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Effect of extrusion on physical and functional properties of millet based extrudates: A review

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Abstract

The aim of this review is to highlight the effect of extrusion on physical and functional properties of millet based extrudates. Extrusion is a combined thermo-mechanical process which causes gelatinization, breakdowns complex starch and protein structure of the food in short span of time. Merely changing the process conditions of the feed composition and moisture content, the cooking temperature along the extruder and the die and screw speed gives a variety of desired product. Various researchers have formulated different millet-based extruded snacks using pearl millet, finger millet, foxtail millet, kodo millet and sorghum and/or supplementation of major cereals and pulses. The studies shows the significant effect of machine and material parameters on physical and functional properties of extrudates including, expansion ratio, bulk density, water solubility index, water absorption index and specific length.

Keywords: Extrusion, millet, physical property, WAI, WSI, bulk density, expansion ratio

Introduction

Millet is the oldest food known to mankind & possibly the first cereal grain to be used for domestic purposes. Millets are small-grained grasses that include proso millet (*Panicum miliaceum*), foxtail millet (*Setaria italica*), Japanese barnyard millet (*Echinochloa frumentacea*), finger millet (*Eleusine coracana*), kodo millet (*Paspalum scrobiculatum*) (Ahmed S.M. *et al.*, 2013; Michaelraj and Shanmugam, 2013) [2, 35] browntop millet (*Urochloa ramosa*) (Nagaraju *et al.*, 2020) [34] which are cultivated around the world. In the world small millets are popularly grown with an area of 31.24 million hectare with an annual production of 28.46 million tons. India's contribution is much in millet production among other countries; the year 2017 witnessed a record millet production of 11.56 million tons with an area of 9.1 million hectare (Nagaraju *et al.*, 2020) [34]. In recent years, millets are gaining importance in the worldwide because of their abundant nutritional values in terms of dietary fiber and low glycemic index (GI) value (Singh KP *et al.*, 2012) [48]. Millets can also be good substitute to rice and wheat because of their higher nutritional values (Ahmed S.M. *et al.*, 2013) [2]. Inclusion of millets in extrusion reduces readily digestible carbohydrates and slowly digestible carbohydrates (Brennan *et al.*, 2012) [12].

Extrusion processing is an advanced technology used in food processing industries becoming more popular for cereal snacks, baby foods, pasta and pet food manufacturing where, starchy and protein rich raw materials are being utilized (Hongyuan and Alan, 2010; Fili *et al.*, 2010; David *et al.*, 2017) [23, 27, 16]. Extrusion cooking is a thermo-mechanical process exhibits many advantages, the major one being that the feeding ingredients undergo a number of physiochemical and biochemical unit operations like mixing, kneading, shearing, shaping, cooking, forming, drying (Hongyuan and Alan, 2010) [27] and other distinct advantage is that the gelatinization of starch, destruction of microorganism, aflatoxin, inactivation of anti-nutrients, tannins (Nibedita and Sukumar, 2003; Saalia FK and Phillips RD, 2011; Liang *et al.*, 2012) [37, 44, 31] and increase in the fiber digestibility in a single energy efficient and rapid process (Stanley, 1986; Singh *et al.*, 2007) [52, 50]. The biggest challenge for food processing industries in improving consumer's health is to maintain and increase the bioavailability of nutrients of the final product. Extrusion cooking is a high temperature, high pressure and short time process where desired quality and abundance of shapes and textured extrudate products obtained by merely changing the raw materials, processing conditions like controlling of feed moisture, regulating operating temperature and speed of the screw and/or extruder die (Patil *et al.*, 2005; Alam *et al.*, 2016) [41, 4]. Various researchers have formulated different millet-based extruded snacks using millets like pearl millet, finger millet, foxtail, kodo millet and sorghum with and without supplementation of cereals and pulses.

Likewise a number of studies have also been carried out for measuring the various physical characteristics such as expansion ratio, rehydration ratio, water solubility index, water absorption index, bulk density, true density, and porosity. In all studies, the influence of different extrusion process variables on these properties was determined. The influence of process variables on physical properties have been shown to be generally significant in most studies.

Effect of extrusion cooking on some physical properties of millet extrudates like Expansion ratio (ER), Mass flow rate (MFR), Bulk density (BD), Water solubility index (WSI), Water absorption index (WAI) and Specific length (SL) of millet based extrudates is covered in this review.

Processing of Raw Feed Materials

All raw materials namely Sorghum, Pearl millet, Finger millet, Foxtail millet, Proso millet, Kodo millet, Corn, Rice, chickpea, soybean, Bengal gram are cleaned, washed, dried and milled separately in attrition/ hammer mill/laboratory disc mill to get the flour. Raw materials can also be subjected to different conventional pre-treatments such as soaking, sprouting, thermal treatment, enzyme application, irradiation, fermentation and preconditioning before milling into flour (Sharmila and Athmaselvi, 2017) [46]. The flour is sieved separately by passing through a desired sieve such as 0.05mm, 0.15mm, 0.88mm and 2.5mm sieves (M. Yusuf *et al.*, 2018; Filli *et al.*, 2010; Geetha *et al.*, 2016; Dayakar *et al.*, 2018) [55, 23, 24, 9] and the underflow is used for further research work. The grounded flour can be fried at predestined time-and-temperature and allowed to cool at ambient (Deshpande and Poshadri, 2011) [18].

Preparation of blend

Blends are chosen based on the preliminary tests without the jamming of extruder screw inside the extruder barrel and for acceptable product's physical and textural characteristics as well as better nutritive value in the final product (Geetha *et al.*, 2016) [24]. The raw materials are used in various combinations and are mixed at various dry-to-dry basis (Harshanti and Abubakr, 2014; Geetha *et al.*, 2016) [26, 24]. To achieve the desired total moisture content of the blend calculated amount of water is added/removed and conditioned to equilibrate for 24h at room temperature. Mixer or ribbon blenders are employed for uniform mixing of the blend. Products of different shapes, textures, colors, and appearances may be produced by altering raw material mix, equipment assembly and operating parameters (Riaz, 2000) [42].

4. Physical Properties

Physical properties such as bulk density, true density, moisture content, water absorption index, water solubility indexes, expansion index and viscosity of the dough and/or extrudate are important parameters. These physical properties play an important role in selecting extruded food for a particular application.

4.1 Mass Flow Rate

The mass flow rate (g/s) can be defined as the rate at which the mass of extrudates exits from the die for specific period of time. The extrudates are collected in a container and weighed instantly after cooling to ambient temperature (Singh *et al.*, 1996) [49]. It gives the knowledge of production rate of extrudates. The constant maintenance of barrel temperature may reduce the variations in the mass flow rate of extrudate samples (Deshpande & Poshadri *et al.*, 2011; Geetha *et al.*,

2016) [18, 24]. It can be calculated by using the equation (1a) & (1b) (Oke *et al.*, 2012) [39] as follows:

$$\text{Mass flow rate (g/s)} = \frac{\text{Weight (g)}}{\text{Time (s)}} \quad (1a)$$

$$M_f = M_p \left(\frac{1-MC_f}{1-MC_i} \right) \quad (1b)$$

Where,

M_f = Mass flow rate of the feed (g/min)

M_p = Mass flow rate of the extrudate (g/min)

MC_i = Moisture content of the feed (% wb)

MC_f = Moisture content of the extrudate (% wb)

4.2 Expansion Ratio

Expansion is an important physical parameter of the snack food. It may be described as degree of puffing by the sample as it exits the extruder. Starch plays a major role during expansion process (Kokini *et al.*, 1992) [28]. Expansion may be a function of viscosity and elasticity of dough governed by ratio of starch, protein and fiber. The more the starch contents of the extrudates the more the expansion (Linko *et al.*, 1981) [32] but the more the protein the less the expansion (Faubion *et al.*, 1982; Adesina *et al.*, 1998; N Lakshmi *et al.*, 2012) [22, 1, 36]. Expansion ratio is measured by ratio of diameter of extrudate to that of the die hole (Fan *et al.*, 1996; Ainsworth *et al.*, 2006) [21, 1, 36] as shown in the Eq. (2a).

$$\text{Expansion ratio} = \frac{\text{Diameter of extrudate}}{\text{Diameter of die hole}} \quad (2a)$$

The sectional expansion ratio (ER) for the extrudates may also calculated by dividing the square of extrudate diameter (d) by the square of die diameter (d_{die}) as shown in Eq. (2b) (de Mesa *et al.*, 2009) [17].

$$ER = \frac{d^2}{d_{die}^2} \quad (2b)$$

The extruded product expansion increases with increase in the level of feed moisture content and screw speed, as adequate water available for expansion of the extrudate. Water present in dough inside the extruder acts as a heat sink/trap and lubricant as well as reduces shear strength (Geetha *et al.*, 2016) [24]. Barrel and die head temperature have significant effect on sectional expansion of kodo based extrudates (Azam and Singh, 2017) [8]. Water may also acts as a binding material, which binds with starch and fiber to undergo transition during extrusion. Besides, it facilitates the deformation of the blend and influence expansion (Shalini *et al.*, 2015) [45]. Sudden change in state of high pressure to atmospheric pressure causes expansion of extrudate and leads to a flash-off of internal moisture and water vapor pressure, which is nucleated to form a bubble in molten extrudate (Emmanuel *et al.*, 2004) [20]. Expansion ratio of extrudates decreases with increase in temperature. Decrease in expansion at higher temperatures may attribute to increase dextrinization and weakening of structure (Lozou *et al.*, 2007) [30]. Expansion ratio of dehulled finger millet grain extrudates is higher than that of regular (unhulled) finger millet grain extrudates (Divate *et al.*, 2015) [7]. Optimum blend composition when subjected to favorable moisture and temperature may contribute to higher Expansion ratio (Chakraborty *et al.*, 2009; Sharmila and Athmaselvi, 2017) [14, 46]. Sectional expansion of extrudates decreases with increase

in the level of soybean in the feed composition (Yatin *et al.*, 2015) [54], little millet flour (Raviraj and Kailash, 2018) [42]. Bulk density may inversely relate to the expansion ratio (Divate *et al.*, 2015) [7]. There may be no significant difference ($P > 0.05$) among the expansion rates of extrudates from the different sorghum varieties (Byaruhanga, *et al.*, 2014) [13]. However, Zamre *et al.*, (2012) [56] reports lesser expansion rates for sorghum based extruded products. This difference may attribute to the varietal differences.

4.3 Bulk density

Bulk density (g/cm^3) can be defined as the heaviness of a food material; it represents the porous structure (Oladele and Aina, 2007) [40]. Bulk density of extrudate is a major parameter considered by the food industries in production of ready to eat (RTE) foods as well as in designing their packaging requirement. The overall expansion of an extruded food product can be revealed by bulk density.

Different methods are adopted by researchers to determine the bulk density of extrudates. The bulk density may be calculated by measuring the actual dimensions of the extrudates (Chinnaswamy *et al.*, 1986). A digital vernier caliper with least count of 0.1 mm is used for measuring the diameter and length of the extrudates (Geetha *et al.*, 2016; Tiwari, 2011) [24]. The weight per unit length of extrudate is determined by weighing measured lengths (about 1 cm). The following equation (3a) is used for calculation of BD.

$$\text{Bulk density} = \frac{4m}{\pi d^2 L} \quad (3a)$$

Where, 'm' is the mass (g) of the extruded product, 'L' & 'd' are the length (cm) and diameter (cm) of the extrudate. It may also be calculated by a simple method called tapping. In a graduated measuring cylinder (100 ml), weighed samples of 5 to 8 cm long piece of extrudate are poured and tapped for the complete settlement. Mass of the 100ml samples is weighed (Bhople S and Singh M, 2017) [11]. The mass of 40-60 mesh powdered extrudate sample is poured into measuring cylinder to known volume (Patil *et al.*, 2005) [41]. The following equation (3b) is used for calculation of BD.

$$\text{Bulk density} = \frac{\text{weight of sample (g)}}{\text{volume of sample (ml)}} \quad (3b)$$

At lower temperature and screw speed bulk density may be higher, as the temperature and screw speed increase results in minimum BD at constant moisture content. The higher bulk density might be due to the presence of more crude fiber (Geetha *et al.*, 2016; Dayakar *et al.*, 2018) [24, 9]. The effect feed moisture on bulk density may found to be complex. The increasing feed moisture may results in increased BD (Filli *et al.*, 2010; Yatin *et al.*, 2015) [23, 54], Nishani *et al.*, 2017 [38], reports that feed moisture content of the finger millet flours may have a decreasing effect on the bulk density. This may be due to extrusion cooking is not enough to vaporize the moisture and leading to retention of moisture in the extrudates (Sharmila and Athmaselvi, 2017) [46] coming out of the die head, resulting in higher pressure differential leading to higher expansion and thus lesser bulk density (Nishani *et al.*, 2017) [38]. Higher barrel temperatures enhance extrudates exiting the die lose more moisture and become lighter in weight (Koksel *et al.*, 2004) [29]. Bulk density increase with increase in level of little millet flour (Raviraj and Kailash, 2018) [42], finger millet flour and temperature may be due to the presence of fiber particles tending to rupture the cell walls

before the gas bubbles expand (Divate *et al.*, 2015; Lue *et al.*, 1991) [7], partially molten starch granules adheres to the cellulosic walls, leads to formation of complex wall of cellulose, gelatinization of starch and cellular protein may restrict the expansion of product (Divate *et al.*, 2015; Chang *et al.*, 1998) [7, 15]. Varietal differences may show significant effect on the bulk density of extrudates (David *et al.*, 2017) [16].

4.4 Water Solubility Index (WSI) and Water Absorption Index (WAI)

Water Solubility Index and Water Absorption Index are critical quality characteristics considered for any extruded snack product. WSI and WAI may effects on hydration properties of such products (Sharmila and Athmaselvi, 2017) [46], because it is consumed in form of gruel (K. B. Filli *et al.*, 2010). The WSI and WAI can be measured according to a technique developed for cereals (Anderson *et al.*, 1969; Beuchat 1977) [6, 10]. The extrudates are grounded to a mean particle size of 0.2-0.25 mm. A sample of 2.5 g is dispersed in 25 ml distilled water for 30 min at ambient in the former where as in the latter One gram (1g) of sample is mixed with 10 ml distilled water for 30 sec in a centrifuge tube. A magnetic stirrer or glass rod can be used to break up lumps. Then the dispersion is centrifuged at 3000 rpm for 15 min. Latter, the samples are kept at 25 °C for 30 min and may centrifuge at 20000-25000 rpm for 30 min. The supernatant is decanted into an evaporating dish with a known weight. The WSI may be described as the weight of dry solids present in the supernatant. It can be expressed as a percentage of the original weight of sample. WAI be described as the weight of gel obtained after removal of the supernatant per unit weight of original dry solids. The following equations (4a) and (4b) can be used to estimate WSI and WAI.

$$\text{WSI} \left(\frac{g}{g} \right) = \frac{\text{Weight of dissolved solids in supernatant (g)}}{\text{Weight of dry solids (g)}} \quad (4a)$$

$$\text{WAI}(\%) = \frac{\text{Weight of wet sediments (g)}}{\text{Initial weight of dry solids (g)}} \times 100 \quad (4b)$$

WSI indicates degradation of molecular components. The amount of soluble polysaccharide released from the molecular starch component after extrusion can be measured by WSI (Ding *et al.*, 2005) [19]. The WSI of the extrudates increases with the Bengal gram flour incorporation from 10 to 30% in the composite flour (Geetha *et al.*, 2016) [24]. The water solubility index increased with increase in feed moisture. The varietal differences and the variation in the feed moisture of various sorghum extrudates may have significant difference in the WSI (David *et al.*, 2017) [16].

The amount of water absorbed by starch for gelatinization can be measured by WAI. The barrel temperature and feed moisture enhance the gelatinization of starch which may greatly effects on WAI of the extrudate (Ding *et al.*, 2005) [19], higher damage of starch may results in higher WAI during extrusion processing (Sharmila and Athmaselvi, 2017) [46]. Increase in level of feed moisture content may increase the WAI and expansion of extrudate; it may be due to the moisture content acts as a plasticizer during extrusion cooking, reduces the degradation of starch granule and results in increased capacity for water absorption (Hagenimana *et al.*, 2006; Geetha *et al.*, 2016) [25, 24]. The high value of water absorption may attribute to lose structure of starch polymers while low value water absorption capacity to the compactness of molecular structure (Sodipo, 2018) [51].

4.5 Specific Length (SL)

Specific length (mm/g) can be described as length per unit mass of the extrudate. The average length as well as average weight of randomly selected three samples is measured for determining specific length. Specific length aids in understanding the longitudinal expansion of the extrudate. The specific length of extrudates increases with increase in feed moisture and feed rate (Yatin *et al.*, 2015)^[54] is in contrast with findings of Singh *et al.* (2006)^[47] who processed Bengal gram brokens and sorghum in extruder reports that specific length increases with decrease in moisture followed by temperature.

5. Conclusion

Extrusion machine and feed material parameters significantly effect on physical and functional properties of extruded products. It is concluded that the extrusion parameters have complex effect on sectional expansion, WAI and WSI, bulk density and specific length of extruded snacks.

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