Processing Technology for Value Addition in Millets

11

Adinath Kate and Anupama Singh

Abstract

Millets are the harbinger of nutrition required for human health. Besides the diverse essential nutritional constituents like minerals, vitamins, micronutrients, etc., millet grains also contain a considerable amount of anti-nutritional constituents. The removal of anti-nutritional compounds from the particular type of millet is a mandatory requirement prior to its consumption otherwise it creates serious health hazards. Different techniques and treatments have been given to the millet grains at household level from ancient times to make them suitable for human consumption. These operations include soaking, heating, roasting, fermentation, cooking, etc. Now, days various unit operations have been standardized and optimized independently for each type of millet. All these unit operations like soaking, dehulling, grinding, roasting, puffing, fermentation, malting, etc., with appropriately designed processing equipment and machines are well-established in industries for commercial-scale processing of millets. The selection criteria for appropriate processing operation, equipment, and production scale are based on the targeted output.

Keywords

Millet processing · Processing equipments · Value addition · Millet products

A. Kate (✉)
ICAR-Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh, India

A. Singh
National Institute of Food Technology and Entrepreneurship Management, Sonipat, Haryana, India

A. Kumar et al. (eds.), *Millets and Millet Technology*,
https://doi.org/10.1007/978-981-16-0676-2_11

11.1 Introduction

Millets are one of the important crop for world's food and nutrition economy and are recognized as one of the necessary food grain for balanced nutrition of humans. Millets are also playing a role as cash crop for small farmers and can adapt themselves to marginal soil for nearly one-third of the world's population (Singh et al. 2010). Millets are also playing a vital role in food security due to its sustainability in adverse and variety of agro-climatic conditions (Ushakumari et al. 2004). They specifically include major (Pearl millet and sorghum) and minor millets (*Finger millet*, *Foxtail millet*, *proso millet*, *little millet*, *kodo millet*, etc.). The crops belonging to this category have huge potential in broadening the genetic diversity and hence potential to key contribution in nutrition security (Mal et al. 2010). These millets are not only rich in nutrition but at the same time offer various health benefits (Veena 2003). In recent years, millets have received attention due to their unparalleled nutritional profile and it can easily be consumed in any suitable form. Because of excellent nutritional and functional qualities millets can be transformed into various value-added products. Besides the rich quality nutrients, the utilization of millets as a staple food is restricted to traditional consumers only, then on-availability of consumer-friendly, ready-to-eat food products is the major reason for it (Hulse et al. 1980). Poor quality attribute of the millets and their traditional preliminary form of consumption like flours such as dark and dull color, coarse and gritty texture, astringent taste, high fiber content, larger cooking time, anti-nutritional constituents, low shelf life have limited their utilization. Most of these limitations can be overcome through the better utilization of appropriate processing technologies. Appropriate techniques of millet processing lead to the promising and successful utilization of millets in various traditional and convenience health foods. Different processed products from millets have been developed in various categories like popped, flaked, puffed, extruded, roller dried, fermented, malted and composite flours, weaning foods, etc. Some of the processing technologies have promising effects on the food qualities and its nutrition like extrusion of pearl millet in weaning foods enhances the protein digestibility (Cisse et al. 1998). Similarly, germination and probiotic fermentation catalyzed in protein profile improvement and mineral availability (Arora et al. 2011).

In this chapter, the focus has been made on detailed description of various processing technologies and development of various value-added products from millets including both major and minor millets.

11.2 Processing Technologies for Millets

The processing and utilization of millet crops are mainly carried out at home scale and hence it is largely confined to production catmint and its valuable nutrients remain unavailable to wide population. In India, various millets are consumed in the form of different products like *porridge*, *chapati*, *laddu*, *machula*, *dubkee*, *churkani*, and various geographical location-specific dishes. Anti-nutritional constituent present in the millet grain is also one of the common reason for its limited utilization. But due to deficiency in proper processing knowledge, the consumption of these crops in desired consumption rate especially in nontraditional area is limited. Different age-old techniques have been carried out to eliminate or reduce such anti-nutritional factors present in different millets and converted into edible form. Home practices carried out using household utensils significantly improve the functional properties with considerable reduction in anti-nutritional constituents. Various traditional operations are followed for the processing of millets prior to its consumption. Most of these techniques are manual, laborious, tedious, crude, and unhygienic without any standardization. Therefore, the uniformities are not maintained in the processed products/dishes. Though there is valuable nutritional importance of millets, they are neglected for commercial production of processed and value-added products as the traditional practices lack with a systematic scientific approach. Keeping in view of these limitations the upgradation with proper scientific study is very much essential. The development and introduction of farmer's friendly equipment and optimization processing protocol is one of the possible appropriate approach for this. Also, the large involvement of women in household traditional processing need to be taken into account while design and introducing machinery for different unit operations.

Different processes mentioned in Table 11.1 have been traditionally carried out from ancient times with the aim of removal of the anti-nutritional factors and alter the taste in different types of millets. Different operations such as soaking, dehulling, and cooking have been carried out from ancient times prior to its consumption at the household level. Development of simple technological inputs in the form of appropriate standardization process parameters, operating conditions, and development of suitable equipment geared the millets utilization from household level to commercial scale industrial level. Various advances based on the improvement of traditional practices studied by the researchers are presented in Table 11.2.

The unit operation wise processing operations with their aim and advancement over traditional home scale practice are as follows:

11.2.1 Soaking

Soaking is one of the popular technique for grains for improvement of mineral bioavailability and reduction of anti-nutritional compounds like phytic acid. Degradation and leaching of compounds like phytates, changes in phytase activity, and concentration of minerals like iron, zinc, etc., get influenced by soaking. Hence, their quantities and concentrations are monitored after soaking different forms of millets utilized for household consumption. The loss due to such leaching was reported quite severe in case of soaking of dehulled and milled grains. At the same time cooking grains by soaking in water has not found any significant increase in phytate degradation (Lestienne et al. 2007) but a considerable amount of leaching of nutritional constitute was observed. Similarly, about 25% loss of iron with endogenous phytates degradation was reported by Eyzaguirre et al. (2006) during soaking

Table 11.1 Traditional processing techniques used for effective utilization of millets and other underutilized crops

S. No.	Unit operation	Objective	Technique used	Limitations
1	Threshing	Separation of grains, husks, and panicle	Beating method	High labor and time, lower output efficiency
2	Winnowing	Separation of foreign materials like chaff, straw, husk, etc., from desired fraction	Manual air blowing and winnowing	Low output capacity, weather dependent
3	Dehulling	Aleuron layer separation as hull from kernel	Wooden pounding	Required huge labor and higher time
4	Soaking	Maintain the desired softness by addition of moisture	Water pounding	Weather-dependent, risk of unwanted contamination, lower output capacity
5	Germination	Alteration of physiological form of grains to achieve nutritional change in grain	Using moist cloth	Lower output capacity and efficiency
6	Blanching	Inactivation of undesirable enzymatic activities	Hot water or steam exposure	Difficult to achieve accurate temperature time combination, batch process
7	Roasting	Flavor and taste improvement	Open type of roasting pan or *Kadhai*	No control on burning of grains
8	Popping	Flavor and taste improvement with defines texture	Popping pans/ *kadhai*	Difficult to maintain accurate process conditions, risk of unwanted contamination, lower output

of pearl millet grains. Minerals like iron, calcium, and phosphorus present in pearl millet were found to be decreased during its soaking in acid medium.

11.2.2 Dehulling/Dehusking/Decortication/Pearling

Traditionally, the dehusking of millet grains (dry, moistened, or wet) is normally done through the method of pounding with a pestle in a stone or wooden mortar. Proper moisture condition in the grains prior to its dehulling is a key requirement of the desired output. Accordingly, about 10% moisture is required for proper detachment of fibrous bran and separation of germ and endosperm. The dehulling of millets removed nonedible part of grain and improves the bioavailability of present nutrients, reduction in the anti-nutritional constituents, and consumer acceptability. Various types of dehullers, decorticators, and pearlers are available for different

Table 11.2 Advanced processing technologies for millets and other underutilized crops

S. No.	Grain processing methods	Process description	Advantages of process	Equipment/ technology available
1	Decortication/ Dehusking	The outer layer of husk removed from kernel of grain	Significantly reduces anti-nutritional factors	Decorticator and Dehusking machines
2	Pearling	In this operation aleurone layer from dehusked grain is peeled/scratched off	Reduces non-digestible and off taste compounds	Mechanical pearlers and millet mills
3	Grinding	Size reduction of the millet grains in different forms based on the targeted processed product	Grain converted into suitable form required for recipe	Millet mill, attrition mill
3	Cooking	Cooking is a process in which desirable changes taking place like starch gelatinization which makes them suitable for digestion and intestinal absorption	Required physicochemical changes taking place to make it suitable for digestion	Open vessel and pressure cooker
5	Roasting	In the roasting operation, the grains are exposed to intensive high heat for short time	Enhance the sensory qualities and decreased anti-nutritional constituents	Open pan, specially designed roasters
6	Puffing	In puffing whole unhusked or decorticated grains with defined moisture content is mixed with hot sand (250 °C, about 15–60 s)	Reduces antinutrients and enhances the taste and flavor. The operation also deactivate the bacteria and hence improves storage quality	In salt using open hot pan
7	Sprouting	Soaking of whole undamaged grains for 2–24 h, and kept in humid space with desired humidity up to 24–48 h	Increases availability of micronutrients, improve digestibility, and reduces antinutrients	Incubators, humidity chambers, germinator
8	Fermentation	In the fermentation process, growing specific strain of microorganisms at controlled conditions over the raw material as identified medium	Enhance the sensory qualities with improvement in nutritional value and digestibility. Also a considerable reduction in anti-nutritional constituents	Fermenters
9	Malting	It involves the combined process of	Resulted in the better digestibility of starch	Malting units

(continued)

Table 11.2 (continued)

S. No.	Grain processing methods	Process description	Advantages of process	Equipment/ technology available
		steeping, germination, drying, toasting, grinding, and sieving	and improve availability of minerals	

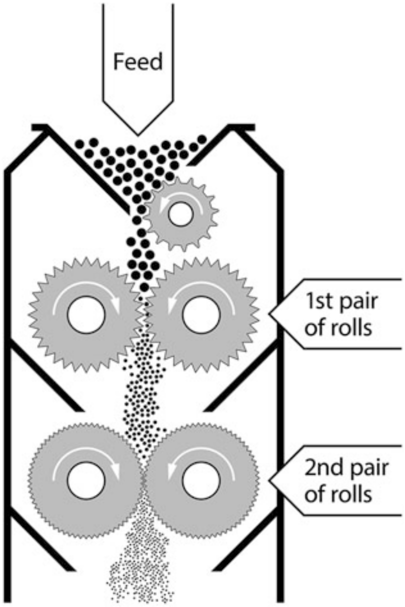
Fig. 11.1 Typical roller mill

types of millets. These motorized mechanical machines have very high output over the conventional laborious, tedious manual operation.

Abrasive type: This type of decorticator are most common for the removal of surface husk or bran from grain surfaces. During the operation, a main functional component, i.e., abrasive disk or roller creates abrasion and friction force on the surface of grain due to which fibrous hull or bran present in pericarp get removed in the form of fine powder or course flaky form. Because of the nonuniformity in the grains, individual grain is abraded at varying extent at different surface points and hence sometime more loss of endosperm occurrs. Such instances are quite common in case of damaged grains even at very low degree of abrasion. According to the suitability of different millet grains, some of the common machines recommended for millets includes:

Roller mills: In these types of machines, generally pearling is done by passing the grains through a set of two steel rollers rotating inside the cylindrical chamber with equal or differential speed in cocurrent or countercurrent manner (Fig. 11.1). Properly tempered grains when comes in contact with rotating

Fig. 11.2 CIAE millet mill



rollers, the pericarp is rubbed with adjacent grain and shearing with the surface of the roller. The degree of pearling and particle size in the flour is maintained by adjusting the spacing between the rollers. The temperature and moisture content of the grain is vital in this process to avoid loss of edible material as well as the machinery.

CIAE-Millet mill: ICAR-CIAE Bhopal has designed and developed CIAE-Millet Mill aiming to process millets with eliminating drudgery involved in the traditional method (Fig. 11.2). The capacity of the machine is 100 kg/h of millet grains with 10–12% of moisture content. The mill operates with 1 Hp electric motor as a power source. The mill is flexible for varying quantities of millets for its milling likewise even a kilogram of grains too be milled in a single pass with the desired degree of dehusking. The machine has a provision of detachment as well as separation and collection of husk simultaneously during dehusking operation. The mill is suitable for dehusking most common millets like kodo millet, proso millet, foxtail millet, little millet, barnyard millet, etc. The provision of adjustment of clearance between dehusking surfaces makes the machine suitable for different types of millets. The dehusking efficiency of this machine is about 95%. The compact processing zone attached with cyclone separator does not allow spillage of any dehusking fraction into direct environment. Similarly, the air and noise pollution during operation of machine is under control. Also, the machine is women-friendly, simple in operation, and does not require any qualified labor and hence machine is suitable to operate in production catchment as well as domestic level.

11.2.3 Grinding

Grinding is one of the important unit operation that deals with the secondary processing of millets. Actual size reduction of the millet grains takes place during the grinding. Particle size and fineness modulus are the representative indices of the grinding process. Different types of particle sizes are selected based on the targeted product. Various types of grinding mills, viz., attrition mills, hammer mills, burr mills are recommended for the millets (Fig. 11.3). Every grinding mill have a specific type of adjustment for maintaining the final size of output particles in the ground sample, i.e., flour. The shelf life of millet grains significantly decreases after its grinding. The increase in the free fatty acid (FFA) is the major concern for reduced shelf life and creates rancidity in millet flour (Yawatkar et al. 2010).

11.2.4 Cooking

Cooking is the essential unit operation that needs to be performed prior to the human consumption of any type of millet grains. The complex changes in physicochemical and functional properties in terms of starch gelatinization, protein denaturation, release of bound phenolic and antioxidants have been taking place at molecular level (Khamgaonkar 2012). At the same time, a considerable level of reduction in anti-nutritional constituents is also found. The time of cooking and temperature is very crucial for maintaining the nutritional constituents especially minerals and phenolic contents present in millets. The FFA content in the decorticated pearl millet grains and flour was found to be significantly reduced due to heat provided during cooking and hence it enhances the shelf life (Meera et al. 2003). There are various types of equipment used for cooking based on the dish to be prepared. The capacity, design, size, etc., of the equipment is based on its application at household level to commercial industrial-scale application. Different size and capacity extruders are the most common type of equipment used in industries for cooking millets.

	
Attrition mill	Hammer mill

Fig. 11.3 Grinding mills for millet grains

11.2.5 Roasting

It is also one of the age-old technique in which millet grains with appropriate amount of moisture content are exposed to intense, high temperature (160–200 °C) conductive heat medium for varying periods of time. The required moisture in grain is maintained through pre-soaking followed by shade drying. During the roasting operation, the cotyledons of grain exposed to heat get shrink more than the outer husk and form a gap in-between which facilitates the loosening of husk from the cotyledon. This loosening of husk further facilitates husk removal during dehusking or pearling. This heat treatment also effectively creates a unique flavor and deactivate unwanted anti-nutritional and toxic constituents present in millets (Siegel and Fawcett 1976). It was found that some of the physicochemical and functional properties of roasted grains get changed. Similarly, roasting enhances the water absorption and water solubility index and due to this considerable changes were observed in their pasting and some of the thermal properties of flours (Sharma et al. 2011). Variety of the different roasters specifically designed for millets are available based on their mode of heat transfer operation. The roasting equipment working on the principle of conduction heating have better performance in terms of the degree of roasting and quality of the roasted product. Nowadays, equipments equipped with appropriate instrumentation for precise control of operating parameters (temperature, time) are quite popular due to the uniform quality of output and flexibility to use different types of commodities.

11.2.6 Puffing

It is the common processing technique mainly carried out for preparation of ready-to-eat expanded snacks and other products from any type of grains. In the process of popping/expansion, the millets were presoaked at desired moisture content and exposed to hot sand in the ratio of 1:6 at high-temperature (230–250 °C) and short-time (20–30 s). Popping of the decorticated finger millet was quite common among the millets where due to the high-temperature short-time heat treatment raw millet grains expanded significantly gets converted into desired expanded form (Fig. 11.4). To obtain the maximum expansion ratio, raw grains need to be flattened to desired shape and maintain desired moisture content in it prior to exposure to

Fig. 11.4 Popped millet grains (pearl millet, finger millet, and sorghum)

heating environment (Saleh et al. 2013). This process of popping of grains not only improves the expansion properties in its physical form but also significantly improves its functional properties. Also a considerable amount of different anti-nutritional constituents present in the millet grains gets reduced (Sreerama et al. 2008). The physical and textural properties of the millet grains also completely get changed due to its puffing. The common millets like sorghum, pearl millet, and finger millet are generally used for puffing based on its expansion and puffing ability (Fig. 11.4). Besides millet, puffing is quite common for grains like maize, chickpea, horse gram, etc., in Asian countries. The equipment/machine required for puffing includes a traditional individual house level system to a large cottage/industrial level system with varying capacities. Nowadays popping gun operating with hot air are used popularly due to its small size, lightweight, robust construction, and desired output for household consumption.

11.2.7 Sprouting

Sprouting is the germination of grains under controlled conditions. During sprouting of the millet grains, the dormant embryo present in the grain gets activated under specified moisture content and environmental condition (temperature and humidity). For the millets, this germination period varies from 48 to 72 h at an ambient temperature of 25–30 °C. The availability of the minerals and vitamins present in millets get significantly increased due to sprouting, whereas the anti-nutritional components like phytic acid and tannin were found to be significantly reduced. Sprouting for more than 48 h resulted in the loss in dry weight of source grain without much improvement in nutrition (Mbithi-Mwikya et al. 2000). Therefore, the process temperature and time need to be precisely maintained during sprouting to maintain desired nutrition in sprouted millets. Traditionally, sprouting of millets have been carried out in environmental chambers but nowadays specialized grain sprouters with the provision of adjustment of environmental conditions including the source of light, wavelength, illumination, etc., to get a quality product with enough safety and shelf life are available. Figure 11.5 represents the sprouted form of some of the common millets.

Fig. 11.5 Sprouted millet grains (barnyard millet, finger millet, pearl millet, and sorghum)

11.2.8 Malting

The malting of the millet grains at appropriate processing conditions improves the sensory attributes, nutritional quality, and digestibility of the grains with a considerable amount of reduction in antinutrients. It is a three-step process carried out in sequence like (1) steeping (soaking of grains in water), (2) germination (sprout development and enhance enzymatic activity), and (3) kilning (grain drying and stopping the enzymatic activity). All three steps may take place in separate equipment or in integrated single unit. An integrated single unit is quite popular nowadays due to ease in operation, time, and processing cost. In the integrated single malting unit, the grains are spread on the grain holding sieves for maintaining the uniform layer of thickness (Kumar et al. 2016). The water sprinkling arrangements made at the top provides the water required for the soaking of grains. This soaking water is replaced 3–4 times by opening the bottom valve during entire period of steeping, which also provides aeration to the soaked grains by the freshwater. After completion of the steeping process, all water is drained out by opening the bottom valve and the grain is left for germination on sieves. After completion of germination process, the side valve is open for the last step of malting, i.e., drying, hot air of the desired temperature comes from the side and cross the sieves so that the hot air spread equally over all sieves and the grain is dried. After the removal of sieves from the unit, we get malt.

11.2.9 Fermentation

Fermentation is one of the age-old preservation technique used for a variety of food products throughout the world. There are a variety of traditional dishes prepared from millets in different parts of the globe. Fermentation process significantly alter the physiochemical attributes in the millet grains and final fermented product. Fermentation process has key benefit due to the decrease in antinutrients, increase in protein availability, protein digestibility, and overall nutrition profile. In the pearl millet fermentation, a considerable amount of improvement in the IVPD was found with traction in unwanted antinutrients. During the fermentation of pearl millet grains, it was observed that significant reduction in anti-nutritional constituents present in the grain (Hassan et al. 2006). At the same time, because of this process, the availability of protein and starch for digestion significantly increased. In addition to amino acids, some of the vitamins were also found increased, while some specific flavaonoids and past behavior gets decreased during fermentation of some millet grain (Akingbala et al. 2002). A simultaneous increase in some of the nutrients was observed while decrease in some of them was also reported due to specific fermentation conditions for specific type of millet. The quantifiable changes in the macronutrients like fiber, protein, fat, etc., and micronutrients like K, Mg, Na, Fe, Cu, Mn, and Zn were observed in the fermentation of pearl millet grain. The enhancement in crude protein and crude fiber was also observed during fermentation of some of the millets especially after 16 h. The reduction in phytic acid and increase in the Zinc availability during the 24 h fermentation of finger millet was also observed (Murali and Kapoor 2003).

The selected microbial strains for fermentation of different types of millets may be chosen based on the properties of raw material and targeted output of the fermentation process (Khetarpaul and Chauhan 1991). Literature suggests that the fermentation with individual or in combination with some other processes and possible to get millet-based final product with rich nutrition value. But the application of these techniques appropriately at commercial scale and development of the innovative millet products are limited and most of them are utilized at household level for the development of traditional food dishes. Hence, the development of modern equipment and proper optimization of processing parameters are vital and crucial things for industrial scale application and commercial production of such products. At the same time, quality and safety need to be taken care for the final product.

11.3 Effect of Different Processing Techniques on Different Bioactive Compounds of Millets

Though the different processing techniques improves the nutrition status of the millets, sometimes they may effect the bioactive constituents. The benefit as well as adverse effects on bioactive active compounds always needs to take into account during optimization of the process parameters. The processing methods like soaking, decortication, malting, and cooking were significantly influenced by the total antioxidant content in the millet grains and their activity. During malting of finger millet, the antioxidant capacity contacting free phenolic acids was found to be increased especially after 96 h while at the same time bound phenolic content gets decreased (Rao and Muralikrishna 2002). Similarly, during the roasting of finger millets and cooking of kodo millet antioxidant value was observed to decrease. The separation of husk and endosperm of kodo millet during the milling or pearling also decreases DPPH activity and phytochemicals (Hegde and Chandra 2005). Similar effect was also observed for little millets when subjected to germination, steaming, and roasting where TPC, TFC, and tannin get increased and affected the nutraceutical and antioxidant value of raw grain (Pradeep and Guha 2011). A physical process like dehulling of whole millet grains was also found to exhibit a considerable reduction in phenolic and antioxidant capacity. Various processing treatments have a significant effect on the change in phenolics and antioxidants of different types of millets (Kalam Azad et al. 2019). Most of these reductions especially in antioxidant and phenolic during different processes might be due to oxidation reactions happened at particular condition. While the reduction due to simple physical operation like dehulling is due to the removal of the outermost protective layer from the grains. Hence, millet processing in terms of grains, flours, and other value-added products needs to be carried out at properly optimized conditions of operating parameters to protect their original quality.

11.4 Millet-Based Food Products

11.4.1 Composite Flour

Consumption of millet in the form of flour is one of the popular traditional form for human consumption. It may be consumed as an individual type of millet flour or by blending them with other common types of flours at appropriate proportion (Singh and Kaur 2005). The blending of different flours is carried out especially to get desired physicochemical, nutritional, and functional characteristic in the flour. Accordingly, in case of wheat flour this substitution was possible in the range of 10–20% level like barnyard millet, finger millet, and proso millet with 20%, 10%, and 15%, respectively. The increase in the quantity of millet flour in the blend increases the ash content and decreases the gluten value, dough loaf volume, percentage of damaged starch, and protein. The blending of flour some may be prepared by more complex way to improve the nutritional status keeping in view of all types of constituents likewise Khamgaonkar (2012) formulated millet-legume-wheat based composite flour by mixing 5% malted finger millet, 5% heat-processed black soybean, 5% popped horse gram, and 85% wheat flour under optimized conditions. This composite flour was found to be nutritionally rich and was used for preparing bread.

11.4.2 Bakery Products

Baked products are foods mainly based on cereal flours which are blended with other ingredients. Popular bakery products such as biscuits, cakes, and cookies were developed using different types of millets. This type of millet-based bakery cum confectionery food products are getting popular day by day due to its low gluten content and rich in dietary fibers. Because of low gluten content in most of the millets, it needs to be incorporated in different variations from 10% to 50% levels to standardize bread (20%), cake (30%), cookies (50%), soup sticks (20%), and khari (40%) with refined wheat flour. The features of bakery products are affordable cost, variation in taste and texture, packaging and better shelf life made them popular all over the world. Furthermore, addition of millets in baked products made them more superior in nutritional value, fiber content, and various micronutrients (Verma and Patel 2013).

11.4.3 Extruded Products

It is a high-temperature short-time cooking process in which feed material (grains) in ground form is fed into the extrusion device called extruder. The appropriate setting of feed rate, temperature, residence time, and pressure is maintained in the equipment. Variety of different types and different properties of millet-based extruded products can be developed with varying grain compositions, feed rate, temperature, pressure, and residence time during the cooking process. The millet-based products in the category of pasta, noodles, and others get popular day by day. An extruded snack was also prepared by Deshpande and Poshadri (2011) mixing flour of foxtail millet, rice, amaranths, cowpea, and Bengal gram in a ratio of 60:05:05:10:20, respectively. In some of the millet blended extruded products, expansion ratio was observed to decrease especially in case of high level of foxtail millet flour. Noodles, one of the popular product among all age groups and having higher shelf life was most commonly prepared through cold extrusion with the addition of different millet flours in varying proportions. The glycaemic index value of such products is quite low.

11.4.4 Flaked and Popped Products

Popping of the grains is one of the age-old traditional practice for value addition. It is generally used for the preparation of snacks or breakfast cereals which are either plain or incorporated with spices, salts, and sweeteners. At present, cereal popped products and flakes prepared from corn are popular breakfast foods. But after the suitable processing at optimized process conditions it is possible to prepare popped and flacked products from millets. Nowadays, the demand for such millet-based ready-to-eat products is increasing because of its properties like better nutrition value, crisp and friable texture, relative smaller size, quick hydration, etc. This technology can be applied successfully for the preparation of RTE from foxtail millet using high-temperature short-time (HTST) process with processing at 230 ± 5 °C temperature (Ushakumari et al. 2004). Similar category products can also be prepared from finger millet using the same technology.

11.4.5 Fermented Products

Different types of fermented millet products were used from ancient times in India. The recipes of these types of products are different at different geographical locations and socioeconomic cultures. Besides the unique taste, fermented products are rich in various major macro and micronutrients and lower level of antinutrients as compared to raw grains or grains processed by other process technique (Maha et al. 2003; Verma and Patel 2013). Millet-based products in this category also have significantly higher protein digestibility. Fermented finger millet flour showed lower antinutrients with an increase in mineral availability like zinc, iron, calcium, etc., as compared to raw nonfermented flour (Antony and Chandra 1998). Some of the popular fermented millet-based recipes are cutlets, weaning mixtures, vermicelli, and biscuits. The special types of fermented weaning foods and beverages developed from the different combinations of millets and specially identified microbial cultures are quite popular nowadays.

11.5 Conclusion

The adoption of appropriate type of processing technology with suitable type of equipment surely decreases the anti-nutritional constituents, off taste, and off flavors from the millet. Because of this, day by day the consumers for millet are continuously increasing. Also, the commercial scale production of various value-added products of millets are boosted due to the availability of suitable type of processing machineries and equipment. The advancement in the processing technologies of millets opens a new horizon and it will help to raise millets at competitive level of staple food.

References

Akingbala JO, Uzo-Peters PI, Jaiyeoba CN, Baccus-Taylor GSHP (2002) Changes in the physical and biochemical properties of pearl millet (*Pennisetum americanum*) on conversion to ogi. J Sci Food Agric 82:1458–1464

Antony U, Chandra TS (1998) Antinutrient reduction and enhancement in protein, starch, and mineral availability in fermented flour of finger millet (*Eleusine coracana*). J Agric Food Chem 46(7):2578–2582

Arora S, Jood S, Khetarpaul N (2011) Effect of germination and probiotic fermentation on nutrient profile of pearl millet based food blends. Br Food J113(4):470–481

Cisse B, Wilson JP, Hess DE, Hanna WW, Youm O (1998) Striga hermonthica infection of wild Pennisetum germplasm is related to time of flowering and downy mildew incidence. Int Sorghum Millets Newsl 3(9):149–150

Deshpande HW, Poshadri A (2011) Physical and sensory characteristics of extruded snacks prepared from foxtail millet based composite flours. Int Food Res J18(2):34–41

Eyzaguirre RZ, Nienaltowska K, De Jong LE, Hasenack BB, Nout MR (2006) Effect of food processing of pearl millet (Pennisetum glaucum) IKMP-5 on the level of phenolics, phytate, iron and zinc. J Sci Food Agric 86(9):1391–1398

Hassan AB, Ahmed IAM, Osman NM, Eltayeb MM, Osman GA, Babiker EE (2006) Effect of processing treatments followed by fermentation on protein content and digestibility of pearl millet (*Pennisetum typhoideum*) cultivars. Pak J Nutr 5(1):86–89

Hegde PS, Chandra TS (2005) ESR spectroscopic study reveals higher free radical quenching potential in kodo millet (Paspalum scrobiculatum) compared to other millets. Food Chem 92:177–182

Hulse JH, Laing EM, Pearson OE (1980) Sorghum and the millets: their composition and nutritive value. Academic press

Kalam Azad MO, Jeong DI, Adnan M, Salitxay T, Heo JW, Naznin MT, Park CH (2019) Effect of different processing methods on the accumulation of the phenolic compounds and antioxidant profile of broomcorn millet (*Panicum miliaceum* L.) flour. Foods 8(7):230

Khamgaonkar SG (2012) Optimization of processing parameters for development of underutilized cereals and legumes based composite flour. Unpublished Thesis, Govind Ballabh Pant University of Agriculture and Technology

Khetarpaul N, Chauhan BM (1991) Biological utilisation of pearl millet flour fermented with yeasts and lactobacilli. Plant Foods Hum Nutr 41:309–319

Kumar S, Singh A, Kohli D, Mishra R (2016) Fabrication of integrated malting unit for production of malts. Int J Eng Res Appl 6(8):33–36

Lestienne I, Buisson M, Lullien-Pellerin V, Picq C, Treche S (2007) Losses of nutrients and anti-nutritional factors during abrasive decortication of two pearl millet cultivars (Pennisetum glaucum). Food Chem 100(4):1316–1323

Maha AMA, Tinay E, Abdalla AH (2003) Effect of fermentation on the in vitro protein digestibility of pearl millet. Food Chem 80(1):51–54

Mal B, Padulosi S, Bala RS (2010) Minor millets in South Asia: learnings from IFAD-NUS Project in India and Nepal. Bioversity International, Maccarese, Rome, Italy and the MS Swaminathan Research Foundation, Chennai, India

Mbithi-Mwikya S, Van Camp J, Yiru Y, Huyghebaert A (2000) Nutrient and antinutrient changes in finger millet (Eleusine coracan) during sprouting. LWT-Food Sci Technol 33(1):9–14

Meera MS, Bhashyam MK, Ali SZ (2003) Effect of heat processing of pearl millet grains on shelf life and functional properties of flour and quality of final products. Paper presented at the 5th International food convention, Mysore, 5–8 December. p 124

Murali A, Kapoor R (2003) Effect of natural and pure culture fermentation of finger millet on zinc availability as predicted from HCI extractability and molar ratios. J Food Sci Technol 40 (1):112–114

Pradeep SR, Guha G (2011) Effect of processing methods on the nutraceutical and antioxidant properties of little millet (*Panicum sumatrense*) extracts. Food Chem 126:1643–1647

Rao MVSSTS, Muralikrishna G (2002) Evaluation of the antioxidant properties of free and bound phenolic acids from native and malted finger millet (ragi, Eleusine coracana Indaf-15). J Agric Food Chem 50(4):889–892

Saleh AS, Zhang Q, Chen J, Shen Q (2013) Millet grains: nutritional quality, processing, and potential health benefits. Compr Rev Food Sci Food Saf 12(3):281–295

Sharma P, Singh H, Cristina G, Rosell M (2011) Effects of roasting on barley β-glucan, thermal, textural and pasting properties. J Cereal Sci 53:25–30

Siegel A, Fawcett B (1976) Food legume processing and utilization (with special emphasis on application in developing countries). International Development Research Centre, Ottawa Canada, vol 4

Singh N, Kaur M (2005) Studies on functional, thermal and pasting properties of flours from different chickpea (*Cicer arietinum* L.) cultivars. Food Chem 91(3):403–411

Singh TP, Rao BD, Patil JV, Ansari A (2010) Overview of millets cultivation in India. In: “Research and development in millets: present status and future strategies”, National seminar on millets. pp 1–11

Sreerama YN, Sasikala VB, Pratape VM (2008) Nutritional implications and flour functionality of popped/expanded horse gram. Food Chem 108:891–899

Ushakumari SR, Latha S, Malleshi NG (2004) The functional properties of popped, flaked, extruded and roller-dried foxtail millet (*Setaria italica*). Int J Food Sci Technol 39(9):907–915

Veena B (2003) Nutritional, functional and utilization studies on barnyard millet. MSc Thesis, University of Agricultural Sciences, Dharwad (Karnataka), India

Verma V, Patel S (2013) Value added products from nutri-cereals: finger millet (*Eleusine coracana*). Emir J Food Agric 25(3):169

Yawatkar AP, Unde PA, Patil AP (2010) Effect of grinding mills on quality of bajra flour and its products. Int J Agric Eng 3(1):144–146