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Review Article

EXTRUDED PRODUCT QUALITY ASSESSMENT INDICES: A REVIEW

KANOJIA VARSHA* AND SINGH MOHAN

Department of Post Harvest Process and Food Engineering, College of Agricultural Engineering, JNKVV, Jabalpur, 482004, Madhya Pradesh, India
*Corresponding Author: Email-varsha.cae023@gmail.com

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Abstract- The extruded product quality assessment is essential for ensuring acceptance of product among the consumers. The qualities which affect the acceptance of extrudate product areas the textural qualities (e.g. hardness, crispiness, crunchiness etc.), physical qualities (e.g. bulk density, sectional expansion ratio, volumetric expansion ratio etc.), nutritional qualities (protein, fat, fiber, carbohydrates etc), organoleptic considerations (e.g. mouth feel, taste), and shelf stability. These qualities are affected by machine parameters (screw speed, temperature in different zone, feed rate etc) and feed parameters (bland ratio and moisture content of feed) during extrusion cooking. This review has focused on findings of different researchers which will help to understand the effects of these different parameters on the quality of extrudate product.

Keywords- Extrusion Cooking, Physical Properties, Textural Properties, Biochemical Properties.

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Introduction

In recent years, extrusion technology has become a popular processing unit due to increasing versatility, reduced cost, product quality, automated high production rate and no process effluents [1, 2]. Extruded food comprise a very large variety of products such as cereal based snacks, including dietary fiber, baby foods, breakfast cereals and modified starch from cereals, crackers, nuts etc [3, 4]. Extrusion is a high temperature short time (HTST) process, in which food material is melted and cooked inside the barrel section by a combination of moisture, pressure, temperature and mechanical shear, resulting in molecular transformation and chemical reactions [6,7,8] can drastically influence the final product quality. The extrusion process is more flexible i.e. one extruder can operate at relatively low temperatures for producing ready to cook extrudates like pasta, or at very high temperatures for manufacturing products with low bulk density, ready to eat snacks [5]. The principle of operation in extrusion is: 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. The food material is pushed through a narrow hole or a die of given shape. Starch gelatinization, protein denaturation, complex formation between amylose and lipids, and vitamins degradation etc. are some physicochemical changes occurs during extrusion in starchy and expansive food material [9].

In order to make an acceptable product, extrusion cooking demands the control of many process parameters that affect the quality of finished product. According to [10] the critical parameters that may partly affect the bulk density, expansion ratio, absorption, solubility, texture and nutrition of extruded snacks are: feed moisture, composition of raw food material, thermal energy input, and retention time. Apart from them, there are several other parameters i.e. control of feed rate, screw speed, barrel temperature and pressure etc. will influence the physical, textural and biochemical properties of product [5]. The higher feed moisture level during extrusion process decreases the radial expansion [11, 12] and increase bulk density of the extrudates. The product quality is strongly influenced by screw rotation velocity and temperature. [6] showed that apparent density, porosity and expansion ratio of extrudates from corn grits were dependent more upon the feed moisture, residence time and temperature, but screw speed had no effects. Geometric characteristics of final die (diameter and length) play an important role in the extrusion process, since they influence the expansion of extruded product. This paper reviews the extrusion process and assessment of extruded product quality indices and the influences of above mention parameters.

Mechanics of extrusion cooking

Extrusion process is a combination of several unit operations including mixing, cooking, kneading, shearing, shaping and forming inside the extruder. The extruder is considered a high-temperature short-time bioreactor that transforms a variety of raw ingredients into modified intermediate and finished food products due to the thermal effect and the shear stress [13]. There are two major types of extruders: Single-screw extruder and Twin-screw extruder (co-rotating and counter rotating).

The first cooking extruder was single screw extruder. The constructional elements of this extruder are feeder, extruder barrel with single screw, temperature and pressure control unit, motor and gear unit. The extruder screw has three zones (feed zone; compression zone; melting and plasticizing zone) and one die zone. A round die head is fixed at the end of the barrel. The raw material is fed into the barrel and conveyed through the screw. On moving forward direction, screw has smaller flights, which restrict the volume of raw feed material and increase the resistance in movement. As a result, it fills the barrel and space between the screw flights and becomes compressed. Here, frictional heat and the external heating system cause rapid increase in temperature. The screw kneads the material into a semi solid and plasticized mass. Further the plasticized food material is forced through a restricted opening i.e. die 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.

Twin screw extruder has a pair of parallel screws, which rotates inside a barrel with an 8-shaped cross-section. Screws may be co-rotating or counter-rotating. The most common type used in food industry is the co-rotating, self wiping twin screw extruder. Self-wiping reduces the risk of residue buildup. Twin-screw extruders have greater ability and flexibility for controlling both product and process parameters. It has more efficient mixing, better pumping efficiency with less dependency on the flow characteristics of the material. Heat transfer rate from barrel surface to the material is faster and more uniform. Some limitations are also there i.e. its mechanical complexity, higher capital and operational cost.

Pre-conditioning of raw feed material before extrusion

Pre-conditioning prior to extrusion enhances extrusion process. The final quality can be improved greatly by preconditioning of raw ingredients. It typically improves the life of wearing component in the extruder by several folds.

The extruder is fed with powdered ingredients. The ingredients are converted into flour and sieved for uniform particle size. The particle size of the feed is a very important parameter, which determines the effectiveness of heat and mass transfer processes occurring inside the extruder barrel [14, 15, 16]. It also determines the rheological properties of the melt in the metering zone.

Feed moisture plays an important role in finished product quality. Hence moisture management in feed is important step prior to extrusion. Initial moisture of ingredients is estimated. According to [17] moisture content of all formulations is adjusted up to the desire level by calculating the amount of water required to be added as shown in [Eq-1]. Then samples are stored at room temperature for 24 h before extruding.

$$W_w = W_d \times \frac{M_2 - M_1}{(1-M_1)(1-M_2)} \quad \text{[Eq-1].}$$

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

[18, 19] found that higher feed water level during extrusion process decrease the radial expansion; decrease volumetric expansion [20] and increase bulk density of the extrudates. Foods with lower moisture contents tend to be more viscous, therefore, the pressure difference would be smaller for higher moisture extruded foods, leading to a less expanded product [19]. The increase in feed moisture content at the same extrusion temperature reduced the degree of starch conversion [21] and increased the apparent density values [6].

[22] showed that a tempering time of 30 minutes for ground corn with coarse and fine particle size before extrusion produced a greater volumetric expansion index in corn meal extrudates. They also reported that uniform moisture distribution enhances the expansion of extrudates.

Physical properties assessment

Moisture Content

Moisture Content of Extrudates is the amount of moisture present in the extrudates after it is fully puffed and cooled to room temperature; The moisture content of the extrudate may be determined by drying them in a conventional air-vacuum oven at 103°C until a constant weight is obtained.

Bulk Density

Bulk density of extrudate product gives an idea about required space to store the product and shows the overall expansion, changes in cell structure including development of pores and voids. Minimum bulk density is desired for acceptable product. There are various methods of bulk density measurement suggested by many researchers:-

Bulk densities of the extrudate may be obtained by volumetric displacement procedure [23] using glass beads as the filler medium. Glass beads with diameters ranging from 100 - 105 μm were used. 10 pieces of extrudate, each 3.5 cm long are used. Three to five layers of extrudates completely covered with glass beads are made in sequence. The bulk density of extrudate may calculate using the equation

$$\rho_{ex} = \frac{W_{ex}}{W_{gb}} \times \rho_{gb} \quad \text{[Eq-2]}$$

where W_{ex} is the weight of the extrudate, W_{gb} is the weight of the glass beads, ρ_{gb} is the density of the glass beads. The density of the glass beads may also be determined using the volume displacement method. The density of the glass beads may be calculated using the following equation:-

$$\rho_{gb} = \frac{W_{gb}}{V_{gb}} \quad \text{[Eq-3]}$$

where V_{gb} is the volume of the glass beads. Observations may be replicated five to ten times to give the average value for bulk density.

The alternative method used to calculate the mean diameter and weight of the extrudate per unit length. Assuming the extrudate are perfectly cylindrical in shape. The volume of the cylindrical shape may then be calculated. The weights per unit length (about 5cm) may be measured by using sensitive electronic weighing machine. Prior to measurement, extrudate samples should be allowed to equilibrate with the laboratory atmosphere for about six days to bring them to uniform moisture content. Five to ten replicates of the diameter and weight give the mean values reported. The results obtained from these methods are comparable. [24, 25] determined the bulk density of extruded snack made of egg albumin powder and cheese powder, by filling a one liter measuring cylinder with the selected extrudates slightly above the liter mark. The cylinder was tapped 12 times till the products measured up to the liter mark. The weight of the extrudates was taken and the bulk density was calculated using the [Eq-2].

$$\text{Bulk Density} = \frac{\text{Weight of the sample (g)}}{\text{Volume of the sample (ml)}} \quad \text{[Eq-4]}$$

[26] reported extrudate density to be most depended on feed moisture content. Increased feed moisture content lead to sharp increase of extrudate density. Screw speed was observed to have slight impact on the density of extrudate. [27] reported that increasing screw speed reduced bulk density of extrudates during extrusion of soy protein and corn starch.

Increment in extrusion temperature decreased bulk density [28, 19]. Higher temperature provides a higher potential energy for flash-off of super-heated water from extrudates as they leave the die. With higher barrel temperatures, the extrudates exiting the die lose more moisture and become lighter in weight.

[29] reported that bulk density was less affected by addition of fish solids to rice flour up to 30%, but when the amount of fish solids was increased to 60% bulk density increased more than twofold. They also reported that as the severity of screw configuration increased the product bulk density decreased. [6] examined the structural property changes of corn starch material during extrusion as a function of feed moisture content and found that higher feed moisture decreased the radial expansion ratio of extrudates, resulting in a higher density and lower porosity values.

True/Solid density, it measures the mass per unit volume (actual) of extrudates, the solid densities of the extrudate may be determined by using air comparism multi-volume pycnometer. The extrudate samples are ground to pass through 80 mesh sieve and placed in pycnometer cup. Masses are recorded and sample volumes are determined. The densities are calculated as mass per unit volume.

Mass Flow Rate of Extrudates (MFR) outside the die, which is the material discharge rate in mass terms through the die, It may be calculated using following expression:-

$$\dot{m}_e = \left[\frac{1 - M_d}{1 - M_e}\right] \times \dot{m}_d \quad \text{[Eq-5]}$$

However, in most of the practical applications the mass flow rate may be directly calculated by noticing the amount of extrudates coming out of the die for a given period of time.

Specific Length (SL)

it is a measure of length per unit mass for extrudates, it can be measured by observing the mass of an extrudate with known length directly and it is expressed in mm/g. Extrudate average length is measured using dial calipers. It is a quality parameter to know the longitudinal expansion of extrudate, which shows that maximum length in per unit mass is desirable for better product quality. The specific length is calculated using the formula as given below [30].

$$\text{Specific Length} = \frac{\text{Length of specimen (mm)}}{\text{Weight of specimen (gm)}} \quad \text{[Eq-6]}$$

[31] reported that SL was highly affected by moisture content and temperature of feed. Specific length increases with decrease in these levels [30].

Sectional Expansion Index (SEI) which is a measure of the expansion in radial direction of extrudate after it comes out of the die. The ratio of diameter of extrudate to the diameter of die expresses the expansion of extrudate [32, 20]. The diameter (mm) of extrudates is measured using digital Vernier caliper. If S_e is the Cross ssectional area of extridates, S_d is the croass sectional area of the die, D_e is the diameter of extrudate & D_d is the diameter of die opening, it is calculated as follows:-

$$SEI = \frac{S_e}{S_d} = \frac{\pi D_e^2/4}{\pi D_d^2/4} = \left[\frac{D_e}{D_d}\right]^2 \quad \text{[Eq-7]}$$

$$\text{Sectional Expansion Index (SEI)} = \left[\frac{\text{Diameter of extrudate}}{\text{Diameter of Die}}\right]^2 \quad \text{[Eq-8]}$$

[33] postulated two factors in governing expansion: (a) dough viscosity, and (b) elastic force (die swell) in the extrudate. The elastic forces will be dominant at low moisture and temperature. The bubble growth, which is driven by the pressure difference between the interior of the growing bubble and atmospheric pressure resisted primarily by the viscosity of the bubble wall, dominate the expansion at high moisture content and high temperature [34]. Increasing feed moisture caused a decrease in sectional expansion. [27] reported that increasing screw speed improved sectional expansion. [35] also reported that increasing feed moisture content from 13 to 18% increased expansion of sorghum extrudates but further increase caused a decrease in expansion. [36] showed that increasing protein content in the feed mixture may decrease expansion ratio during extrusion. [26] reported no significant effect of feed rate on the expansion ratio was observed during extrusion of rice – based expanded snacks. Increasing the feed moisture content from 18 to 22% caused a decrease in expansion ratio for tapioca and corn starch [37]. The increase in feed moisture content at the same extrusion temperature reduced the degree of starch conversion [21].

Longitudinal Expansion Index (LEI) which is a measure of the expansion in the longitudinal direction of the extrudates after it comes out of the die, the expression used to calculate the Longitudinal Expansion Index is calculated as below:-

If V_e is the extrudate velocity after expansion, V_d is the extrudate velocity in the die, S_d is the cross sectional area of the die, and $\dot{Q}_d$ is the volumetric flow rate through the die, $\dot{m}_d$ is the mass flow rate of the dough entering the die, $\dot{m}_e$ is the mass flow rate of the extrudate, M_d and M_e are the wet basis moisture content of dough and extrudate, ρ_d is the density of the dough behind the die, which is often assumed as constant 1250 kg/Cu. m., L_{se} is the specific length of the extrudate defined as the length of the extrudate per unit mass (m/g), then

$$LEI = \frac{V_e}{V_d}$$

Where,

$$V_d = \frac{\dot{Q}_d}{S_d}$$

Mass balance for mass flow:

$$\dot{m}_d = \left[\frac{1 - M_e}{1 - M_d}\right] \times \dot{m}_e$$

Volumetric Flow rate

$$\dot{Q}_d = \frac{\dot{m}_d}{\rho_d}$$

$$LEI = \frac{V_e \rho_d S_d}{\dot{m}_d} \times \left[\frac{1 - M_e}{1 - M_d}\right]$$

$$V_e = L_{se}\dot{m}_e$$

$$LEI = \frac{\pi D_d^2}{4} L_{se}\rho_d \left[\frac{1 - M_e}{1 - M_d}\right] \quad \text{[Eq-9]}$$

Longitudinal expansion is also defined as the length of extrudate per unit dry weight [38] and may also be calculated in terms of SEI using following equation [39]:

$$LEI = \frac{\rho d}{\rho e} \times \frac{1}{SEI} \times \left\{\frac{1 - Md}{1 - Me}\right\} \quad \text{[Eq-10]}$$

[40] reported that moisture content of feed has negative effect on LEI, i.e. LEI decreases as moisture content is increased while barrel temperature and screw have positive effect on LEI. [17] observed that when barrel temperature and screw speed increased then LEI increased. This may be due to a reduction in viscosity, which resulted in less mechanical damage to starch, thus enabling dough to expand more and faster. As temperature increased, starch became more fully cooked and thus better able to expand. This confirmed similar results reported by [40] and [26].

Volumetric Expansion Index (VEI)

It is a measure of the multiplied effect of radial as well as longitudinal expansion of extrudates after it is fully puffed out side the die. It is calculated by following expression:-

$$VEI = LEI \times SEI \quad \text{[Eq-11]}$$

Higher water feed level during extrusion process decrease volumetric expansion [20]. [21, 41] explained a sharp decrease in volumetric expansion with increased moisture content by the shrinkage and collapse of the extrudate after maximum expansion. [18] noted that the expanded volume of cereal flour decreases with increasing amounts of protein and lipid but increases with starch content. [42] appeared that an increase in barrel temperature increased the volumetric expansion. Combination of moisture content with barrel temperature gave positive effect on volumetric expansion index [30]. [43] reported that blending with legume flours decreased the expansion ratio.

Specific Mechanical Energy (SME)

The basic concept behind SME is to measure the energy going into the extrusion system per unit mass in the form of work from the motor. The energy is put into the extrudate through viscous dissipation. The energy is converted primarily into heat in the extruder. There are other reactions that can occur, such as gelatinization of starch or denaturation of protein. Unfortunately, there are a lot of uncertainties in measuring the mechanical input, so getting an extremely accurate SME is somewhat uncertain. However, the total specific mechanical energy input during extrusion is estimated by using the following expression [54].

$$SME = \frac{RPM\ of\ Screw\ (actual)}{RPM\ of\ Screw\ (rated)} \times \frac{percent\ torque\ (run)}{100} \times \frac{motor\ power\ rated\ kW}{MFR\ (kg/h)} \quad \text{[Eq-12].}$$

Water Absorption Index (WAI)

The water absorption index (WAI) is the measure of the volume occupied by the extrudate starch after swelling in excess water, which maintains the integrity of starch in aqueous dispersion, which can be used as an index of gelatinization [26]. It is used to express the ability of standard size extrudates particles to absorb the water, it is expressed as follows:-

$$WAI = \frac{Weight\ of\ Sediment}{Weight\ of\ Dry\ Solids} \quad \text{[Eq-13]}$$

The WAI is determined using the method described by [26]. The ground extrudate samples were suspended in water at temperature of 30°C for 30 minutes; It was then stirred gently and immediately centrifuged at 3000 x g for 15 minutes. The WAI was considered as the weight of gel obtained after removal of the supernatant through a strainer (pore size = 500μm) per unit weight of original dry solids (g H20/1g sample).

$$WAI = \frac{W1-W2}{W1} \times 100 \quad \text{[Eq-14]}$$

Where, W_1 = Weight of grind extrudate, W_2 = Weight of grind extrudate sample after keeping in water (gel).

[44] reported that the highest values of WAI were obtained at higher range of moisture content i.e. at 19–22% because moisture content, acting as a plasticizer during extrusion cooking, reduces the degradation of starch granules and these results in an increased capacity for water absorption. [45] reported the water absorption index achieved a maximum value at extrusion temperatures 180 – 200°C. An increasing WAI is advantageous [46]. [47] reported increased water absorption index with decrease in the feed moisture during extrusion of mango starch. [48] reported increased extrudate WAI as the percentage of cowpea increased in sorghum. [49] extruded the wheat flour and corn starch with the addition of 10% brewer's spent grain (BSG) and red cabbage (RC) and found that WAI increased and WSI decreased as feed moisture level 12– 17% increased for all formulations.

Water Solubility Index (WSI)

Water Solubility Index describes the rate and extent to which the component of a powdered material or particles dissolves in water. WSI, often is used as an indicator of degradation of molecular components, this to a certain extent measures the amount of soluble components released from the starch after extrusion process. However, this will also depend mainly on the chemical composition of the powder and the physical state of the material. WSI often is used as an indicator of degradation of molecular components [50], which measures the degree of starch conversion during extrusion process, this is to a certain extent is the amount of soluble polysaccharide released from the starch component after extrusion. It is the measure of ability of water to dissolve the standard sized (200 to 250 μm) particles of ground extrudates, and is expressed as below:-

$$WSI\ (\%) = \frac{Weight\ of\ dissolved\ solids\ in\ supernatent}{Weight\ of\ dry\ solids} \times 100 \quad \text{[Eq-15].}$$

The WSI is determined using the method described by [26]. The ground extrudate samples were suspended in water at temperature of 30°C for 30 minutes; It was then stirred gently and immediately centrifuged at 3000 x g for 15 minutes. The supernatant was decanted into an evaporating dish of known weight. The WSI was considered as the weight of dry solids in the supernatant expressed as a percentage of the original weight of sample.

[45] reported the increase in soluble starch with increasing extrusion temperature and decreasing feed moisture. They found out that as extrusion temperature increased at the feed moisture of 18.2%, water solubility index increased. [51] reported that WSI would decrease during extrusion of legumes, since extrudates of high legume content contain more starch aggregates or micro gels which will be suspended in water. This suggests that water solubility index (WSI) is not only due to starch contents but also due to water soluble components, like proteins which are present in cowpeas. Cowpea proteins have relatively higher water solubility than sorghum proteins [52, 53]. [29] reported that water solubility index increased with severity of screw configuration. This trend was observed for rice flour as well as to its blends with 30% and 60% fish solids during extrusion process. An increase in shear energy inputs as well as residence time by incorporation of reverse screw elements can cause both depolymerisation and degradation of food components. High shearing can also cause fragmentation of products from both starch and proteins during extrusion cooking. The degradation products, which are mostly small molecules, are generally water soluble in nature [29]. During extrusion process water is usually absorbed and bound to the starch molecules with resulting change in the starch granule structure.

Residence Time

The residence time of the dough in the extruder are determined by introducing colored dye tracer in the feed at the entrance of the extruder. The residence time is determined by timing the time it takes the colored dough to be extruded. Different screw speeds were used during the experiment. Fifteen to twenty five replicates may give a fairly good average value.

Textural parameters

Textural properties extrudate are perceived by the final consumer as prime criteria of acceptance. Textural quality attributes of food may be evaluated by sensory (subjective) evaluation or instrumental (objective) measurement but the instrumental analysis of texture in foods provides fast and relatively inexpensive indications on product characteristics and consumer acceptance. The instrument Texture Analyzer is generally used with different kinds of probes like cylindrical, needle, knife with blades etc.

Hardness

Hardness of extruded product is the surface property, which is essential to gain a shape. It is expressed as the maximum force applied by mouth teeth to compress the food. Extruded product having minimum hardness is highly acceptable among the consumers. As the moisture of feed increases, the hardness of extrudate also increases [55, 56]. When the value of moisture content of feed increased by keeping blend ratio at constant level, the value of hardness increased [57]. According to [58] addition of proteins to high starch flours could change the behavior of transformation into a 'protein type' extrudate when less expansion occurs and the products are harder. Only starch granules that have been gelatinized can participate in the formation of a stable expanded structure. Effect of screw speed on hardness was not significant [26]. On increasing the barrel temperature, the hardness decreased because an increase in the barrel temperature will increase the degree of superheating of water in the extruder encouraging bubble formation and also a decrease in melt viscosity [12].

Crispness

Crispness is related with rapid drop of force during mastication process, attribute that is based on fracture propagation in brittle materials [59]. When force is applied to brittle snacks, rupture of the cellular structure occurs, generating a typical sound that contributes to the crispness sensation [60]. Materials considered to be crisp usually generate irregular force–deformation curves. Crispness was measured in terms of number of major positive peaks [61]. In this curve, difference between peak and valley shows the quality of extrudate product. If the difference is more, the product is crispy and harder; but if the difference is less that means the product is crispy and soft.

Effect of barrel temperature on crispness was found positive. [45] reported that soluble starch increased with increasing extrusion temperature and decreasing feed moisture. At high temperatures, the feed moisture flashes off as steam and causes bubble growth resulting a higher crispy texture of extrudates. Increasing screw speed improved the expansion of extrudate [27] (Seker 2005) ultimately higher screw speed resulted the higher crispness. MC of the feed formulation has a crucial role to play in the generation of vapour bubbles in the feed formulation during the exit of the extrudates from the extruder-die [62].

Cutting strength

Cutting strength is same as the hardness but it is measured using a probe having blade with knife. So, the surface area of cutting is increased and Cutting strength is always higher than hardness of product.

The feed moisture shows the positive effect on hardness i.e. on increasing the feed moisture, the hardness of extrudates also increases and product becomes harder at high moisture. [19, 63]

Biochemical parameters

Effect of starch

Starch plays an important role in extrusion cooking of cereals being a major component of the extrudate matrix and a key element responsible for expansion. Most studies recognize that gelatinized starch plays a prime 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 stretch ability of the starchy matrix. [64] reported that the lower limit of starch content for good expansion is 60–70%.

Starch gelatinization is an important phenomenon occurring in extrusion cooking of cereals. Strach gelatinization is responsible for a specific textural and structural characteristic for the extruded products. The knowledge of the kinetics of starch gelatinization and melting is required for food process engineers to design and optimize processes [65]. The most significant changes in cereal grain during extrusion cooking occur in starch as starch makes two thirds of a grain weight that as fresh has no palatability and edibility. It is known that starch macromolecules that succumb many processes of transformation under thermal and mechanic effects result in different physical structures and properties [66, 67]. If starch is heated in the presence of water, the structure of starch granules is disrupted and granules lose their double-helical structure and Maltese cross occurs. This phenomenon, known as gelatinization, occurs within the temperature range from 62 to 80°C for dent maize starch, 63 to 72°C for waxy maize starch and 52 to 85°C for wheat starch [68]. Uncooked spaghetti enriched with resistant starch was observed with the lowest gelatinization temperature range [69].

Effect of Protein

Proteins are very important for biological functions and cell structure. They have complex composition, composed of hydrogen, carbon, nitrogen, oxygen and sulfur. Twenty ά-amino acids are the building blocks of proteins linked by peptide bonds. Officially, Kjeldahl method is applied for protein analysis, in which food sample is digested with sulfuric acid in the presence of catalysts. The total organic Nitrogen is converted to ammonium sulfate. The digest is neutralized with alkali and distilled into a boric acid solution. The boric anions formed are titrated with standardized acid, which is converted to nitrogen in the sample. The result of the analysis represents the crude protein content of the food, since nitrogen also comes from non-protein components.

Decreasing feed moisture content or increasing barrel temperature significantly reduced lysine content of extrudates during extrusion [70]. At more severe extrusion cooking conditions, the protein digestibility (PDI) and the availability of amino acids may be reduced through the Maillard reaction, leading to a decrease in the availability of lysine in particular [71, 72, 73, 74]. Available lysine may thus serve as an indicator of protein damage during processing [75]. Protein content decreased with increase in moisture content, which means denaturation of protein, was more in higher moisture percentage of blend. Similar result was also reported by [30]. Proteins do not expand as well as starch. Increasing soybean protein from 0 to 25% resulted in decreased expansion of extruded corn starch, according to the report lipids also affected expansion of extrudates. [27] further reported that mixtures of soy protein isolate/modified starch had higher sectional expansion indices than those of native starch/soy protein isolate, indicating that feed materials (in addition to phase transition) may contribute to the reduced expansion of extrudates containing soy protein.

It was also noted by [18] that the expanded volume of cereal flour decreases with increasing amounts of protein but increases with starch content. Incorporation of protein reduced starch conversion and compressed bubble growth resulting in a dense product and reduced crispness of extrudates. Addition of proteins to high starch flours could change the behavior of transformation into a 'protein type' extrudate when less expansion occurs and the products are harder and more resistant to water dispersion.

Effect of dietary fiber

Dietary fiber is added to extrudate for increasing the healthiness of product [76, 77]. The quality of snacks depends upon the solubility of fibers. Soluble fiber enhances the elasticity of feed [78] and bubble formation. Consequently, enhances the crispness of extrudate. Presence of insoluble fiber in feed lowers the expansion due to increase in viscosity, decrease of elastic properties and low affinity between starch and insoluble fibers [79].

Increasing dietary fiber content in feed resulted in decreased diameter but enlarged length of the extrudate [80]. Concentration of safed musali powder had negative effect on crispness of extrudate. Safed musli is a root crop, having higher percentage of fiber and it intervenes with air bubble formation and increases air cell wall thickness [42].

Concentration of safed musali powder had negative effect on crispness of extrudate [81]. Safed musli is a root crop, having higher percentage of fiber and it intervenes with air bubble formation and increases air cell wall thickness. [42] also reported that increase in bulk density with increase in level of grape pomace may be due to the increasing fiber content of feed material. This was because the presence of fiber particles tended to rupture the cell walls before the gas bubbles had expanded to their full potential [82].

Effect of lipids

Fats and oils can be described as lipids. Lipids are a group of substances that in general are soluble in either chloroform or other organic solvents but are sparingly soluble in water. The semi-continuous solvent extraction is often considered the standard method of fat extraction. During fat extraction, the solvent is to be filled up in extraction chamber for 5-10 min so that solvent may completely surrounds the sample. Fat % is measured by weight loss of sample.

Lipids have a powerful influence in extrusion cooking processes by acting as lubricants, because they reduce the friction between particles in the mix and between the screw and barrel surfaces and the fluid melt. Extrusion of food material having high fat content is not advisable as lipid level over 5-6% [83] because lipid reduces slip within the barrel and insufficient pressure is developed during extrusion resulting poor expansion [84]. Low lipid level (<5%) facilitates steady extrusion and improves the texture.

Conclusion

The raw material characteristics and processing variables of extrusion cooking directly affect the physical, textural and biochemical properties of extrudates. This review paper gives brief knowledge about the evaluation of process performance and product quality of extruded snacks. From this review, the following conclusions can be drawn:

for better Lower feed moisture, higher extrusion temperature and higher screw speed result decrease in bulk density, hardness, cutting strength and increase in specific length, crispness, SEI, LEI, VEL, of extrudate. Higher feed moisture lowers the protein content. Composition of feed ingredients greatly affects the extrudate quality i.e. higher protein, fiber and lipid percentage contribute in poor quality of extrudate. During extrusion process the starch is gelatinized and resulting expansion of extrudate. Minimum 60-70% of starch is recommended product quality.

In order to make an acceptable product, extrusion cooking demands the control of many process parameters that affect the quality of finished product. According to [10], the critical parameters that may partly affect the bulk density, expansion ratio, absorption, solubility, texture and nutrition of extruded snacks are: feed moisture, composition of raw food material, thermal energy input, and retention time. Apart from them, there are several other parameters i.e. control of feed rate, screw speed, barrel temperature and pressure etc. will influence the physical, textural and biochemical properties of product [5]. The higher feed moisture level during extrusion process decreases the radial expansion [84, 12] and increase bulk density of the extrudates. The product quality is strongly influenced by screw rotation velocity and temperature.

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