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REVIEW ARTICLE

Popping and Puffing of Cereal Grains: A Review

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Abstract

Popping is a simultaneous starch gelatinization and expansion process, during which grains are exposed to high temperatures for short time. During this process, super heated vapour produced inside the grains by instantaneous heating, cooks the grain and expands the endosperm suddenly, breaking out the outer skin. Puffing is a similar process; differ from popping as a process in which controlled expansion of kernel is carried out, while the vapour pressure escapes through the micropores of the grain structure due to high pressure or thermal gradient. Popping and puffing imparts acceptable taste and desirable aroma to the snacks. There are different methods of popping/puffing used viz., conventional method of dry heat, sand and salt treated, hot air popping, gun puffing, popping in hot oil and by microwave heating. Though a wide range of cereals and millets such as rice, wheat, corn, sorghum, ragi, foxtail millet are used for popping/puffing; only few of them pop well. The reason behind this may be the factors which influence popping qualities of cereals, such as season, varietal difference, grain characteristics such as moisture content, composition of grain, physical characteristics, types of endosperm, and also the method of popping. Therefore, this paper aimed at providing brief review of popping characteristics of different cereal grains and popping methods in response to high popping yield and greater volume expansion ratio.

Keywords: Popping, Puffing, Gun puffing, Popping yield, Volume expansion ratio.

1. Introduction

The snack food is one of the most important areas of the food industry. Designing snack foods today can be a complex process to meet changing consumers taste and expectations and elusive search for something unique that also appeals to a wide variety of people. Most snack manufacturers use some form of existing technology as the basis for creating snack products and incorporate variations that increase the resulting snacks' health image. Therefore, puffing and popping using advance technologies are processes, which can accomplish all these targets. As a simplest, inexpensive and quickest traditional method of dry heat application for preparation of weaning food formulations and ready-to-eat snacks products, popping and puffing have been practiced since hundreds of years. Explosion puffing by sudden release and expansion of water vapour is a relatively well known and widely used process (Sullivan and Craig, 1984).

Popping and puffing imparts acceptable taste and desirable aroma to the product. Popped/ puffed grain being a pre-cooked ready-to-eat material can be used in snack foods, specialty foods and as a base for development of supplementary foods. Examples of the use of the puffing process are the manufacture of expanded rice (Hoke *et al.*, 2005) or parboiled rice flour (Lai and Cheng, 2004). Convenient snack foods like popcorn, popped and puffed rice, popped sorghum, popped wheat roasted and puffed soybean and other legumes are very popular not only in Indian sub-continent, but also worldwide (Anderson, 1971; Jaybhaye *et al.*, 2014).

Generally, cereal grains are puffed or popped with hot air, hot sand, frying in hot oil, microwave heating and by gun puffing methods. Roasting has a risk of burning and producing defects, while the oil from frying can be adsorbed and easily turns rancid. Moreover, the husk or wood chips fired furnace that is usually used in sand roasting method, based on conduction heating (Hoke *et al.,* 2005), presents environmental hazard as well as silica contamination. In comparison, high temperature short time (HTST) fluidized bed air puffing has better puffing efficiency as the product uniformly exposed to the heating medium (Brito-De La Fuente and Tovar, 1995). To avoid the limitations of conventional popping of puffing methods, electromagnetic waves such as microwaves are used now-a-days, which provides better energy efficiency in very short time. Microwave energy is worldwide used for producing popcorn.

Though a wide range of cereals are used for popping; only few of them pop well. The reason for this may be the factors which influence popping qualities of cereals, such as season, varietal difference, grain characters i.e. bran content, bran thickness, moisture content, type of endosperm, physical characters of grains and also the method of popping (Hoke *et al.,* 2005; Mirza *et al.,* 2014; Joshi *et al.,* 2014a). For example, rice with high amylose content is not suitable for puffing because it gives a lower puffing index than rice with medium amylose content (Shuh and Tsai, 1995). The effect of puffing is also strongly influenced by the morphology and composition of the kernel (Mariotti *et al.,* 2006). Initial micropore size, popping temperature, surface tension, yield stress and rupture stress are some other factors that influence the popping characteristics of the grains (Henry *et al.,* 1995). The kernel properties of cereals, such as size, shape and density also affect expansion volume (Hoke *et al.,* 2005; Joshi *et al.,* 2014a). In case of corn, large kernels generally give lower popping volume than small kernels, because they contain a high percentage of soft endosperm (Pajic and Babic, 1991). Whereas, rice having higher L: B has positive relationship with volume expansion (Chandrasekhar and Chattopadhyay 1991; Joshi *et al.,* 2014a). Dofing *et al.* (1990) cited that three-way or single cross hybrid corn varieties produced higher expansion volumes than an open-pollinated variety. This paper presents a brief review on the previous research studies related to various methods of popping and puffing of cereals grains, so as to understand the concept of puffing and popping, to analyse the factors which are influencing better popping efficiency with minimum time and energy requirement, in response to high popping yield and greater expansion ratio.

2. Concept of Popping and Puffing

Popping of cereals has been practiced since hundreds of years. Popping is a type of starch cookery, where grains are exposed to high temperature for short time. Popping is a process in which kernels are heated until internal moisture expands and pops out through the outer shell of the kernel (Arkhipov *et al.,* 2005), whereas, puffing is a process where, sudden release of water vapour and expansion of pre-gelatinized kernel (Sullivan and Craig 1984; Hoke *et al.,* 2007) takes place. Superheated vapour is produced inside the grains by instantaneous heating, which cooks the grain and expands the endosperm while escaping with great force through the micropores of the grain structure. Most of the water in the kernel is superheated at the moment of popping and provides driving force for expanding the kernel once pericarp ruptures. Hoseney *et al.* (1983) proposed that during the popping of popcorn the pericarp acts as a pressure vessel and popping occurs at about 177°C, which is equivalent to a pressure of 135psi inside the kernel. The electron scanning microscope image implied that in a translucent endosperm, the superheated water appears to vaporize in to the hilum, expanding the starch granules to a thin film. In the opaque endosperm large voids are produced and the starch granules remain birefringent. The voids around the starch provide an alternative site in to which the superheated water vaporizes. Thus, the starch granules are not expanded and retain their birefringence. During popping the material practically gets sterilized and most of the seed microflora are destroyed (Hadimani, 1994). Popping also improves the digestibility of starch as it involves gelatinization of starch and degradation of dietary fibres (Holm *et al.,* 1985; Nyman *et al.,* 1987).

3. Methods of Popping and Puffing

Popping and puffing can be accomplished by using dry heat such as sand roasting, roasting using salt, gun puffing, hot oil frying, using heating medium such as hot air or microwave radiation (Jaybhaye *et al.,* 2014). Hoke *et al.,* (2005) reported that in India, the most frequent way is, puffing in hot sand (temperature of sand is about 250°C) or in oil (200-220°C).

3.1 Sand Roasting

Roasting is cooking in dry heat in an oven or on a split with the addition of fat or oil. Radiant heat is the means of cooking when using a split; oven roasting is a combination of convection and radiation. In sand roasting method, pre-gelatinized cereals are exposed to hot sand, while temperature of sand is about 250°C. Due to sudden thermal gradient, the moisture inside the grains vaporizes and tries to escape through the micropores, expanding the starchy endosperm in size in this process (Chinnaswamy and Bhattacharya, 1983a). Bengal gram can also be puffed when the preliminary roasting of grains with sand at 170°C for 75 s was carried out followed by tempering the grains for about 90 minutes to reach the moisture content of about 14.9% (wb). The tempered grains were then dipped in water for 5 seconds and impacted between a roller and a hot plate for de-husking and splitting. Under these conditions the bulk volumes of grains doubled during puffing (Pratare and Kurlien, 1986).

3.2 Gun Puffing

Gun puffing is a process in which the milled grains are introduced in to the gun or high pressure chamber after preheating, and then a superheated steam is introduced to the closed rotating chamber (Luh, 1991). The steam pressure is critical to the final texture of the puffed product, as too low pressure would result in product lacking crispiness and too high pressure would shatter the rice. Sufficient time is allowed for the superheated steam to cook the grain in semi-plastic state and in the end, the pressure is suddenly released for obtaining the crispy puffed grain. Keesenberg (1978) developed a puffing gun, which was composed of a rotating horizontal cylinder having the length of 1.2 m and the inner diameter of 200 mm. The cylinder was closed on one side and the steam inlet is placed at this point. On the opposite side a heavy cast iron lid was placed. When structural characteristics of pre-gelatinized rice flour produced by gun puffing compared with hot air puffing method for three varieties and found that gun puffing method resulted in structural disintegration of starch granules, which affected the pasting properties. Similar results were reported by Mariotti *et al.* (2006), who has investigated the changes associated with gun puffing method for different grains. It was observed that puffed rye and rice had a very porous matrix, made up of numerous cavities of different sizes separated by very thin wall puffed wheat; emmer wheat and barley on the other hand, shown a much more compact, homogeneous and less porous structure. Puffed buckwheat was characterized by a large number of small and regular cavities.

3.3 HTST Fluidized Bed Puffing and Popping

A fluidized bed is formed when a quantity of a solid particulate substance (usually present in a holding vessel) is placed under appropriate conditions to cause the solid/fluid mixture to behave as a fluid. Fluidization is known to increase the heat and mass transfer as product surface area is uniformly exposed to the heating medium, therefore, fluidized bed high temperature short time (HTST) puffing is more efficient than hot air or conduction roasting or puffing process. Venkatesh *et al.* (1989) designed and fabricated a fluidized bed popping machine of capacity 20-25kg/h, which involved HTST process and could be operated in continuous mode. Surface heat transfer coefficient is an important parameter in fluidized bed puffing. The temperature ranging from 240°C to 270°C with corresponding exposure time of 7 to 9.7 s was found to be optimum for higher expansion ratio (8.5 to 10) and better colour of the product (Chandrasekhar and Chattopadhyay, 1989). In fluidized bed popping, it was not only influenced by the moisture content, but also by the moisture in the heating media (Konishi *et al.*, 2004).

3.4 Microwave Popping and Puffing

The use of microwave energy in food processing has evolved and now is an established phenomenon as a source of clean thermal energy and has a promising potential of cooking, tempering, drying, heating, baking, blanching, popping and puffing processes (Buffler 1993; Roussy and Pearce, 1995). Microwave popcorn is a very popular snack worldwide and this technology has also been used to pop and puff other cereal grains. Moisture is the driving force in microwave expansion of starchy grains. During microwave heating, glassy starch simultaneously lose moisture and expand (Boischot *et al.*, 2003; Ernoult *et al.*, 2002). Degree of gelatinization and moisture content of the starchy grains were two of the most important factors in determining the shape, expansion bulk volume, density and popping efficiency of the microwave products (Lee *et al.*, 2000). Very low moisture and high moisture may not be causing the necessary expansion (Morau and Kokini, 2003). During microwave expansion of cereal grains, the microwave energy heats the product through the vibrational energy imparted on moisture. Upon heating, moisture generates the superheated steam necessary for expansion, which accumulates at the nuclei in the glassy matrix, creating a locally high pressure. As cereal matrix undergoes a phase transition from glassy to rubbery state, it starts to yield under high superheated steam pressure and expansion takes place. As moisture is lost from the matrix, and upon cessation of microwave heating, the matrix cools down and reverts to the glassy state and the final structure sets. At high moisture content, the matrix will become too soft that collapse occurs. Moreover, microwave product may not have same expansion compared to conventional methods as in the former case residence time is short in addition to the uneven heating pattern.

Microwave process parameters such as microwave power level, microwave power density and residence time are major factors deciding the popping quality of the cereals in domestic microwave oven (Singh and Singh 1999; Moisont and Nakrugsa 2010; Sweley *et al.*, 2012; Joshi *et al.*, 2014b; Sharma *et al.*, 2014). Various coating can be done over the grain kernels such as hydrogenated oil, sodium chloride, butter, sodium bicarbonate in order to achieve maximum number of popped kernels during microwave heating (Singh and Singh, 1999).

4. Structure of Grains after Popping/Puffing

The structure of the vitreous endosperm of grains after popping or puffing of different grains is more and less similar when seen using scanning electron microscopy (Parker *et al.*, 1999). To examine the effect of popping on endosperm structure of sorghum grain Parker *et al.* (1999) carried out the electron scanning microscopy of both raw and popped sorghum and corn grain. When an un-popped grain was fractured, the endosperm of the grain, it could be clearly observed from the fluorescence microscopy that the polygonal starch granules filled with protein bodies were tightly packed and devoid of air spaces. When popped, the air bubbles were seen in the expanded endosperm having outline of gelatinized starch film. They also noticed that the cell walls of the popcorn were completely shattered in to small angular fragments some of which were less than 1µm across. They also observed that the floury endosperm was slightly expanded and the walls of the protein rich cells immediately below the aleurone layer remained intact. They verified that the gelatinisation and expansion of starch granules play important role in the formation of popped grain foam. It was also seen that floury endosperm and sub-aleurone layer contribute little to the bulk of the starch foam. In addition, it demonstrated the shattering of the vitreous endosperm into minute fragments during the explosive process of popping. A beneficial consequence of cell wall fragmentation in popped cereals appears to be the improved accessibility of starch and protein digestibility (Axtell *et al.,* 1981; Hamaker *et al.,* 1987).

5. Popped and Puffed Cereal Products

5.1 Puffed Rice

Puffed rice is very popular in many countries as a cereal breakfast component or as a light food. It is a whole grain puffed product from parboiled milled rice. It is prepared from hydrothermally treated or pre-gelatinized milled rice by heating in high temperature air, oil and sand or by gun puffing method. Puffed rice is ready for consumption and easily digestible. It is commonly used in snacks, cereals drinks, Ready- to-Eat (RTE) breakfast cereals and infant foods. Chinnaswamy and Bhattacharya (1983a) gave the basic flowchart of puffing rice produced by traditional method (Fig 1).

During puffing, rice kernels increase their volume several times and a fully heat-treated crisp, porous, ready-to-eat product is created. Regardless of the puffing process two important parameters should be taken into account: the selection of an appropriate sort of rice, and the use of a proper hydro-heat treatment of raw rice. The optimum moisture content for puffing of rice for puffing expansion in most of the studies found to be 13-14% (Murugen and Bhattacharya 1991; Hoke *et al.*, 2005; Moisont *et al.*, 2010). Salt solution is invariably added to milled rice before it is heat-expanded in the industry. The effect on expansion was investigated (Chinnaswamy and Bhattacharya, 1983a). Salt appreciably increased the expansion ratio. Interestingly, not only sodium chloride but also other salts had the same effect. Gerkens and D'arnaud (1963) in his studies of the heat expansion of cooked starch postulated that salt helped the expansion by facilitating the heat conduction inward and the exit of moisture outwards. The microwave popping ratio and expansion volume of dried rice increased with an increase of the storage time and also the amounts of alcohol or sodium chloride added (Chang and Chien, 1997). Murugen and Bhattacharya (1991) found that soaking paddy in 2 % common salt (NaCl) solution increased the expansion by about 15%. Their finding was supported by Chandrasekhar and Chattopadhyay (1991) and Hoke *et al.* (2005). Mohapatra and Das (2011) have reported puffing of pre-conditioned rice using different levels of microwave energy (combination of power levels and time). It was reported that the puffing quality of rice depends on input energy and salt level in the kernels. An energy level of 29.21 kJ (880 W and 33.1 s) and salt concentration of 4.6 % was found to be optimum for puffing percentage and expansion ratio of 98.26% and 5.826, respectively.

The beneficial effect of parboiling as a pretreatment before puffing was confirmed many researchers (Chinnaswamy and Bhattacharya, 1983a; Chinnaswamy and Bhattacharya, 1986; Kaddus Miah 2002; Hoke *et al.*, 2005; Dutta and Mahanta, 2014) concluded that milled parboiled rice gave minimal expansion, which increased with increasing severity of parboiling up to a steam pressure of 1.5 kg/cm^2 for 10 min. Their study revealed that good expanded product produced when the paddy was soaked for minimum of 45 minute at 80°C before steaming. Pre-drying of the paddy in the sun to 9% moisture content (wb), puffing expansion increased as much as 30% (Murugen and Bhattacharya, 1991). In fact it was seen by the researchers that the increase of the expansion ratio was independent of the drying method adopted except if the drying air was too hot (above 70°C) which provided much worse results. The expansion ratios of puffed rice obtained from rice samples having different degrees of milling increased to a certain value and then stagnated (Chandrasekhar and Chattopadhyay, 1991).

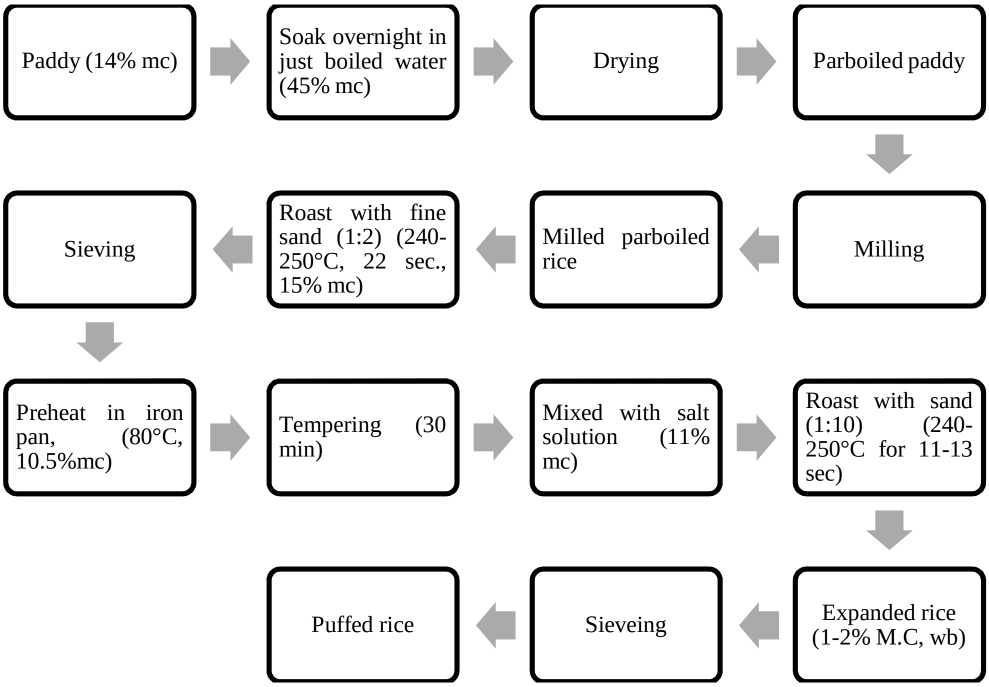

Fig 1: Process flow chart of expanded rice making in a local industry in Mysore (Chinnaswamy and Bhattacharya, 1983a)

It was observed that a minimum of about 6% degree of milling was necessary to produce optimum expansion of puffed rice, beyond which the degree of milling showed no appreciable effect on Expansion Ratio (ER). This might be due to the higher resistance offered by the existing bran covering at a lower degree of milling against the spontaneous release of high-pressure steam formed inside the grain at the time of puffing.

Many of the researchers observed that physical and chemical characteristics correlated with the expansion ration and puffing yield of rice. They concluded that rice varieties with higher L: W ratio (Chinnaswamy and Bhattacharya, 1983b), high true density and grain hardness (Joshi *et al.*, 2014a) found to be had higher volume expansion ratio. Amylose content was plays an important role in puffing and popping quality of paddy having strongly positive correlation with expansion ratio of rice kernels; higher the amylose content, the higher expansion during puffing (Madhuri, 2002). Maisont and Narkrugsa (2010) observed that kernels with high amylopectin content produced a low density product with homogeneous expanded texture, but kernels with high amylose content resulted in a hard product with low expansion. However, the exact effect of amylose content on puffing quality of rice was not cleared yet, because many of the researchers also reported that amylose content had negative correlation with both expansion volume and percentage puffing (Bhat Upadya *et al.*, 2008) and the result was supported by Joshi *et al.* (2014a), while puffing rice in a domestic convective-microwave oven. Other physical properties that affect the puffing quality of rice include husk interlocking, presence of white belly in the grains, husk content, hydration capacity of paddy, and percentage of cracked kernels (Murugesan and Bhattacharya, 1991; Srinivas and Desikachar, 1973). Varietal difference is another important aspect of puffing/popping of rice, demonstrated by many researchers. Joshi *et al.* (2014a) screened twelve varieties of indica rice and for the best puffing quality based on their chemical composition and physical characteristics such as amylose content, protein content, length, width, thickness, hardness, husk content, true density, and bulk density. The data were analyzed using Pearson's correlation, and a strong positive correlation was found to exist between amylose content and expansion ratio. At the same time, protein content was found to be negatively related with amylose content, length expansion ratio, and volume expansion ratio. From the analysis Gurjari, Jaya, GR-5, and GR-6 varieties were found to be suitable for puffing.

Processing parameters such as heating temperature and heating time influence the puffing and popping characteristics of rice as well as the product attributes. Higher expansion ratio was received at temperature between 240-270°C, while higher temperature above 270°C resulted in the browning of rice and further expansion was not apparent (Chinnaswamy and Bhattacharya, 1983a). The whirling bed hot air puffing was employed at 200 to 240°C at constant whirling air velocity of 3.97 m/s for the 50 s of puffing duration to successfully develop the soy-fortified rice-based cold extrudate, after requisite steaming, was puffed in whirling bed of hot air using the HTST whirling bed puffing system by Pardeshi and Chattopadhyay (2014). Joshi *et al*. (2014b) optimized the process parameters for puffing of rice in a domestic microwave oven and the optimized condition was found to be 220°C preheating temperature in convective mode and then puffing at 900 W power level for 60 s. Swarnakar *et al*. (2014) studied microwave popping characteristics of a particular variety of paddy using a domestic microwave oven. The maximum popping percentage of 63.47% was obtained at a moisture content of 14.15% and energy level of 80 kJ (1000 W and 80 s) while the maximum expansion ratio of 4.42 was obtained at 14.94% moisture content and energy level of 68 kJ (850 W and 80 s). Optimum values of microwave power, time of heating and moisture content of paddy were achieved at 1000 W, 80 s and 15% respectively, corresponding to popping percentage and expansion ratio of 58.73 and 3.58.

5.2 Popcorn

Popcorn is an important snack food made from corn and is growing popular day by day. The microwave popcorns are becoming popular with the increasing availability of microwave ovens at home scale. The popcorn coated with different ingredients such as butter, hydrogenated oil, sugar syrup, salt, savors, etc., are sold in market in small packs. The quality of popcorn has been reported to be affected by moisture content, popping temperature, kernel size and shape, variety, pericarp thickness, kernel density and kernel damage (Richardson 1959; Mohamed et al. 1993). The popcorn was coated with different ingredients in order to decrease number of unpopped kernels and improve their sensory quality (Singh and Singh, 1999). However, among all factors affecting expansion volume, moisture content is the most critical factor, because it affects the rate and extent of pressure builds up in starch granules (Hoseney *et al.,* 1983). So far, much research has been carried out in the area of moisture content and its effects on expansion volume as the dielectric constants of agricultural products such as grain and seed increases with increase in moisture content (Lin and Anantheswaran, 1988). Studies have shown that maximum popping volume is produced at moisture ranging from 11.0% to 15.5% (Metzger *et al.,* 1989; Song and Eckhoff 1994; Gokmen 2004; Farahnaky *et al.,* 2013). Varietal difference in corn also found to be had significant effect on popping quality both in conventional method of popping and microwave popping (Sweley *et al.,* 2012; Farahnaky *et al.,* 2013).

Pordesimo *et al.* (1990) evaluated kernel dimensions/sphericity, kernel size and specific gravity of popcorn as indicators of popping characteristics of microwave popcorn. Expansion volume correlated positively with sphericity whereas there was poor correlation between sphericity and unpopped kernel ratio. Smaller, shorter and broader kernels had a higher sphericity and such kernels had higher expansion volume. Unpopped kernel ratio decreased with increasing kernel size when popped in a microwave oven. Specific gravity of kernels had a significant effect on expansion volume and flake size, but not on unpopped kernel ratio. Expansion volume increased with increasing specific gravity. Flake size increased up to specific gravity of 1.350 to 1.370 and then levelled off. Pericarp thickness was also reported to be affecting the popping qualities of grain (Helm and Zuber 1972; Hoseney *et al.,* 1983; Mohamed *et al.,* 1993) as pericarp in grain acts as barrier to the vapor pressure developed inside the grain due to volumetric heating, so that when a sufficient pressure developed inside the kernel, it releases suddenly resulting expansion of the endosperm. Pordesimo *et al.* (1990) quantified horny and floury endosperm in popcorn and their effects on popping performance in a microwave Oven. According to them, the amounts of horny and floury endosperm in popcorn kernels, as indicated by their measured areas over median longitudinal sections parallel and perpendicular to the face of the kernels (lateral and sagittal sections, respectively) were measured using a technique combining photography and planimetry. They observed the horny endosperm measured over the sagittal section was correlated positively with unpopped kernel ratio. Measurements from the lateral section were found to have better correlation with expansion volume. Expansion volume increased with decreasing area of floury endosperm. The same trend was found relative to the floury/horny endosperm ratio. Since, the floury endosperm envelopes the germ, a larger germ area measured over the lateral section indicated a more symmetrical orientation of the floury endosperm within the popcorn kernel. Further, expansion volume increased with increasing germ area.

The optimum ingredients concentration and microwave power for popcorn with lowest bulk density and maximum percentage of popped kernels and expansion index were 10% hydrogenated oil, 2% butter, 0.5% sodium chloride and 70% power (Singh and Singh, 1999). Higher levels of sodium chloride in the absence of hydrogenated oil show positive effect on quality of popcorn. The effect of microwave processing parameters on popping quality of popcorn were reported by Singh and Singh (1999), showed that bulk density increased with the increase in power level and maximum popped kernels were achieved at 70% power. Contrarily, percent popped kernels increased with the increase in power level in the absence of any ingredient. An increase in microwave heating power from 70% to 90% without addition of any ingredient increased percent popped kernels from 39% to 50%. They also suggested a coating system for maximum popping expansion of popcorn in a domestic microwave oven (Fig 2). In microwave oven popping temperature is affected by power used and power absorption by the kernels which in turn depend upon the dielectric and thermo-physical properties of the coating material (Buffler, 1992).

Method of popping is another important parameter and environment inside the popper regulates the popping characteristics of the popcorn. Quinn et al. (2004) designed an apparatus, shown in Fig 3 to yield popped kernels with an increased volume by lowering the surrounding pressure in the pot. They started with a standard pressure cooker and altered it to include a vacuum pump used to remove the air and hence, lower the pressure in the pot. A thermocouple connected to a thermometer and a pressure gauge was included to allow measurements of the temperature and pressure inside the pot. The temperature of the pot was controlled with a heating pad attached to the bottom of the pot. A shut-off valve was built into the apparatus, allowing us to break the vacuum seal once the experiment was completed. The popcorn popped in the bottom of the pot with oil and observed that size can be controlled by changing the surrounding pressure and that reducing the pressure lowered the un-popped number of kernels by a factor of 5. Many researchers had studied popping of corn in hot air popper and oil popper in their experiments or with some modifications (Metzger *et al.*, 1989; Shimoni *et al.*, 2002) and reported that hot air popping produced popcorn of higher popping volume. There are currently different methods for popping popcorn, but in general, popcorn is popped better in conventional methods than microwave oven (Dofing *et al.*, 1990). On the other hand, the number of household that has a microwave oven has increased in recent years and microwave popcorn has become very popular among consumers (Gokmen, 2004). However, there are some problems such as low expansion and a large number of un-popped kernels associated with microwave popping. Although many studies have evaluated the poppability in hot-air and oil poppers, not much published data is available on the popping performance in a microwave oven.

5.3 Popped Sorghum

Popped sorghum is a very popular, traditional snack food in central India. Popped grains mixed with oil and spice or sweetened are popular snack foods. It can also be used in weaning food formulations and as ready-to-eat products (Thorat *et al.,* 1988). Popped sorghum had been well utilized during festival times; usually laddus are prepared out of popped sorghum grains. Popped sorghum is a very popular, traditional snack food in central India. Popped grains mixed with oil and spice or sweetened are popular snack foods. It can also be used in weaning food formulations and as ready-to-eat products (Thorat *et al.,* 1988). Popped sorghum had been well utilized during festival times; usually laddus are prepared out of popped sorghum grains.

Structural changes took place in sorghum starch when popped and the process of popping changed the starch granules into thin lattices of inter-connecting sheets. Whereas, protein bodies remained intact but protein surrounding individual starch granule disrupted (Harbers, 1975). Varietal difference in sorghum grain had significant effect on popping characteristics of during conventional method of popping as well as in microwave popping (Gundboudi, 2006). Thirty six pop sorghum germplasm accessions maintained at the ICRISAT center were screened for superior pop sorghum (Murty *et al.,* 1982). Most suitable pop sorghums for popping exhibited small grain size, white colour, medium thick pericarp, breaking strength of about 7 kg, hard endosperm and a very low germ/endosperm size ratio. Gupta et al. (1995) studied effect of storage conditions on popping quality of sorghum var. 'Gwalior White', stored at 50 to 80±3% relative humidities at 24±8°C for 6 to 12 months. Samples stored at 80±3% RH showed the highest popping, popping volume, expansion volume, flake size and organoleptic qualities.

Researchers have reported that the composition of the sorghum grain such as amylose content, protein content, moisture content and physical parameters such as grain size, thousand grain weight, bulk density, hardness affects the popping quality of both in conventional and microwave popped products (Murthy *et al.,* 1983; Thorat *et al.,* 1988; Anonymous 2002; Gaul and Rayas-Duarte, 2008). Recently ready-to-eat (RTE) foods were developed (Pawar *et al.,* 2014) with high temperature short time (HTST) microwave puffing process. Cold extruded dough sheet pieces prepared from sorghum and soy powder in the proportion 90:10 were steam cooked and then puffed in microwave oven setup using central composite -

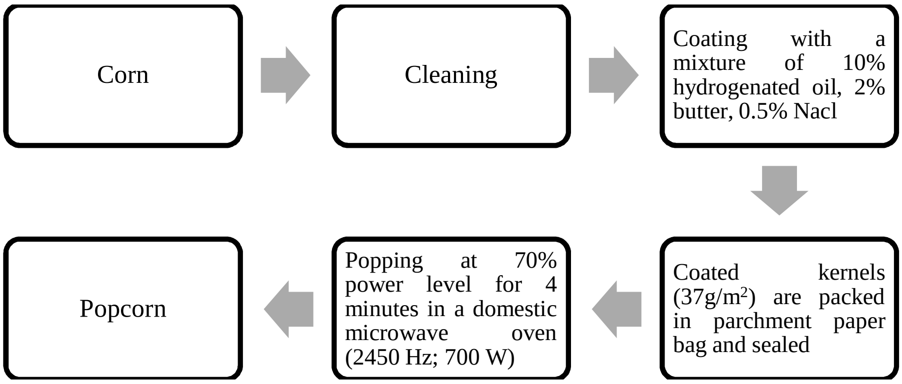

Fig 2: Process flowchart of popcorn making by using coating system in a domestic microwave oven (Singh and Singh, 1999).

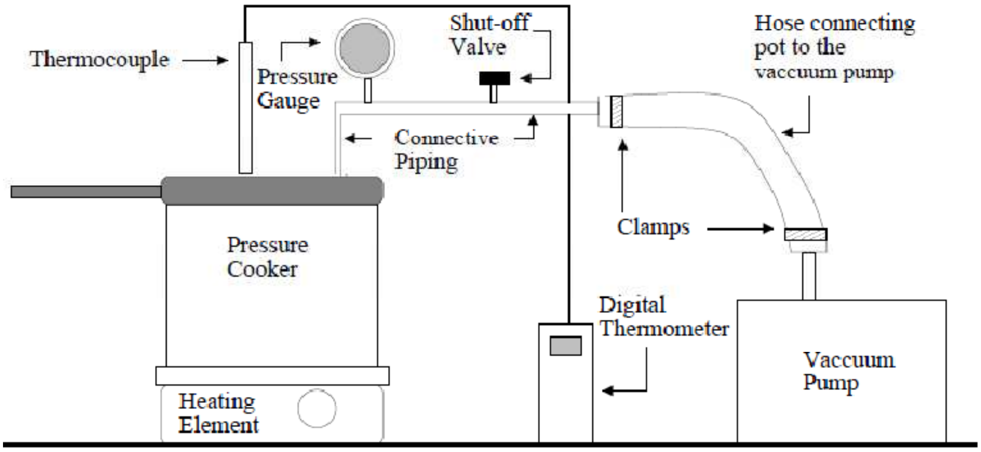

Fig 3: Schematic of the apparatus used to pop the kernels in pot designed by Quinn *et al.* (2004)

rotatable design (CCRD). The optimal product quality were obtained at the optimal process condition as convective heating at 210 °C for 240 s followed by microwave heating with 80 % of total power of 1350 W for 60 s having moisture content of 0.2374 kg/kg dm, hardness 1620.7 g crispiness 21(+ve picks) and expansion ratio 2.0416.

Most of the research showed that most suitable sorghum for popping exhibited small grain size, breaking strength of about 7 kg, hard endosperm, higher specific gravity and high amylose content. Moisture is a critical factor for popping quality of sorghum cultivars of all genotypes. 12% (w.b) level of grain moisture is suitable for popping of the sorghum genotypes for getting highest popping percentage (70.19%), the highest popping volume (122.33 ml) and the highest expansion volume (12.33 ml/g) (Khedker *et al.*, 2008). Pre-treatments such as salt and oil treatment can significantly increase the popping ratio and expansion volume (Young *et al.*, 1993). However, Gaul and Rayas-Duarte (2008) reported tempering to 17% (wb) moisture content increased the popped volume of the grains in their study and according to the recent research, it was found that in microwave popping method of sorghum at 21% (wb) moisture content produced higher popping yield, expansion ratio and flake size (Sharma *et al.*, 2014).

Popping quality of sorghum processed by different methods differed significantly. Popping by dry heat, moist grain and dry heat and oil as heating -

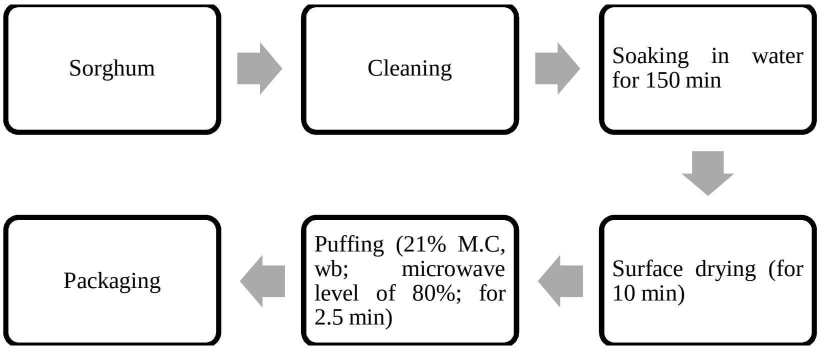

Fig 4: Process flow chart of pop sorghum making (Sharma *et al.,* 2014)

media showed the highest popping yield, whereas it was only 60% in microwave oven (Yenagi, 2005). Expansion ratio of popped grain was significantly high in dry heat popping and low in microwave method. Flake size of popped grain was the highest in moist grain and the lowest in microwave. Moreover, moisture conditioning of sorghum grain prior to popping in a microwave oven gave higher popping yield up to 83%, expansion ratio of 4.4 ad flake size of 0.18 ml/grain (Sharma *et al.,* 2014). Though there are many researches showing the factors affecting the popping quality of sorghum and popping methods for production of better quality pop sorghum, however, very few researches have demonstrated the processing conditions affecting the popping quality of sorghum and the optimized process conditions for production of superior quality pop sorghum. Sharma *et al.* (2014) reported that at 21% (wb) moisture content 100 percent power level for 3 min produced highest puffing yield (89%), expansion volume (8.67) and flake size (0.28). They also standardized the process of popping of sorghum grain using a domestic microwave oven (Fig 4).

5.4 Other Popped and Puffed Cereals

Unlike maize and paddy, other cereals such as wheat, ragi, barley, Amarnath seed, Buck wheat, Kamut, foxtail millet, barnyard millet, proso millet, kodo millet etc are also popped or puffed for making breakfast cereals and also are nutritious.

Malleshi and Desikachar (1981) studied the optimal conditions for puffing of ragi which were moistening to 19% moisture and equilibration for 4 h, followed by puffing in sand to 270°C. Wide varietal variation has been found in the puffing quality, among the fourteen varieties studied. No consistent relationship was observed between the grain in amylose, protein content or thickness of bran with puffing quality. ‘Purna’, ‘Annapurna’, ‘Shakti’, ‘P.R.202’ and ‘Indaf-3’ possessed good puffing quality. Moreover, a wide variation in yield as well as volume expansion of popped grains was observed. The yield of popped grains varied from 47 and 94% whereas expansion volume ranged between 4.8 to 11.6 ml/g (Malleshi and Desikachar, 1981). Foxtail millet, finger millet, barnyard millet and proso millet can also be popped, and out of all the highest popping yield (92.77%) and expansion volume (6.51) were observed for proso millet followed by finger millet, foxtail millet and barnyard millet (Srivastava and Batra, 1998). The popping quality of some high yielding and local varieties of minor millets, viz., Bargu, Haraka, Navane, Savi and Udalu was reported by Kulkarni (1990). By considering the completely popped percentage and expansion ratio, he found that Harak was the best among the millets varieties followed by Savi variety. However, millets Baragu, Navane and Udalu varieties were least poppers.

Novel process for ready to eat (RTE) foods based on minor millet like barnyard millet, finger millet and tubers like potato and sweet potato was developed using microwave puffing method by Dhumal *et al*. (2014) employing response surface methodology. They reported that the estimated shelf life of the final product based on accelerated storage studies at 95% relative humidity and 40 °C could be of one month, while the product could be well stored for 2 months in 65% RH and 6 months in 35% RH at 30 °C, after packing in 150 g metalized polyester. The soy fortified wheat based flat cold extrudate, after requisite steaming, was puffed in hot air using the HTST whirling bed puffing system (Pardeshi *et al.,* 2014a). The product temperature attained by wheat-soy snack foods was about 110-111 °C to initiate puffing effect at all the puffing temperatures while the puffing time required to initiate puffing reduced from 20 s at 200 °C to 10 s at 240 °C. Further they reported that the average material temperature attained for wheat-soy snack foods to reach the optimum puffing effect reduced with increase in puffing air temperature. The experiments were carried out by Pardeshi *et al*. (2014b) to prepare wheat-soy snack food with maximum soy fortification up to 7.5 % in refined wheat flour. The cold extrudates prepared by adding 0.5384 kg/kg dm initial moisture content to heat-soy composite flour could be optimally steamed at 70 kPa for 10.75 min and puffed in whirling bed hot air high temperature short time (HTST) puffing system at 215 °C for 30 s. However, the higher moisture content of the puffed samples required further oven toasting at temperature of 113 °C for 27 min yielding wheat-soy ready-to-eat snack food having moisture content of 0.0457 kg/kg dry matter, colour (L-value) of 56.54, crispness of 18.00 and hardness of 930.20 g.

Research report on popping of amarnath seeds showed that maximum expansion volume can be obtained by popping of seeds having initial moisture content of 16% (wb) when popped with hot air of 260°C for 15 s, whereas heating by superheated steam decreased the volume slightly (Konishi *et al.,* 2004). Popping of amaranth seeds was influenced not only by moisture content of the seeds, but also the by the moisture in the heating media. Similar results were reported by Iyota *et al.* (2005). Effect of varietal difference on popping characteristics of grain amaranthus was studied by Bhuvaneshwari (1995) showed the expansion ratio and popping number was higher in variety IC-42258-1 (4.6 and 61.66 per cent, respectively) whereas the variety R-104-1-1 showed lower expansion ratio and popping number (4.2 and 52.33 per cent, respectively). Beside these, naked barley, which have exceptional nutritional value for humans can be puffed after preprocessing of the grain such as grinding and polishing (Hoke et al. 2007).

6. Conclusion

Popping is a simple and less expensive processing method which improves textural and sensory qualities of cereals and also there are minimum changes with respect to nutrient composition in the processed product. Traditionally, popped products are prepared only during few specific occasions. This type of home processed ready-to-eat snacks has a great market potential as value added health products, convenient food, as consumer needs are changing towards more convenient foods as well as less refined or polished grains. The present review concludes that there is a need to optimize processing methods and factors which governs the popping characteristics of different cereal grains in order to get high popping yield, less un-popped kernels and higher expansion volume. Popped and puffed cereals are Ready-To-Eat whole cereal food. Hence, further needs to be assessed for micronutrients availability, dietary fiber content and in vitro protein and carbohydrate digestibility, to develop value added health foods to meet the community nutritional problems. There is also need for technology development for popping and puffing of different cereals and puff-able non grains to accomplish the target of achieving consumer satisfaction, such as microwave popping, fluidized bed puffing etc.

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