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Review Article

A Review on Food Extrusion Its Classification and Quality Attributes

A. Anand[1*], Y. S. Dhaliwal[2] and R. Verma[3]

[1]PhD Scholar, [2]Professor and Dean, [3]Associate Professor

Department of Food Science, Nutrition and Technology

CSK- Himachal Pradesh Agricultural University, Palampur-176062 (India)

*Corresponding Author E-mail: abhaanand23@gmail.com

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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 its types and quality attributes are 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 and functional properties of extrudates varied by operational conditions of extruder and process parameters.

Keywords: *Extrusion, Quality attributes, Screw configuration, Bulk density, Barrel temperature and Parameters*

INTRODUCTION

Proper nutrition involves intake of carbohydrates, fats and proteins at an appropriate level for balancing the body with fiber, vitamins, minerals and energy. As generation changes, globalization increases with consumption of fast food including high calorie food styles. This has brought a drastic change in day-to-day lifestyle with lot behavioural changes towards foods. Change in process technology and methods of agriculture from organic to scientific have brought changes in nutritional values. Due to changes and non-consumption of nutritious food, people are prone to non-communicable diseases, including obesity, diabetes and cancer (Allal et al., 2014). Health and nutrition play a vital role in the society and it also remains as one of the challenging field in this era.

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It is always a necessary fact to monitor the nutritional quality of the food as it directly affects the health of an individual. Processing of food at high temperature remains a challenge in food processing industries as it leads to deterioration of nutritive values in food. In order to avoid this, extrusion cooking is adopted as it has unique features when compared to the other heat process. Extrusion cooking is mostly preferred, as it owes high productivity and significant nutrient retention. This process involves high temperature and short time as food materials are cooked in a tube by the combination of pressure, moisture and mechanical shear resulting in molecular transformation (Shivendra et al., 2007). This high temperature short time process is known as extrusion technology, reduces microbial contamination, inactivates the enzymes as it is one of the methods which supports in the prevention of both cold and hot extruded products with the water activity of 0.1 to 0.4 (Bordoloi and Ganguly, 2014).

The role of shear, temperature, moisture and feed composition are significant in the process of transformation of starch by extrusion. Extrusion cooking is a high-temperature short-time (HTST) process which reduces microbial contamination and inactivates enzymes. The main method of preservation of both hot- and cold-extruded foods is by the low water activity of the product (0.1–0.4), and for semi-moist products in particular, by the packaging materials that are used. The principles of operation in extrusion are similar in all types: raw materials are fed into the extruder barrel and the screw(s) then convey the food along it. Further down the barrel, smaller flights restrict the volume and increase the resistance to movement of the food. As a result, it fills the barrel and the spaces between the screw flights and becomes compressed. As it moves further along the barrel, the screw kneads the material into a semi-solid, plasticized mass. If the food is heated above 100ºC the process is known as extrusion cooking (or hot extrusion).

Here, frictional heat and any additional heating that is used cause the temperature to rise rapidly. The food is then passed to the section of the barrel having the smallest flights, where pressure and shearing is further increased. Finally, it is forced through one or more restricted openings (dies) at the discharge end of the barrel as the food emerges under pressure from the die, it expands to the final shape and cools rapidly as moisture is flashed off as steam. A variety of shapes, including rods, spheres, doughnuts, tubes, strips, squirls or shells can be formed. Typical products include a wide variety of low density, expanded snack foods and ready-to-eat (RTE) puffed cereals. Cold extrusion, in which the temperature of the food remains at ambient is used to mix and shape foods such as pasta and meat products. Low pressure extrusion, at temperatures below 100ºC, is used to produce, for example, liquorice, fish pastes, surimi and pet foods.

TYPES OF EXTRUSION SYSTEM

The use of thermoplastic extrusion in food processing is facilitated by the dynamism of extruders, which can be divided into two types: single-screw and twin-screw extruders (Riaz, 2000). A variety of extruders with different configurations and performances have been developed and they are categorised based on their applications, design and configurations. Extruders are composed of five main parts: (i) the pre-conditioning system; (ii) the feeding system; (iii) the screw or worm; (iv) the barrel; (v) the die and the cutting mechanism. They can vary with respect to screw, barrel and die configuration. The selection of each of these items will depend on the raw material used and the final product desired (Riaz, 2000). The food (melt) is fed at one end of a tubular structure housing the screw. Inside this housing the melt is worked upon to form a semi solid mass. The semi solid mass is forced through a restricted opening (die) at discharge end of the screw. The food comes out expands as it touches the atmosphere. This expansion is because of the bubble growth in the semi solid mass because of the moisture that it contains (Kokini et al., 1992).

The expanded product is the extrudates can be consumed as it is, or after desirous processing. Single-screw extruders are the most common extruders applied in the food industry. The classification of single-screw extruders can be defined based on process or equipment parameters such as moisture content (dry or wet) conditioning, solid or segmented screw, desired degree of shear and heat source. From a practical point of view, the main classification used considers the degree of shear and the heat source (Riaz, 2000). The screw configuration comprises there are screws made up of only one piece or screws of multiple pieces. Twin-screw extruders are composed of two axis that rotate inside a single barrel, usually the internal surface of the barrel of twin-screw extruders is smooth. Depending on the position of the screws and their direction of rotation, four different types of configurations are possible: (i) co-rotating intermeshing screws; (ii) co-rotating non-intermeshing screws; (iii) counter-rotating intermeshing screws; and (iv) counter-rotating non-intermeshing screws. Although intermeshing screws result in greater residence time of the material in the extruder, non-intermeshing screws cause greater degrees of shear, especially if they rotate in opposite directions. However, twin screw type of extruder is little used in the food industry, even though they present more efficient displacement properties (Steel et al., 2012)

Extruder Variables Screw speed, barrel temperature, screw and barrel configuration, die opening and feed rate are some of the parameters that affect the extruded performance. Extruder operation depends on pressure build up in the barrel (prior to exiting the die), slip at the barrel wall (transportation), and the degree of filling. The screw speed is responsible for the rate of shear development and the mean residence time of the feed. The heat dissipation from the mechanical energy input to dough depends on screw speed, which in turn influences dough viscosity. The feed zone temperature must be low to avoid plugging and back flow of material travel down the screw. The barrel temperature has positive effect on the degree of starch gelatinisation and extruded expansion whereas it has a negative effect on product colour especially at elevated temperature. Several studies have indicated that elevated temperature leads to more moisture evaporation when exiting the die and thus results in more expanded products (Muthukumarappan & Karunanithy, 2012). Extruder feed rate depends on the types of screw element, screw speed, type of feeding element and feed moisture. The federate has an influence on residence time, torque requirement, barrel pressure and dough temperature. Feed Ingredient Variables Feed composition, moisture content and particle size have the greatest effect on extrusion. The typical composition of any blend consists of starch, protein, lipid/fat and fiber which contribute the product quality. The starch degradation usually reduces products expansion. The infant and weaning foods have high starch digestibility which is largely dependent on full gelatinisation (Camire, 2000). The lipid levels over 5- 6% acts as a lubricant, reducing the slip within the barrel and resulting in poor product expansion. The fibers are the non interacting component that contributes to low expansion, cohesiveness, durability and water stability. Higher fiber content usually results in high screw wear. The moisture is critical variable that has multiple fractions in starch gelatinization, protein denaturation, barrel lubrication and the final product quality. A dry extruder can process materials with 8- 22% moisture with no additional drying of extrudates. Most extrudates snacks have moisture content between 8-12% and require additional drying to impart desired texture and mouthfeel (Rokey, 2000). General rule of thumb that the extruder feed should not have particles larger than one third the diameter of die holes. Particle size also plays an important role in moisture distribution, heat transfer, viscosity and final product. Quality course ingredient particles have more effect on wear than fine particles. A product composed of fine particles will have good water stability, water absorption index, expansion (Riaz, 2000).

SOURCES OF RAW MATERIAL IN EXTRUSION COOKING

The most used raw materials in the extrusion process are starch and protein based materials.

This technique has been widely used with raw materials such as corn, wheat, rice and soybean. Natural biopolymers of raw materials such as cereals or tuber flours are rich in starch, or oilseed legumes and other protein rich sources. Most commonly used materials are wheat and corn flours, but many other materials are also used such as rice flour, potato, rye, barley, oats, sorghum, cassava, tapioca, buckwheat and pea flour. The protein rich materials such as pressed oilseed cake from soya, sunflower, rape, field bean, faba beans or separated proteins from cereals such as wheat (gluten) (Guy, 2001). Expanded (Ready to Eat) RTE cereals are manufactured from mixtures of cereal flours and starches combined with small amounts of malt, fat, sugars, emulsifiers, and salt. The raw materials in the extrusion cooking processes cover various combinations of ingredients including: cereals, grains and starches, tubers, legumes, oil seeds, cereals as well as animal fat and proteins (Ilo et al., 2000).

The main characteristics of the raw material for extrusion cooking are type of material, moisture content, physical state, chemical composition (quantity and type of starch, proteins, fats and sugars) and pH of the material. Most raw materials used in food extrusion are solid (Steel et al., 2012). The structure of the extruded products may be formed from starch or protein polymers. Most products, such as breakfast cereals, snacks and biscuits are formed from starch, while protein is used to produce products that have meat-like characteristics and that are used either as full or partial replacements for meat in ready meals, dried foods and many pet food products (Guy, 2001). Typical raw materials used in the popular extruded products, each of which offers a wide variety of functions: structure forming, facilitating physical transformation during the extrusion-cooking, affecting the viscosity of the material and its plasticization, facilitating homogeneity of the dough ingredients, accelerating starch melting and gelatinization and improving the taste and colour of products (Moscicki, 2011). Further, ready to eat breakfast was successfully developed using the low amylose rice flour incorporated with seeded banana powder in a single-screw extruder (Borah et al., 2015). Dhumal et al. (2014) developed cold extrudate, microwave puffed and oven toasted low fat ready to eat fasting foods successfully using potato and barnyard millet.

PHYSICAL AND FUNCTIONAL 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).

Expansion ratio (ER)

When moisture content of the feeding material increases, there is decrease in the specific mechanical energy (SME), apparent viscosity, and radial ER during extrusion of maize grits. Parsons et al., (1996) reported a decrease in the ER of corn meal when the extrusion moisture content was increased from 19.5 to 21.5% (w/w). Kokini et al., (1992) and Della Valle et al., (1997) explained a sharp decrease in volumetric expansion with increased moisture content by the shrinkage and collapse of the extrudate after maximum expansion. Most studies recognize that gelatinized starch plays a major role in expansion by providing the gas-holding capacity to the extrudate melt, whereas other ingredients such as proteins, sugars, fats, and fiber act as diluents or dispersed phase fillers that reduce the stretchability of the starchy matrix. Conway (1971) reported that the lower limit of starch content for good expansion in 60-70 % in the ratio of products.

Water hydration (WH) WH capacity

It increased with extrusion temperature and, in general, at any specific extrusion temperature WH decreased with increased moisture content. Higher WH might result from a greater extent of starch gelatinization (McPherson et al., 2000). WH also is greatly affected by the degree of porosity or expansion of the extrudate, as higher porosity and thinner cell walls in the extrudates lead to greater water absorption.

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 & Singh, 2017). 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).

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). 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). Bulk density of the maize based extruded products increased with an increase in feed moisture and screw speed (Christofides et al., 2004). Bulk density of extrudates increased with okara level in feed materials (Kanojia V and Singh M, 2016a). 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). Highest bulk density of pearl millet, sorghum and soybean flour blended extrudates observed at increased level of feed moisture (Yatin et al., 2015)

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 & Singh, 2016).

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 & Singh, 2016).

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.

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 & Singh, 2017).

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). The effect of okara content on specific length and found that it was decreased with increase in okara content in feed (Kanojia & Singh, 2016a) while specific length increases with barrel temperature (Bhople & Singh, 2017a). Highest specific length of extrudates observed at increased level of feed moisture (Yatin et al., 2015).

Sectional Expansion Index (SEI)

It is defined as the ratio of diameter of extrudate to diameter of die (Bhople & Singh, 2017; Kanojia & Singh, 2016; Patil et al., 2005). 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. 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). 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). Barrel temperature and die headtemperature revealed significant effect on sectional expansion index of kodo based extrudates (Azam & Singh, 2017).

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 & Singh, 2016; Yousf et al., 2017). 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 110o C. Then WAI was calculated by taking the weight of gel obtained after removal of the supernatant liquid per gram of solid (Kanojia & Singh, 2016; Patil et al., 2005; Yousf et al., 2017).

Water Solubility Index (WSI) can be measured by weight of dissolved particles (200 to 250 ץm) 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. 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 & Kumar P, 2015). WAI of extruded products increased with feed moisture content and WSI reduced in pre-gelatinized rice flour based expanded snacks found (Gat & Ananthanarayan, 2015). Maximum water absorption index 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 & Singh, 2017a). It was found that water absorption index increased, while water solubility index decreased with increase in moisture (Pardhi et al., 2017). 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). 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).

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.

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