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Effect of extrusion cooking on physical properties: A review

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Abstract
Extrusion cooking is very important process in food snacks industries to produce the wide range of products. During extrusion cooking, modification in the structure of raw materials such as starch gelatinization, protein denaturation, complex formation between amylose and lipids, degradation reactions of vitamins, pigments etc occurred. Small variations in processing conditions affect process variables and product quality. Extruded snack product's quality depends on type of extruder, screw configuration, feed moisture, screw speed, feed rate and operational temperature. Effect of extrusion cooking on physical properties covered in this review. Observations found by many researchers that bulk density of extrudates increased with moisture content and feed blends and decreased with increase in temperature. Barrel temperature, feed moisture and blend ratio showed the significant effect on sectional expansion index, specific length, WAI and WSI of extrudates. It was concluded that physical properties of extrudates varied by operational conditions of extruder and process parameters.

Keywords: Extrusion cooking, Blend ratio, Operational parameters, Physical properties

1. Introduction

Extrusion cooking technology is an advanced food processing technique, adopted by food industries. Maintaining and increasing the bioavailability of nutrients during the processing of food is a major challenge for food industries for improving consumer's health. It is an important research area in extrusion technology field (Singh *et al.,* 2007) [18]. Variety of extruded products such as baby foods, breakfast cereals, pasta, pet foods and snacks foods produced by extrusion cooking (Filli *et al.,* 2012) [8]. Snack foods are very much popular particularly in children for their taste. These extruded snacks accepted by many individuals in their diet for significant nutritional values (Da Silva *et al.,* 2014) [6]. The advantages of extrusion cooking with respect to the nutritional content of the final product are the inactivation of antinutrients, destruction of aflatoxin and increase the digestibility of fibre (Saalia FK and Phillips RD, 2011; Singh *et al.,* 2007) [17, 18].

Extrusion cooking is a thermo-mechanical shear process (Alam *et al.,* 2016) [1]. Several unit operations involved in food extrusion cooking process such as conveying, kneading, heating, mixing and forming (Kehinde *et al.,* 2016) [14] to prepare extruded snacks. It is done in extrusion cooker called extruder which operates at high temperature, high pressure for short period of time. Desired quality of extrudates obtained by controlling feed moisture through pre-conditioning of feed and regulating the operating temperature under shear forces, which cause for physical and biochemical modifications in raw materials (Alam *et al.,* 2016; Patil *et al.,* 2005) [1, 16]. Effect of extrusion cooking on some physical properties is covered in this review.

2. Role of Pre-Conditioning of Raw Feed Materials before Extrusion

Moisture content of feed material is an important parameter to obtain the best quality final product. It is achieved by preconditioning of raw feed materials. Pre-conditioning helps to enhances extrusion process. It is the process of moisture management in which adjusting the moisture in feed up to the desire level by addition/ removal of water. It is done prior to extrusion. Firstly, initial moisture of ingredients must be estimated. Then all samples are properly stored for 24 h at room temperature. Requirement of water addition/ removal can be estimated by the following formula (Kanojia V and Singh M, 2016) [13]:

$$W_w = W_d \; X \frac{M_2 \; - M_1}{(1 - M_1)(1 - M_2)}$$

Where, W_w = Amount of water to be added, W_d = Bone dry weight of raw flour, M_1 = Initial moisture content of flour (% wb in decimal), M_2 = Desired moisture content of flour (% wb in decimal).

3. Physical Properties
The suitability of extruded foods for a particular application depends on their physical properties such as bulk density, water absorption index, water solubility indexes, expansion index and viscosity of the dough (Hernandez- Diaz *et al.,* 2007) [10].

4. Bulk density
Bulk density of extruded product represents the pores structure and voids space developed with change in structure. The overall expansion of product also revealed by bulk density. Bulk density can be defined as the mass of sample per unit bulk volume. Bulk volume means volume including void spaces. There are several methods adopted by researchers to calculate the bulk density of extrudates.

It is also calculated by the simple method i.e. tapping. In this method, weighed samples of 5 to 8 cm long piece of extrudate are poured in the graduated measuring cylinder of capacity 100 ml and tapped them till the complete settlement. Allow to settle samples inside the cylinder. Then weigh the mass of 100ml samples (Bhople S and Singh M, 2017) [4]. The another simple method for measuring the bulk density of extrudates by calculating the mass of 40-60 mesh powdered extrudate sample into measuring cylinder to known volume (Patil *et al.,* 2005) [16]. Bulk density can be calculated by the following formula:

$$Bulk\ density = \frac{Weight\ of\ sample, g}{Volume\ of\ sample, ml}$$

It was found that bulk density of whole grain wheat flour based corn grit, rice flour, cocoa and sugar blended expanded breakfast cereals have, increased with feed moisture content (Wójtowicz *et al.,* 2015) [21]. Higher bulk densities observed with higher concentration of NDM in modified corn-starch based non-fat dry milk powder (NDM) expanded snacks (Tonya Schoenfuss, 2013) [19]. Bulk density of the maize based extruded products increased with an increase in feed moisture and screw speed (Christofides *et al.,* 2004) [5]. Bulk density of extrudates increased with okara level in feed materials (Kanojia V and Singh M, 2016a) [12]. The effect of extrusion temperature on bulk density of corn starch based extruded products and found that it is decreased with increase in temperature (Delgado-Nieblas *et al.,* 2015) [7]. Highest bulk density of pearl millet, sorghum and soybean flour blended extrudates observed at increased level of feed moisture (Yatin *et al.,* 2015) [22].

5. True/Solid density
It is the mass per unit volume (actual) of extrudates, determined by using pycnometer. In this method, 80 mesh ground extrudate a sample is placed in pycnometer cup. Density is estimated by recorded mass and volume of respective sample (Kanojia V and Singh M, 2016) [13].

5. Moisture Content of extrudates
Moisture content of extruded products is the amount of moisture present in the fully puffed extruded snacks after cooled to room temperature. It can be determined by hot air oven method by conventional drying at 103□ until a constant weight is obtained (Kanojia V and Singh M, 2016) [13].

$$Moisture\ Content\ (\%, w.b.) = \frac{(Initial\ mass\ of\ sample - final\ mass\ of\ sample\ )}{Initial\ mass\ of\ sample}\ X100$$

6. Mass Flow Rate of Extrudates (MFR):
Rate at which the mass of the extrudates come out from the die for specific period of time called Mass Flow Rate of extrudates. Its unit is gram per second. It helps to know the production rate of the extrudates. It can be calculated by the following formula (Bhople S and Singh M, 2017) [4]:

$$Mass\ flow\ rate\ (g/sec) = \frac{Mass\ of\ sample\ collected, g}{Time\ taken\ to\ collect\ the\ sample, sec}$$

7. Specific Length (SL)
It is defined as length per unit mass of extrudate. Its unit is mm/g. It is calculated by taken an average length of three samples selected randomly which is measured by dial callipers. This parameter is helpful to know the longitudinal expansion of extrudate to identify the product quality. It can be calculated by the following formula (Bhople S and Singh M, 2017) [4]:

$$Specific\ lenght\ (mm/g) = \frac{lenght\ of\ specimen, mm}{Weight\ of\ specimen, g}$$

Various researchers found the effect of extrusion cooking parameters on specific length. The specific length of pearl Millet, sorghum and soybean flour blended extrudates increased with increase in feed moisture (Yatin *et al.,* 2015) [22]. The effect of okara content on specific length and found that it was decreased with increase in okara content in feed (Kanojia V and Singh M, 2016a) [12] while specific length increases with barrel temperature (Bhople S and Singh M, 2017a) [3]. Highest specific length of extrudates observed at increased level of feed moisture (Yatin *et al.,* 2015) [22].

8. Sectional Expansion Index (SEI)
It is defined as the ratio of diameter of extrudate to diameter of die (Bhople S and Singh M, 2017; Kanojia V and Singh M, 2016; Patil *et al.,* 2005) [4], [13], [16]. Diameter of extrudates is measured by taking the average value of data observed along two mutually orthogonal axis by screw gauge. It is a ratio of two diameters hence expressed as ratio or fraction. It is also a measure of radial expansion and degree of puffing of extrudates. Following expression can be used to estimate the Sectional Expansion Index (SEI):

$$Sectional\ Expansion\ Index\ (SEI) = \left[\frac{Diameter\ of\ extrudate}{Diameter\ of\ Die}\right]^2$$

Decreased level of sectional expansion index of extrudates was obtained with increase in the level of soybean in the feed composition (Yatin *et al.,* 2015) [22]. On the other hand, reduced level of sectional expansion index was showed with high level of okara content in blends observed (Kanojia V and Singh M, 2016a) [12]. Barrel temperature and die head temperature revealed significant effect on sectional expansion index of kodo based extrudates (Azam M and Singh M, 2017) [2].

9. Water Absorption Index (WAI) and Water Solubility Index (WSI)

Water Absorption Index (WAI) is the measure of volume taken by starch polymers, present in extrudates after swelling in excess water. While Water Solubility Index (WSI) is the rate and extent to which amount of powdered materials (polysaccharides) release from the granule, dissolved in the water, it helps to indicate the degradation of molecular components (Kanojia V and Singh M, 2016; Yousf *et al.,* 2017) [13, 23].

For the estimation of water absorption index (WAI), 2.5g ground sample was dispersed in 25 g of distilled water for 30 minutes at 30°C temperature with continuous stirring with glass rod or by using magnetic stirrer to break up any lump and immediately centrifuged at 3000 rpm for 15 minutes. Supernatant liquid through a strainer (pore size = 500µm) was obtained. This liquid was poured carefully in to tared evaporating dish. The supernatant was evaporated in the temperatures range from 90 to 110°C. Then WAI was calculated by taking the weight of gel obtained after removal of the supernatant liquid per gram of solid (Kanojia V and Singh M, 2016; Patil *et al.,* 2005; Yousf *et al.,* 2017) [13, 16, 23]. WAI can be estimated by the following formula:

$$WAI = \frac{Weight\ of\ sediment, g}{Weight\ of\ dry\ solids, g}$$

Water Solubility Index (WSI) can be measured by weight of dissolved particles (200 to 250 μm) of ground extrudates in distilled water. Ground samples were dispersed in water for 30 minutes at 30°C temperature, followed by centrifugation at 3000 rpm for 15 minutes. Supernatant liquid was poured into weighed evaporating dish. After that taken the weight of dissolved solids in the supernatant. WSI can be estimated as the following expression:

$$WSI\ (\%) = \frac{Weight\ of dissolved\ solids\ in\ supernatent, g\ X100}{Weight\ of\ dry\ solids, g}$$

WAI and WSI decreased with increase in the level of fenugreek seed flour (FSF) fenugreek leave powder (FLP) in corn and rice based extrudates (Wani SA and Kumar P, 2015) [20]. WAI of extruded products increased with feed moisture content and WSI reduced in pre-gelatinized rice flour based expanded snacks found (Gat Y and Ananthanarayan L, 2015) [9]. Maximum water absorption index (788) was obtained at 18% moisture content, 170°C die head temperature, 160°C barrel temperature and 100 rpm screw speed found in ashwagandha and spinach flour blended rice based extrudates (Bhople S and Singh M, 2017a) [3]. It was found that water absorption index increased, while water solubility index decreased with increase in moisture (Pardhi *et al.,* 2017) [15]. Screw speed showed the inverse effect on WAI and WSI. WAI decreased with increase in extrusion temperature. WSI increased with increase in moisture content (Kakade *et al.,* 2016) [11]. Highest water solubility index (WSI) and water absorption index were obtained at higher extrusion temperature and lower feed moisture content obtained (Delgado-Nieblas *et al.,* 2015) [7].

10. Conclusion

Extrusion cooking is very much showing the significant effect on the physical properties of extruded products. Various points covered related to effect of extrusion cooking on physical properties of extrudates in this review. It was concluded that bulk density of extrudates increased with moisture content and feed blends and decreased with increase in temperature. Sectional expansion index of extrudates decreased with increase in the level of blends in feed. Significant effect of extrusion temperature, feed moisture and blend ratio showed on sectional expansion index, specific length, WAI and WSI of extruded snacks.

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