flour are combined to make mudde, which partially gelatinizes the starch that gives the dough its binding properties. The dough is then steamed and formed into balls. | Bharathi, A. V., & Malleshi, N. G. (1991). |
| Composite flour | Millets, pulses, and other flours are combined to create multigrain or composite flour that is rich in nutrients such as protein, minerals, vitamins, and dietary fiber. | Makinde, F. M., & Akinoso, R. (2015). |
| Fermented foods (Idli and Dosa) | A mixture of black gram and millets is blended moist and digested overnight in a ratio of 1:3. Wet pastries or Dosa are made from the prepared batter by baking it, and idli is made by steaming it. | Prabhasankar, P., & Sadasivam, S. (2000). |
| Papad | It is created by combining finger millet flour, up to 15-20%, with additional ingredients including spice, rice, and black gram. The finger millet flour is first boiled in water to gelatinize before being used to make papad. Following curing to a moisture percentage of 7, the gelatinized dough is then formed into sheet form and trimmed into the desired size and shape. | Hymavathi, T. V., & Mohan, B. (2003). |
| Millet flakes | Millets' tiny size makes them ideal for making flakes. Pearled grains are boiled at high pressure to thoroughly gelatinize the starch before being dried to a water content of 18% and pressed against powerful rollers to create flakes. | Chauhan, R., & Bhardwaj, R. (2015). |

| | | |
|---|---|---|
| Puffing or popping | An elevated, brief treatment was necessary to prepare expanded millet decorticated finger millet. The flattening of the grains to the proper shape and the moisture content are the two elements that have the biggest impact on the maximum expansion ratio. The best circumstances for any millet product to achieve its maximal expansion ratio are a shape factor of 0.52 to 0.58, 40% water activity before flattening, and a drying duration of 136 to 150 minutes. | Reddy, T. J., & Vasanthi, P. (2000). |
| Noodles-vermicelli | A blend of millet and legume flour is used to make noodles. The pearled grains are cooked, extruded, and dried after being immersed in water for between 24 and 48 hours. When fried, the result is an outstanding, crispy component. | Shivhare, U. S., & Arora, S. (2013). |
| Bakery items (nankhatai, biscuits, bread and muffins) | The biscuits made from a blend of pigeon pea and millet flour with a 35% pea and 65% millet blend received the top ratings for texture, flavour, and all-around acceptability among bakery goods. The bread made using composite millet flour is just as palatable as bread made with wheat flour. | Srivastava, B., & Siddiqui, S. (2012). |

## Conclusion

It is imperative to restart the huge farming and use of millets, particularly in the semiarid and arid regions of developing countries where the production of key crops like rice and wheat is challenging due to unfavorable climatic circumstances. Protracted food security will be aided by millet consumption and production. Despite the fact that millets are very nutritious, it is evident from the research that there is a dearth of efficient technology that is capable of processing millets in comparison to other cereal crops. Therefore, it is crucial to produce ergonomically safe machinery with higher performance and simple operations so that it is accessible and simple to use on a farm and in remote people's homes. Innovation in such machinery could therefore do away with the tediousness of traditional processing and produce high-quality goods. By developing new food items with millet in them, awareness must also be raised in industrialized countries where these millets are not thought to be fit for human consumption.

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