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Popping and puffing of various millets: A review

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Abstract
Millets are among the oldest known foods to humanity and may have been the first cereal grain used for domestic purposes. For centuries, millets have served as staple foods for people living in the semi-arid tropics of Asia and Africa, where other crops may struggle to thrive. Throughout history, millet has been a common part of the diet in Asia and India. We can create a variety of value-added products from millets, with puffing and popping being the most effective methods to make different ready-to-eat snacks, practices that have been followed since hundreds of years. Popping is a process where starch gelatinization and expansion happen simultaneously, as grains are subjected to high temperatures for a brief duration. During this process, superheated vapour generated inside the grains through rapid heating cooks the grain and abruptly expands the endosperm, causing the outer skin to break open. Puffing resembles this process but differs in that it involves the controlled expansion of the kernel, allowing vapour pressure to escape through the micropores of the grain's structure due to high pressure or temperature gradients. Here an overview of different puffing/popping method and pop or puff from millets.

Keywords: Puffing, popping, millets

Introduction

Millets serve as a crucial food source in many developing nations due to their resilience in challenging weather conditions, including low rainfall. For thousands of years, millets have been a staple food in India and Africa. It is documented that millet cultivation in India dates back to approximately 2500 BC (Singh *et al*. 2022) [50]. The significance of these crops in agriculture comes from their resilience, adaptability to harsh climates, and the ability to be cultivated with minimal resources in arid regions. Key millets that are primarily grown in Asian and African nations include pearl millet (*Pennisetum americanum*), finger millet (*Eleusine coracana*), foxtail millet (*Setaria italica*), little millet (*Panicum miliare*), kodo millet (*Paspalum scrobiculatum*), proso millet (*Panicum miliaceum*), and barnyard millet (*Echinochloa frumentacea*) (Jaybhaye *et al*. 2014).

Millet production in the African region accounts for the highest share at 48.5%, closely followed by Asian countries at 47.7%. In 2022, the estimated total global millet production reached 30,513 MT; India stands as the top millet producer, projected to yield 2.05 million tonnes in that year, with China and Niger contributing to over 55.0% of worldwide production. In India, Rajasthan leads with 36% of production, followed by Uttar Pradesh at 12%, Karnataka at 11%, Gujarat at 9%, and Haryana at 8% (Govt. of India, 2022).

Millets are recognized as crops that contribute to food security due to their resilience in challenging agro-climatic conditions (Ushakumari *et al*. 2004) [58]. These crops have significant potential to enhance the genetic diversity of our food supply and promote better food and nutrition security (Mal *et al*., 2010) [28]. In addition to their nutritional value, millets provide health benefits when incorporated into the daily diet, aiding in the management of conditions such as diabetes mellitus, obesity, hyperlipidaemia, and others (Veena, 2003) [61]. Millets possess distinct health advantages due to their high content of micronutrients, especially minerals and B vitamins, as well as beneficial compounds known as nutraceuticals

One of the most significant sectors of the food industry is snack foods. Today, creating snack foods can be a challenging process in order to satisfy shifting consumer preferences and expectations as well as the illusive need for something distinctive that appeals to a broad range of consumers.

Using modern techniques, puffing and popping are practices that can achieve all of these goals. Popping and puffing is a traditional dry heat application technique that has been used for hundreds of years to prepare weaning meal formulations and ready-to-eat snack products. It is the simplest, least expensive, and fastest way. A rather well-known and frequently employed technique is explosion puffing, which involves the abrupt release and expansion of water vapor (Sullivan and Craig, 1984) [55].

Consumers in today's modern culture consume a variety of RTE (ready-to-eat) snack foods, such as popcorn, puffed cereals, fried chips, wafers, flakes, granules, extruded and spiced products, etc. Popping, or the production of enlarged products from grains and legumes, is one of the ancient food processing methods used to produce RTE light and crisp dishes (Ushakumari *et al.* 2007) [57].

Grain puffing is an ancient, traditional technique of cooking grains, either plain or with spices, salt, or sweeteners, for use as breakfast cereals or snacks. Starch provides a variety of necessary novel qualities and is the primary food source for humans. It is evident that the quality of the starch is correlated with its preparation and structure (Lehman *et al*. 2007) [25].

Various techniques for popping/puffing are utilized, including the conventional dry heat method, sand and salt treatment, hot air popping, gun puffing, popping in hot oil, and microwave heating. While numerous cereals and millets like rice, wheat, corn, sorghum, ragi, and foxtail millet are utilized for popping or puffing, only a select few achieve good popping. This could be attributed to the elements that affect the popping traits of cereals, including season, varietal differences, grain attributes like moisture content, grain composition, physical traits, endosperm types, and the popping technique used

Four varieties of millet that can be popped include foxtail millet, finger millet, barnyard millet, and proso millet. Proso millet exhibited the greatest popping yield (92.77%) and expansion volume (6.51), succeeded by foxtail millet, finger millet, and barnyard millet (Srivastava *et al*. 1998) [52].

Different processing methods such as Sand Bed Puffing, Microwave puffing, Gun Puffing, Oven Puffing, Extrusion puffing, HTST Air puffing, Oil puffing, Hot air puffing can be used commercially to produce expanded cereals, Pulses and Millets.

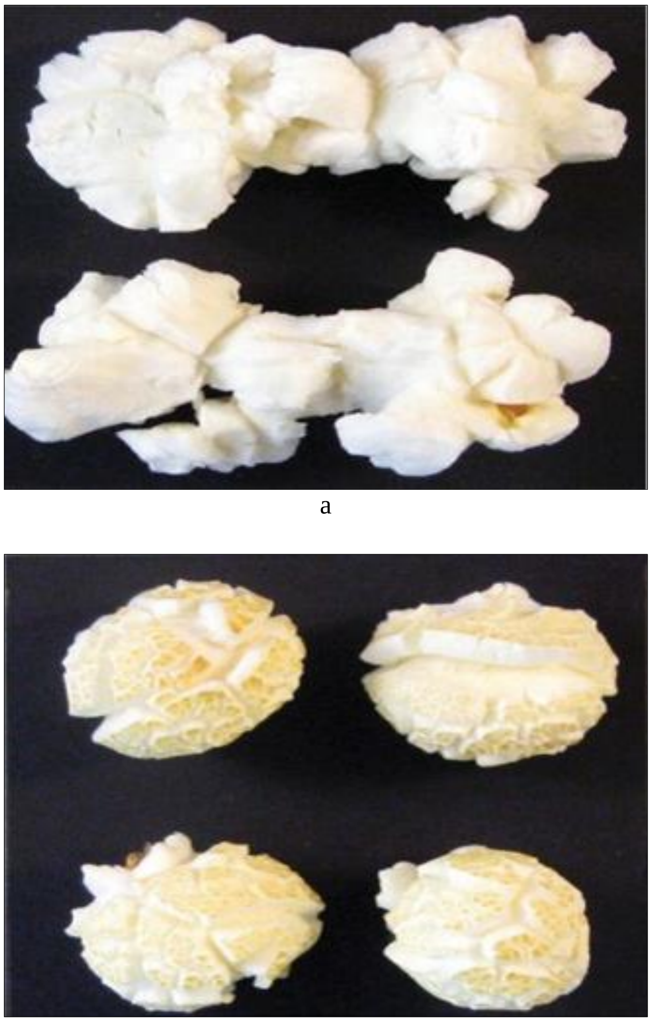
Definition of Puffing and Popping

Puffing describes a technique in which the expanded product is made from pre-treated cereals or similar items (cooking, salting, curing) and moisture conditioning (drying and tempering) followed by roasting at high temperatures (intense heating) (Dash & Das, 2019a) [7].

The puffing process involves warming the grain until the starch changes from a rigid amorphous state to a malleable state, allowing the water vapor to escape from the grain (Gulati & Datta, 2016 [12]; Malfait, 2004) [29]. After the emergence or increase of water vapour within the product, the grain structure can either deteriorate, expand, or develop an internal structure (Payne *et al*., 1989) [39].

Popping is a technique used on moisture-treated whole unprocessed grains (such as paddy, sorghum, corn) or following minimal processing (Malleshi & Desikachar, 1985) [30].

The tough outer layer of the kernel plays a key role in the popping process. This tough layer protects the endosperm and acts as a pressure container surrounding it (Bhatupadya *et al*., 2008 [2]; Hoseney *et al*., 1983) [15].



a

b

Fig 1: (a) Pop grain structure. (b) Puff Grain Structure.

Methods of Puffing and Popping

Sand Puffing

The sand roasting method entails placing pre-gelatinized grains in hot sand with a temperature of approximately 250 °C. Sand roasting and baking are gaining popularity as inexpensive, efficient, oil-free, and healthy cooking techniques. Srinivas *et al*. (1974) [51] state that when fully mature, crack-free grains with a moisture content of 14% (wb) are puffed at the optimal sand temperature of 275 °C, the maximum expansion occurs

In the sand roasting technique, pre-gelatinized grains are placed in hot sand at approximately 250°C. The rapid thermal change causes moisture within the grains to vaporize and escape through tiny pores, resulting in an increase in the size of the starchy endosperm during this process (Chinnaswamy and Bhattacharya, 1983a) [6].

Gun Puffing

Gun puffing involves the addition of processed grains into the gun or high-pressure chamber post-preheating, followed by the introduction of superheated steam into the sealed rotating chamber (Luh, 1991) [27]. The ultimate texture of the puffed product relied significantly on the steam pressure; excessive pressure would damage the product, whereas insufficient pressure would result in a lack of crispness. An adequate duration is provided for the superheated steam to prepare the grain in a semi-plastic condition, and ultimately, the pressure is abruptly released to achieve the crispy puffed grain (Mishra *et al*. 2014) [33]. The primary benefit of the gun puffing technique is the uniform expansion in expanded cereal.

Mariotti *et al*. (2006) [32], examined the changes linked to the gun puffing technique for various grains. Puffed rye and rice exhibited a highly porous matrix, consisting of many cavities of varying sizes divided by very thin walls; in contrast, puffed wheat, emmer wheat, and barley demonstrated a significantly denser, more uniform, and less porous structure.

The technique known as "explosion puffing" entails initially air drying the product to a moisture level of 0.175 to 0.538 kg/kg dm, subsequently applying heat under pressure using a steam gun, and finally releasing the pressure, leading to rapid moisture evaporation that causes the product to expand (Hailand *et al*. 1977) [14].

Batch Type HTST Whirling Bed Puffing

Whirling air is known to enhance heat and mass transfer as the product surface area is consistently presented to the heating medium; thus, fluidized bed high temperature short time (HTST) puffing is more effective than hot air or conduction roasting or puffing methods (Mishra *et al*., 2014) [33]. The surface heat transfer coefficient is a crucial factor in the puffing of fluidized beds. An optimal temperature of 240°C to 270°C with an exposure time of 7 to 9.7 s was identified, yielding a higher expansion ratio (8.5 to 10) and improved colour of the product (Chandrasekhar and Chattopadhyay, 1989) [4].

In fluidized bed popping, the moisture content affected the process, as did the moisture in the heating medium (Konishi *et al*. 2004) [22].

Venkatesh *et al*. (1989) [62], created and constructed a fluidized bed popping machine with a capacity of 20-25kg/h, utilizing the HTST process and capable of continuous operation. The surface heat transfer coefficient plays a crucial role in the puffing of fluidized beds.

Ushakumari *et al*. (2007) [57], created expanded finger millet as a ready-to-eat innovative product utilizing HTST. Decorticated finger millet subjected high-temperature treatment to create expanded millet, a new ready-to-eat product. It was noted that shaping the grains to the appropriate form and moisture level were essential elements for achieving millet with the highest expansion ratio. The ideal conditions for creating a product with the maximum expansion ratio were determined to be around 40% moisture content before flattening, with the shape factor between 0.52 and 0.58 and drying time between 136 and 150 minutes.

Hot Air Puffing

This system can be adjusted to achieve any preferred puffing air temperature and speed with great precision. It comprises an electrically heated air blower system with manual controls, a puffing chamber, and an outlet for the puffed grains accessible at any point during the puffing process, alongside a feature for ongoing hot air circulation (Katkar *et al*. 2023) [20]. The air warmed to the specified temperature in the heating chamber was transferred to the puffing chamber. The temperature of the puffing air (regulated within ± 2% uncertainty) was recorded directly in the puffing chamber. Pardeshi *et al*. (2014) [36], conducted a study to optimize process parameters for the hot air puffing of wheat-soy based Ready-to-Eat (RTE) snacks. He makes wheat-soy snack food with a maximum soy enrichment of 7.5% in refined wheat flour.

Kambale (2011) [19], created a hot air puffing system for amaranth seeds, assessing its performance by examining various moisture levels (11.65-20.83) and temperatures and fix parameters such as puffing time, expansion ratio, and puffing efficiency, concluding that the puffing time was greatest for the sample with the greatest moisture content and the opposite for lower moisture levels

Microwave Puffing

Microwave puffing is an alternative method employed for puffing. Microwave energy has been utilized in food processing for many years; it is now acknowledged as a dependable source of clean thermal energy with potential uses in baking, blanching, popping, and puffing alongside cooking and tempering (Roussy and Pearce, 1998) [43]. While heating in a microwave, glassy starch concurrently loses moisture and expands (Boischot *et al*. 2003) [3].

Parameters of the microwave process, including microwave power level, power density, and residence time, are crucial determinants of the popping quality of the grain in home microwave ovens (Singh and Singh 1999) [48]. Employing response surface methodology, Dhumal *et al*. (2014) [10], created an innovative microwave puffing technique for ready-to-eat (RTE) meals utilizing minor millet types like finger millet and barnyard millet, along with tubers such as sweet potato and potato.

The moisture content and degree of gelatinization of starchy grains were among the key factors affecting the shape, expansion bulk volume, density, and popping efficiency of microwave products (Lee *et al*. 2000) [24]. Extremely low moisture and excessive moisture might not be leading to the required expansion (Morau and Kokini, 2003).

Microwave products might not exhibit the same expansion as traditional methods due to the shorter residence time and uneven heating patterns in the former case (Mishra *et al*. 2015).

Extrusion Puffing

Numerous ready-to-eat puffed cereals were made by extruding superheated and pressurized dough through an opening into the atmosphere, resulting in a rapid increase in volume. The procedure can be performed in either double or single screw extruders. The benefit of utilizing extrusion lies in the control of temperature and pressure, allowing for the manipulation of product sizes and shapes through various die and dimensions (Luh, 1991) [27]. Extrusion integrates several unit processes like mixing, cooking, shearing, puffing, final shaping, and drying into a single, energy-efficient, continuous operation (Harper, 1979).

Extrusion is the method where a product is created through a combination of elevated pressure, heat, and mechanical shear. The primary benefits of this process compared to other manufacturing methods are its capacity to produce highly intricate cross-sections and to handle brittle materials, as the material experiences compressive and shear forces. The product leaves the extruder via a die, where it typically expands and alters its texture due to the release of steam and standard forces (Vasanthan *et al*. 2002) [60].

Oil puffing

Essentially, deep-fat frying puffing is a dehydration process where fat acts as the heating medium, causing the water within the food material to heat up and vaporize. Due to the elevated temperature, which results in puffing (Varela *et al*. 1988) [59].

Heating vegetable oil at 200 to 220°C causes hot oil popping or puffing, resulting in larger products. It is a commonly utilized commercial and traditional technique for popping corn (Hoseney *et al*. 1983) [15].

Popping and puffing of different millets

Sorghum

Sharma *et al*. (2014) [46], noted that limited reports on sorghum popping indicated that it expands effectively under high temperature and short time (HTST) conditions. Popped sorghum, as a pre-cooked item ready for consumption, can serve as a foundation for snack foods, specialty items, and the creation of additional food products. They utilized a microwave oven for popping sorghum. They attempted to pop sorghum at three varying moisture levels and three different microwave power settings, resulting in popping yields that varied from 63.67% to 88.88%. They determined that moisture levels have a considerable impact on the popping yield and expansion ratio. The expansion ratio rise with rise in moisture content from 18 to 21%, and then fell as moisture reached 24%.

Nakade *et al*. (2020) [34], studied sorghum popping through high temperature short time process techniques, where the air temperature, puffing duration, and initial moisture content of the material are crucial elements. Sorghum popping involves soaking grain in water at 80ºC for 2 minutes, followed by a 3-hour conditioning period. The popping process is executed using a multigrain popping and puffing (HTST) machine set at 260 º C and 3 RPM.

Pawar *et al*. (2014) [38], examined the process parameters to enhance the quality of microwave puffed sorghum. Ready-to-eat items were created through a high-temperature short-time method. They made the cold extruded dough by steaming the sorghum and soy powder blended in a (90:10) ratio. They utilized the process parameters such as heating temperature, heating time, microwave power, and moisture content, and examined the responses regarding expansion ratio, hardness, and crispiness. The best product quality was achieved under ideal process conditions with convective heating at 210 °C for 240 s, followed by microwave heating at 80% of total power of 1350 W for 60 s, resulting in moisture content of 0.2374 kg/kg dry matter, hardness of 1620.7 g, crispiness of 21 (+ve picks), and an expansion ratio of 2.0416.

a

b

Fig 2: (a) Raw Sorghum (b) Puff Sorghum

Pearl Millet

The popping of conditioned pearl millet utilizing heated sand at 250ºC produced yield and expansion ratios for popped grains that ranged from 8.3-77.1% and 2.3-11.3%, respectively (Hadimani *et al*. 1995) [13].

When popping, the lipase enzyme is denatured, resulting in a longer shelf-life for popped products compared to other types of millet products. This is very beneficial for pearl millet, since processed pearl millet has a significantly short shelf-life. The popping enhances not just the shelf-life but also the nutritional quality regarding the bioavailability of nutrients (Pradeep *et al*. 2013 [41], Mishra *et al*. 2014).

Ritu Kumari Conducted research on eleven types of pearl millet to assess their popping traits and nutritional value. Five varieties, specifically CZP 9802, PC 443, HHB 67, PC 701, and PC 383, demonstrated the highest popping yield, and the popping index suggests their suitability for popping.

a

b

Fig 3: (a) Raw Pearl Millet (b) Pop Pearl Millet

Finger Millet

Wadikar *et al*. (2007) [63], produced puffed grains from various finger millet varieties by conditioning the grains for 2 hours at a moisture level of 20% and then puffing them using hot sand at a temperature range of 220-230ºC. The varietal influence of finger millet on puffing quality indicates that brown-seeded varieties are better for puffing, while white-seeded varieties produced organoleptically higher quality puffs (Shukla *et al*. 1986b) [47]. The brown seeded type 'PR 202' produced the highest puffing yield, while 'JNR 852' resulted in moderate expansion.

Malleshi and Desikachar (1981) [31], investigated the ideal conditions for puffing ragi, which involved moistening to 19% moisture and equilibrating for 4 hours, then puffing in sand at 270°C. Significant varietal differences in puffing quality were observed among the fourteen varieties examined. Additionally, a significant difference in yield and the expansion volume of popped grains was noted. The yield of popped grains ranged from 47 to 94%, while the expansion volume fell between 4.8 and 11.6 ml/g (Malleshi and Desikachar, 1981) [31].

Senapati, (2019) [44] done Puffing of finger millet using microwave oven The best process parameters for microwave puffing finger millet were found using a microwave oven at 900 W microwave power and 16% moisture level and exposure time of 137 seconds to achieve optimal puffing output (16.35%), expansion ratio (3.05), and lowest bulk density (644.66 kg/m3).

Raya *et al*. (2015) [42], examined the impact of pre-treatment on finger millet puffing. The mean yield (%) of puffed finger millet, which underwent water pre-treatment, exceeded that of the citric acid pre-treated sample, recording 90.34% compared to 85.56%.

Barnyard millet

Srivastava *et al*. (2003) [53], created popped grains from barnyard, foxtail, and little millet by using common salt as a heating medium in an open iron pan with a sample and salt ratio of 1:20 at 240-260 ºC for 15-25 seconds.

Jaybhyae and Srivastav, (2010a) create (RTE) barnyard millet (*Echinochloa frumentacea*) based snacks by producing thin rectangular shaped, steam cooked cold extrudates and puffing them using the HTST puffing method.

Dhumal *et al*. (2014) [10], developed microwave-cooked, cold-extruded puffed barnyard millet ready-to-eat fasting foods with similar sensory quality.

Jaybhaye, (2011) [18] created and built a hot air puffing machine to produce puffed ready-to-eat snack foods using barnyard millet flour. A lab-scale hot air puffing machine powered by a 1 Hp electric motor was designed to puff pre-gelatinized cold extrudates (0.03 kg per batch) made from composite flour dough. It was created with an overall height of 145 cm and intended for operation by one individual.

Jayebhaye *et al*. (2015), created a ready-to-eat (RTE) puffed item using Barnyard millet (*Echinochloa frumentacea* L.), which is a coarse grain high in carbohydrates. Cold-extruded dough sheets made from barnyard millet flour, potato mash, and tapioca powder in a ratio of 60:37:3 were steamed and subsequently puffed using the High Temperature Short Time (HTST) method in a hot air puffing machine.

a

b

Fig 4: (a) Raw Barnyard Millet (b) Puff Barnyard Millet

Kodo Millet

The optimal temperature for traditional popping and machine popping is 250°C and 290°C at 14% moisture (Shirisha *et al*. 2024). Shirisha *et al*. (2024), report that there are notable reductions in the moisture level of pop kodo millet, alongside decreases in ash, crude fiber, protein, fat, starch, and energy levels. Conversely, the amount of carbohydrates rose considerably.

Balaji, (2020) [1] optimized quality process factors for sorghum grain, bajra grain, finger millet grain, kodo millet grain, and kutki grain. Expansion ratio (ER) values of 9.224, 4.243, 2.439, 2.358, and 3.626 were obtained respectively.

Pops, indicated that the nutritional analysis of kodo millet pops and the refinement of popping conditions show that the ideal temperatures for traditional popping and machine popping are 250°C and 290°C, respectively, at 14% moisture.

Proso Millet

The puffed Proso Millet is significantly expanded, lighter in density, and has a greater protein content. Proso Millet achieves good puffing quality with a moisture content of 15 to 18%. The maximum puffing yield ranges from 12 to 18% (Levwis *et al*. 1992) [26].

Proso millet seeds can be popped in a way akin to popcorn. Puffed millet is a crispy and healthy snack that can also serve as a garnish for salads, cereals, or desserts (Singh and Bansal).

Srivastava and Batra, (1998) [52] examined the connection between the physical characteristics and popping attributes of different genotypes of foxtail millet, finger millet, barnyard millet, and proso millet. Notable variations in puffing yield among different genotypes of the aforementioned millets were noted. Among all the millets, proso millet exhibited the greatest popping yield (92.77%) and expansion volume (6.51), followed by finger millet, foxtail millet, and barnyard millet.

Nithyashree and Vijayalaxmi, (2022) [35] examined the impact of popping on nutrients and anti-nutrients in proso millet. They discovered that the correct level of moisture is essential to create sufficient pressure within the grain for it to burst open, making moisture content a key factor in this procedure. When moisture levels are low, the endosperm fails to generate sufficient steam for complete expansion, but it does so when moisture is high. The seed's expansion can result in cracks in the outer layer, which aids in avoiding pressure accumulation. The temperature of the particulate medium also needs to be increased to convert the moisture within the grain into superheated steam. Excessively high temperatures can give a charred taste, while low temperatures fail to generate sufficient heat within the grain to convert the moisture into superheated steam. Seasoning the grain or, at times, charred it.

Amaranthus

Chávez-Servín *et al.* (2017), reported that the popping percentages of amaranth grain grown in greenhouses and open fields were 84 and 82 percent, respectively. Several researchers have indicated a broad variation in popping percentage; Murty *et al.* (1983) and Thorat *et al.* (1988) observed that the popping percentage was influenced by grain moisture and grain hardness.

Puff amaranthus is a crispy, light, and toasted treat created from small amaranthus seeds. Amaranthus is customarily eaten by puffing the seeds. Treats and confections created from puffed amaranthus seeds are healthy and popular in Asia and South America (Singhal and Kulkarni, 1988). The perfect puffing temperature for Amaranthus seeds is between 250 and 290ºC (Tikekar, 2007) [56]. The popping of Amaranthus seeds was affected by both the moisture content of the seeds and the moisture present in the heating medium.

Quinoa

Deepak *et al.* (2020) [8], examined the Optimization of Factors Affecting Puffing Quality of Hot Air Oven Puffed Quinoa. They state that Quinoa is a healthy and bioactive pseudocereal that can be converted into a crunchy and expanded snack suitable for immediate consumption through hot air oven puffing. The optimal puffing conditions included 60 seconds of residence time, a salt concentration of 0%, an oven temperature of 253.8ºC, and 0.2 ml of moisture for every 10 g of sample. Producers could benefit from the quadrupled output resulting from enhanced conditions.

As stated by Kumar *et al.* (2022) [23], the optimal puffing yield occurs with heat treatment of puffed quinoa at 230°C for 30 seconds. Compared to puffed quinoa, quinoa that has undergone puffing shows improved protein, carbohydrate, and *in vitro* digestibility of protein and starch. The processed products exhibited improvements in bulk density, expansion volume, and water absorption capacity, which would aid future formulations. Puffed quinoa at 240°C for 30 seconds showed the highest protein and carbohydrate values at 13.49 and 69.05 g/100g, respectively.

Table 1: The proximate composition of various raw and puffed/popped millet grains.

Millets	Raw Grain					Puffed/ Popped Grain				
	Moisture	Protein	Fat	Ash	CHO	Moisture	Protein	Fat	Ash	CHO
Sorghum	8.31±0.2%	11.30±0.2%	1.56±0.02%	1.40±0.1%	75.45±0.5%	5.28±0.07%	12.45±0.01%	1.07±0.01%	1.88±0.01%	76.98±01%
Pearl Millet	7.74%	12.14%	5.19%	1.69%	74.16%	1.84%	11.41%	8.28%	3.95%	75.71%
Finger Millet	13.36 ± 0.11%	8.30 ± 0.37%	1.36 ± 0.07%	2.75 ± 0.08%	68.37 ± 4.91%	3.82 ± 0.19%	6.94 ± 0.42%	1.16 ± 0.11%	2.58 ± 0.23%	82.75 ± 4.17%
Kodo	7.35 g/100g	7.92 g/100g	1.44 g/100g	3.98 g/100g	69.48 g/100g	3.35 g/100g	8.02 g/100g	1.41 g/100g	3.92 g/100g	74.38 g/100g
Barnyard millet	10.25%	11.89%	4.20%	2.17%	81.74%	4.76%	14.07%	2.94%	1.31%	81.68%
Proso Millet	8.95g/100g	10.90 g/100g	0.90 g/100g	2.05 g/100g	74.75 g/100g	3.50-3.80 g/100g	10.51-10.92 g/100g	0.80-0.83 g/100g	1.95-2.5 g/100g	79.07-80.00 g/100g
Amaranthus	10.96%	17.8%	8.64%	5.92%	50.12%	9.62%	11.59%	7.97%	5.28%	60.57%
Quinoa	11.30 g/100g	12.61 g/100g	5.17 g/100g	3.19 g/100g	65.11 g/100g	6.55-7.32 g/100g	13.23-13.49 g/100g	4.97-5.11 g/100g	2.69-2.91 g/100g	69.13-70.50 g/100g

(Ref. Dhadke *et al*. 2022 [9]; Chauhan *et al*. 2015 [5]; Khan and Dutta, 2018 [21]; Kumar *et al*. 2022 [23]; Nithyashree and Vijayalaxmi, 2022 [35]; Patel *et al*. 2018 [37]; Senapati, 2019 [44]; Sharad *et al*. 2024.)

Conclusion

Expanded grain products are the most popular ready-to-eat breakfast worldwide and are traded globally in different names. Its production processes vary from age-old unhygienic traditional practices in rural sector to modern and costly methods of gun puffing, microwave puffing/popping or hot air popping/ puffing in small and medium scale industries. Today microwave heating, hot air, gun puffing and roasting in the heating pan or hot sand using conduction heat are well-established commercialized methods for producing expanded grains. Microwave puffing is a relatively new method and provides an option for hygienic production, conveniently packaged food and RTE forms that attract the consumer's appeal. For making puff and pop grain, millet is a very good option because nowadays many people are becoming health conscious and turning toward millet, as it is very healthy nutritious, and affordable also.

References

1. Balaji ST. Development of Semi Automated Multigrain Continuous Hot Air Puffing System. 2020.
2. Bhatupadya VG, Bhat RS, Shenoy VV, Salimath PM. Physico chemical characterization of popping—Special rice accessions. Karnataka Journal Agricultural Science. 2008;21(2):184-186.
3. Boischot C, Moraru CI, Kokini JL. Expansion of glassy amyopectin extrudates by microwave heating. Cereal Chemistry. 2003;80(1):56-61.
4. Chandrasekhar PR, Chattopadhyay PK. Studies on micro-structural changes of parboiled and puffed rice. Journal of Food Processing and Preservation. 1989;14:27-37.
5. Chauhan SS, Jha SK, Jha GK, Sharma DK, Satyavathi T, Kumari J. Germplasm screening of pearl millet (*Pennisetum glaucum*) for popping characteristics. Indian Journal of Agricultural Sciences. 2015;85(3):344-8.
6. Chinnaswamy R, Bhattacharya KR. Studies on expanded rice: optimal processing condition. Journal of Food Science. 1983;48:1604-1608.
7. Dash KK, Das SK. Optimization of fluidized bed preconditioning for microwave puffed rice using integrated artificial neural network and genetic algorithm approach. Journal of Food Process Engineering. 2019a;42(6):e13158.
8. Deepak S, Sharmila T, Maheswari M, Shivaswamy MS. Optimization of Variables that Influence Puffing Quality of Hot Air Oven Puffed Quinoa. International Journal of Pharmaceutical Research (09752366). 2020;12(3).
9. Dhadke SG, Pawar VS, Wanole PD. Effect of popping on nutritional composition of sorghum. In Biological Forum-An International Journal. 2022;14(4):1199-1202.
10. Dhumal CV, Pardeshi IL, Sutar PP, Babar OA. Optimization of process parameters for development of microwave puffed product. Journal of Ready to Eat Food. 2014;1(3):111-119.
11. Govt. of India. India estimated to produce 205 lakh tonne millet in 2022-23. The Times of India. 2022.
12. Gulati T, Datta AK. Coupled multiphase transport, large deformation and phase transition during rice puffing. Chemical Engineering Science. 2016;139:75-98.
13. Hadimani NA, Ali SZ, Malleshi NG. Physicochemical composition and processing characteristics of pearl millet varieties. Journal of Food Science and Technology. 1995;32:193-198.
14. Hailand WK, Sillivan JF, Konstance RP, Craig JC, Cording JJ, Aceto NC. A continuous explosion puffing system. J. of Food Technol. 1977;31(11):32.
15. Hoseney RC, Zeleznak K, Abdelrahman A. Mechanism of popcorn popping. Journal of Cereal Science. 1983;1:43-52.
16. Jayabhaye RV, Dhumal CV, Pardeshi IL, Sutar PP. Development of potato and barnyard millet based ready to eat (RTE) fasting food. Journal of Ready to Eat Food. 2014;1(1):11-17.
17. Jaybhaye RV, Srivastav PP. Oven toasting of barnyard millet based ready-to-eat (RTE) snacks: Process parameter optimization and sensory evaluation. Proceedings of International Conference on 'Food Technology - Edition II' from 30 - 31 October, 2010.
18. Jaybhaye RV, Kshirsagar DN, Srivastav P. Development of barnyard millet puffed product using hot air puffing and optimization of process parameters. Int. J. Food Eng. 2011.
19. Kambale RB. Development of hot air puffing system for Amaranth seeds [Unpublished M. Tech Thesis]. Post Harvest Technology Centre, IIT, Kharagpur (W.B.), India - 721 302; 2011.
20. Katkar KC, Pardeshi IL, Swami SB, Durgawati, Sutar PP, Athmaselvi KA, *et al*. Study on high temperature short time (HTST) hot air puffing of rice. Drying Technology. 2024;42(3):563-575.
21. Khan R, Dutta A. Effect of popping on physico-chemical and nutritional parameters of amaranth grain. Journal of Pharmacognosy and Phytochemistry. 2018;7(3):954-958.
22. Konishi Y, Iyota H, Yoshida KM, Moritani J, Inoue T, Nishimura N, *et al*. Effect of moisture content on the expansion volume of popped amaranth seeds by hot air and superheated steam using a fluidized bed system. Bioscience, Biotechnology and Biochemistry. 2004;68(10):2186-2189.
23. Kumar M, Bharti A, Dhumketi K, Ansari F, Patidar S, Tiwari PN, *et al*. Comparative Study of Nutritional and Physical Characteristics of Raw and Puffed Quinoa. 2022.
24. Lee E, Lim K, Lim JK, Lim ST. Effect of gelatinization and moisture content of extruded starch pellets on morphology and physical properties of microwave-expanded products. Cereal Chemistry. 2000;77(6):769-773.
25. Lehmann U, Robin F. Slowly digestible starch-its structure and health implications: a review. Trends in Food Science & Technology. 2007;18(7):346-355.
26. Lewis KD, Lorenz K, Tribelhorn R. Puffing quality of experimental varieties of proso millets (*Panicum miliaceum*). Cereal Chemistry. 1992;69(4):359-365.
27. Luh BS. Rice utilization. Springer Books, 2nd edition; 1991.
28. Mal B, Padulosi S, Ravi SB. Minor Millets in South Asia: Learnings from IFAD-NUS Project in India and Nepal. Maccarese, Rome, Italy: Bioversity Intl., and Chennai, India: M.S. Swaminathan Research Foundation; 2010. p. 1-185.
29. Malfait JL. U.S. Patent 6,676,983 B2. 2004.
30. Malleshi NG, Desikachar HSR. Milling, popping and malting characteristics of some minor millets. Journal of Food Science and Technology. 1985;22:401-403.
31. Malleshi NG, Desikachar HSR. Varietal differences in puffing quality of ragi (Elusine coracana). J. Food Sci. Technol. 1981;26:26-28.
32. Mariotti M, Alamprese C, Pagani MA, Lucisano M. Effect of puffing on ultra-structure and physical characteristics of cereal grains and flours. Journal of Cereal Science. 2006;43(1):47-56.
33. Mishra G, Joshi DC, Panda BK. Popping and puffing of cereal grains: A review. Journal of Grain Processing and Storage. 2014;1:34-46.
34. Nakade K, Khodke S, Kakade A, Othzes N. Optimization of Process Technology for Popping of Sorghum. Int. J. Curr. Microbiol. App. Sci. 2020;9(01):180-192.

35. Nithyashree K, Vijayalaxmi KG. Effect of Popping on Nutrients and Anti-nutrients in Proso Millet. Mysore Journal of Agricultural Sciences. 2022;56(4).
36. Pardeshi IL, Chattopadhyay PK. Whirling bed hot air puffing kinetics of rice-soy ready-to-eat (RTE) snacks. Journal of Ready to Eat Food. 2014;1(1):01-10.
37. Patel A, Parihar P, Dhumketi K. Nutritional evaluation of kodo millet and puffed kodo. International Journal of Chemical Studies. 2018;6(2):1639-1642.
38. Pawar SG, Pardeshi IL, Borkar PA, Rajput MR. Optimization of process parameters of microwave puffed sorghum based ready-to-eat (RTE) food. Journal of Ready to Eat Foods. 2014;1(2):59-68.
39. Payne FA, Taraba JL, Saputra D. A review of puffing process for expansion of biological product. Journal of Food Engineering. 1989;10:183-197.
40. Pops KM. Optimization Of Popping Parameters And Nutritional Profiling Of.
41. Pradeep PM, Dharmaraj U, Sathyendra Rao BV, Senthil A, Vijayalakshmi NS, Malleshi NG, *et al*. Formulation and nutritional evaluation of multigrain ready-to-eat snack mix from minor cereals. J. Food Sci. Technol. 2013;51(12):3812-20.
42. Raya JP, Kumar BA, Babu DR, Sravanthi A. Effect of pre-treatment on puffing of finger millet, bengal gram and maize and their flours. Internat. J. Agric. Engg. 2015;8(2):000-000.
43. Roussy G, Pearce JA. Foundations and industrial applications of microwaves and radiofrequency fields. Chichester: John Wiley and Sons; 1995.
44. Senapati N. Studies on microwave puffing of finger millet [Doctoral dissertation]. Orissa University of Agriculture and Technology, Bhubaneswar; 2019.
45. Sharad JS, Pardeshi IL, Swami SB, Ranveer RC, Kadam JH. Process optimization for hot air puffing of barnyard millet (*Echinochloa frumentacea*).
46. Sharma V, Champawat PS, Mudgal VD. Process development for puffing of sorghum. International Journal of Current Research and Academic Review. 2014;2(1):164-170.
47. Shukla S, Gupta O, Sharma Y, Sawarkar N. Puffing quality and characteristics of some ragi cultivars. Journal of Food Science and Technology. 1986b;23:329-330.
48. Singh J, Singh N. Effects of different ingredients and microwave power on popping characteristics of popcorn. Journal of Food Engineering. 1999;42:161-165.
49. Singh N, Bansal S. Proso Millet (Chena). Millets: forgotten grains regaining prominence. p.68.
50. Singh RP, Qidwai S, Singh O, Reddy BR, Saharan S, Kataria SK, *et al*. Millets for food and nutritional security in the context of climate resilient agriculture: A Review. International Journal of Plant & Soil Science. 2022:939-953.
51. Srinivas T, Lakshmi TK, Desikachar HSR. Varietal differences in puffing quality of paddy. 1974.
52. Srivastava S, Batra A. Popping qualities of minor millets and their relationship with grain physical properties. Journal of Food Science Technology. 1998;35:265-267.
53. Srivastava S, Dhyani M, Singh G. Popping characteristics of Barnyard and foxtail millet and their use in preparation of sweets. Recent Trends in Millet Processing and Utilization. Hisar, India: Chaudhary Charan Singh Hisar Agriculture. University; 2003. p. 38-40.
54. Subrajanani G. Development of popped pearl millet products [Doctoral dissertation]. Madurai Kamaraj University; 2020.
55. Sullivan JF, Craig JD Jr. The development of explosion puffing. Food Technology. 1984;38(2):52-55,131.
56. Tikekar RV, Karwe MV. Development of a continuous method for puffing amaranth (*Amaranthus spp.*) seeds. Journal of Food Process Engineering. 2009;32(2):265-277.
57. Ushakumari SR, Rastogi NK, Malleshi NG. Optimization of process variables for the preparation of expanded finger millet using response surface methodology. J Food Eng. 2007;82(1):35-42.
58. Ushakumari SR, Shrikantan L, Malleshi NG. The functional properties of popped, flaked, extruded and roller dried foxtail millet (*Setaria italica*). International Journal of Food Science and Technology. 2004;39:907-915.
59. Varela G, Bender AE, Morton ID. Frying of foods. Ellis Horwood Ltd., Chichester, UK; 1988.
60. Vasanthan T, Gaosong J, Yeung J, Li J. Dietary fiber profile of barley flour as affected by extrusion cooking. Food Chemistry. 2002;77(1):35-40.
61. Veena B. Nutritional, functional and utilization studies on barnyard millet [M. Sc. Thesis]. University of Agricultural Sciences, Dharwad (Karnataka), India; 2003.
62. Venkatesh VC, Goh TN, Wong KH, Lim MJ. An empirical study of parameters in abrasive jet machining. International Journal of Mechanical Tool Manufacture. 1989;29:471.
63. Wadikar D, Premavalli K, Satyanarayanaswamy Y, Bawa A. Lipid profile of finger millet (*Elusine coracana*) varieties. Journal of Food Science and Technology. 2007;44(1):79-81.