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Extrusion Cooking Technology in Food Processing – An Overview

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Abstract - *The extrusion cooking technology plays an vital role in food processing for the developed of new and innovative food products like pasta, Textured Vegetable Protein (TVP), RTE such as snacks produced from cereals, baby foods, breakfast cereals, pet foods, dietary fibre, modified starch based products and traditional food products. The sequence of many different processes such as sorting, mixing, kneading, shaping, making and cooking are carried out in extrusion processing. Extrusion cooking aids to reduce the microbial activity and supports in enzymatic inactivation. Extrusion technology has a major effect on the potentials of food because of high temperature. The effect is on nutritional properties along with chemical properties of the food material. Due to alteration in chemical structure, the properties of starches, protein, and other ingredients will be modified. Extruder is a physical device which permits the ingredient or food material through some particular die and the newly prepared food material with the help of extruder are recognized as extruded. In this, we focus on the extrusion technique followed in some food processing industries along with different types of extrusion and effects of extrusion processing on many diverse properties of extruded food products.*

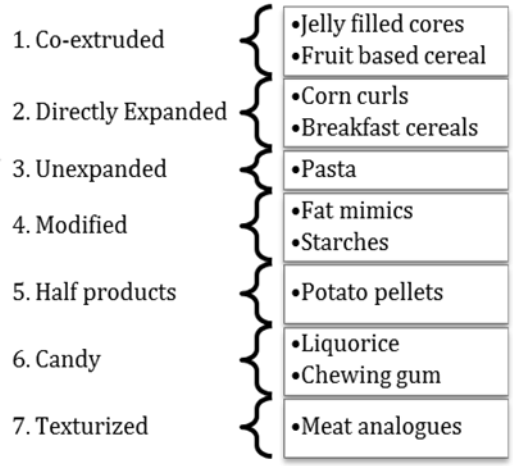
Key Words: Extrudate, Extrusion, Food Processing Extrusion system, extruded foods, extruder, extrusion cooking

1. INTRODUCTION

The Extrusion is defined as a technique of forcing the mixed ingredients out through a narrow opening, called a die, to make and shape the food materials (Launay & Lisch, 1983). The word "extrudate" originates from the Latin word "ex" (out) and "trudere" (to thrust) (Tadmor & Klein, 1970). Food extrusion could be a combination of both physical and chemical processes. Extrusion technology is usually utilized in the fashionable food industry because of its product quality, multifunction, adaptability, low budget, highly output energy and eco-friendly. In extrusion cooking, starchy, moisturized, and proteinaceous food material are processed through the applying of using of mechanical shear, heat and pressure (Rossen & Miller, 1973; Smith, 1976). This is often done through the barrel and screw mechanism in extruder. The key effect is on nutritional qualities and physiochemical properties. Because, the nature of food materials like protein, starch, and other ingredients are changed because of modification in chemical structures (Harper & Clark, 1979). Extrusion cooking will comes under the HTST (High temperature short-time) method, established for the development of innovative value added RTE (ready to eat) food products like produced from grains and cereals, during which infant foods, dietary fibres, cereal based products for breakfast, cereal based modified starch food products, pet foods, and traditional food product (Sebio & Chang, 2000). Most of the ingredients used in food extruder are in solid medium (Steel et al., 2012).

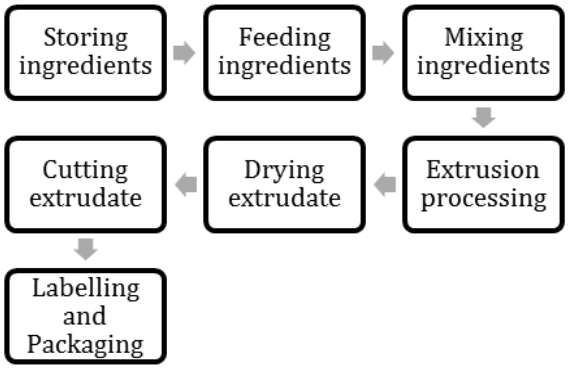
The extrusion processing is applied by two parameters, under warmth and air mass, or it's simple a non-cooking method, forming process (Pardeshi & Chattopadhyay, 2014). By the using of many raw ingredients, extrusion cooking produces an oversized range of food products (Pawar et al., 2014). Food extrusion has become more popular and important within the food processing and production industries as effective production process (Kolani, 1993). By the using of various forms of simple and raw ingredients, the extrusion cooking technology creates the quantity of food materials for human consumption with various textures, flavor, shape, and colours (Harper, 1986). The extrusion processing supports in producing snacks based food, pet foods and conveying and accommodating softened shapes of pastes and dough forms of prepared simple food material. Extrusion cooking is an HTST (High temperature short-time) process, it brings inactivation of raw enzymes, lowers the microbial activity from the finished products, denaturation of protein, deactivation of natural toxic substances, modification of lipids and gelatinization of starch(Faubian & Hoseney, 1982). The extruded products are sterile due to thorough gelatinization of starch, very digestible (Seib, 1976). Extruded food materials have lower water activity (0.10-0.40) and because of the tide activity of cold extruded and hot extruded food are easily preserved for very long time (Bordoloi & Ganguly, 2014). Quality parameters and major perception as food these two features reserve for extruded food products in human diet. The extruded foods are easily digestible, palatable and safe for consumption. Extruded food products are classified into animal feed products, human feed products, non-consumable products and biodegradable materials.

2. Human consumable Extruded food products for are divided into 7 types. They are as follows:

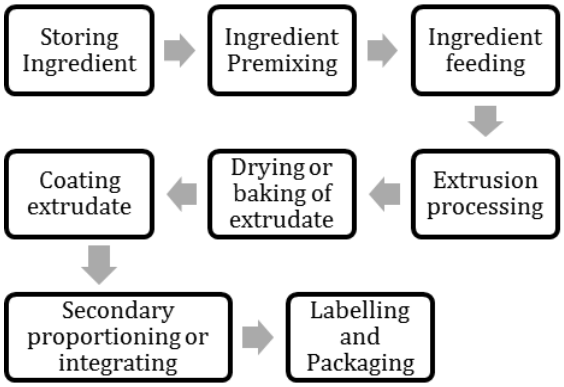


3. Processing flowcharts of some extruded food products

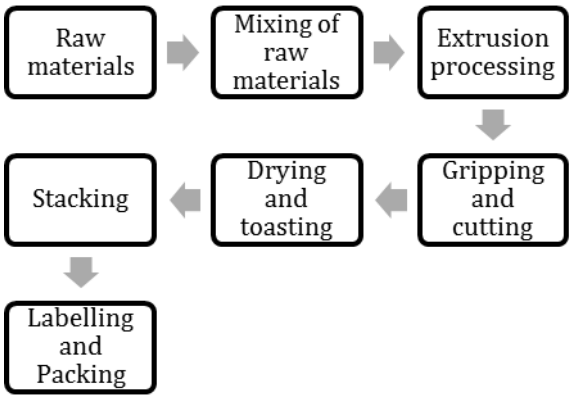
3.1 Processing of Pasta



3.2 Processing of Snack food



3.3 Processing of crispy bread



4. Processing of Extruded food products

In extrusion processing, first the ingredients used for the product preparation are grinded at the coarse flour consistency to the optimal particle size. From the pre-conditioner the processed raw material is distributed, the ingredients are added to the processed raw material based on the final product. To initiate the cooking procedure steam is inserted and the processed raw ingredient (extruded) from the pre-conditioner is treated through the extruder. The big rotating screw existing in the extruder is attached inside a barrel which has the die or orifice at the one end. The extruded material passes through the die because of the big rotating screw pushes the extruded material towards the die. The residence time is the time spends by the material inside the extruder. The texture and quality of extruded food products such as puffs changes their structure due to the effect of heat and moisture release along with reduction in forces. The texture change occurs and it will have a different quantity. The rate of the change is considered as the expansion ratio. The output product from the extruder that is the extruded is cut into the specific length with the help of blades, at a uniform speed which revolve about openings of die. During the maintenance of the porosity, the products will become rigid after the cooling and drying. Due to the presence of pressure generation (10 bar-20 bar) in the extruder product it produces its own heat and friction and in the extruder cooking process will takes place. Based on some of the parameters and inputs, starch gelatinization and protein denaturation can takes place in this process (Mercier *et al.*, 1989). HTST (High Temperature Short Time) methods involve in the many food extrusion processes. Speed of the blade, Dampness of the material, extruded composition, rotating speed and length of the screw, temperature of barrel and shapes of die/ orifice are the vital factors which influence the extrusion process. These are controlled by the dependent on the ideal item to guarantee consistency of the yield. From these different factors of the extrusion process, the moisture content is one of the main key factors which acting on plasticizing the extruded products and affecting the mixing viscosity. Product temperature, torque and viscosity decreases when the moisture content increases and bulk

density increases. Due to this, die pressure will also decreases. Many extrusion processes needs regulating the moisture level from low moisture level to intermediate moisture level that is underneath to about 40% moisture. The process in which the high moisture extrusion takes place is known as wet extrusion, after the introduction of twin screw extruder the wet extrusion is mostly used, which is having a gradually proficient passing on ability. Temperature is the most vital rheological factor of high starch extruded in the wet extrusion (Suvendu & Gour, 1994). The salt level of some extruded products will decide the colour and texture of extruded. Salt concentration of the extruded product is responsible for the airiness and expansion ratio of the extruded product, possibly because of starches and salt concentration remaining in extruded causes the chemical reaction (Nancy *et al.*, 1992). Salt concentration changes the colour of extruded product this is due to the, "water activity of extruded item is changed by the salt and subsequently browning reaction rate also changes". Some of the minor ingredients including flavours and food colours are dispersed by the use of salt. After the extrusion process, these are all the more similarly dispersed over the item's surface in the commencement of being blended with salt. In 1870s, for manufacturing of sausage the first extruder was developed. Since 1930s, by the using of extrusion technology breakfast cereal and packaged dry pasta have been developed, and in 1950s extrusion method is used for the production of pet foods.

Cold extrusion and hot extrusion are the two types of extrusion methods in the extrusion technology. By using hot extrusion process, various types of food products are produced in which cereal based crispy snacks food, weaning foods from soybean, and sugar based confectionary. Hot extrusion process is also known as extrusion cooking. In cold extrusion, mixing and shaping of food is done by the non-cooking method including pasta, biscuit dough. Equipment used for both hot extrusion and cold extrusion method is known as "Extruder"

5. Extrusion technology has become famous due the following reasons

- **Flexibility of the products:** Several types of food products are produced by changing the shape of the die, working state of the extruder and processed raw ingredient.
- **Originality of the product:** Extrusion cooking technology needs low heat for processing therefore, loss of heat sensitive compound is prevented.
- **Reduced prices:** Extrusion cooking reduces the handling costs and increases profitability than forming or other cooking methods. Many conventional techniques such as cornflakes production and hotdogs are progressively proficient and less expensive when supplanted by extrusion.
- **Higher yield and automatic processes:** Extruders works persistently and have high outputs efficiency.

6. Extruder

Extruder device is used to give new shape for the extruded by pushing the ingredient from a particular type of orifice or die. An extruder is a thermodynamically processing unit. To operate the rotating screw of the extruder, it consists of an electric motor which runs with the help of power supply, and the rotating screw is surrounded by the barrel and feeder raw material. The rotating screw is used to transfers the processed raw material to the orifice or die that gives the new shape to the product. Different process like heating, mixing, conveying of pre-grounded and conditioned ingredient is done when the ingredients enters through the screw. The material leaves the extruder machine over a kick the bucket where it generally starts to puff and changes surface from the arrival of the steam and ordinary powers. Extruder used for grain processing offers great open doors for little scale food processing organizations in India since raw materials are quickly accessible, extruders are sensibly moderate and when the items are picked properly, they will be having a decent interest and also can be productive. The preparing units have advanced from straight forward passing on gadgets to end up exceptionally modern in the most recent time.

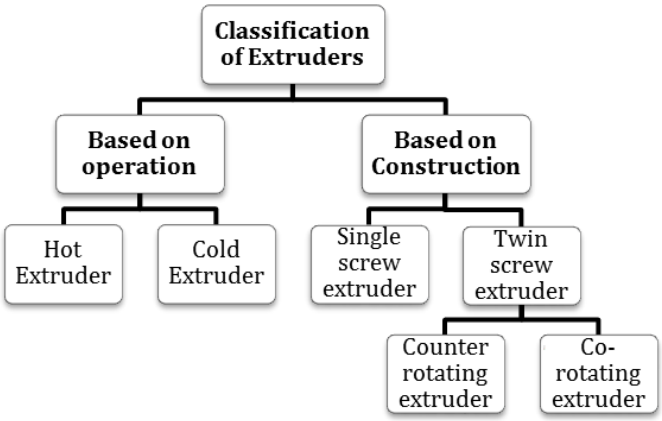
7. Major Parts in Extruder

1. Pre-conditioning system
2. Barrel
3. Die and the cutting mechanism.
4. Feeding system
5. Screw or worm

There are different types of parts used in the extruder according to the die configuration, screw and barrel. The use of each and every part of the extruder will depend on the raw material used and type of final product (Riaz, 2000). In the barrel of the extruder there is rotating screws which helps to transfer the material through the barrel and uniformly mix the material into different types. In cold extrusion process heat is not required it simply shapes the food into different forms by just applying the pressure and the material is discharged from the barrel through the specific type of die. In hot extrusion or extruder cooker the

material present in the barrel is warmed by friction and it will rises up and passes from the die on pressure. Some breakfast products have crispiness and light texture and also they extend quickly due to the steam releases because of the pressure when the material rises up through die or orifice.

8. Classification of Extruders



8.1.1 Cold Extrusion technology

The Discolouration of whey proteins from the Millard reaction, racemization of proteins during the cross-linking, destruction of sulphur containing amino acids, methionine, and cysteine, and some other problems occurs due to high cooking temperatures used in normal extrusion (Onwulata & Pordesimo, 2008). In cold extrusion, heating of food is carried out up to 100 degree Centigrade. In Cold extrusion, the temperature of the food is maintained constant which is used in shaping and mixing of food which including meat products and pasta. Temperature less than 100 degree Centigrade is also used for the low pressure extrusion. Example: Pet Foods. Chilling, baking or drying methods are also used for the preservation of cold extruded products. While the extrusion cooking also removes contaminating micro-organisms and preserve the dry food products for longer period of time. Packaging of dry food products prevents the oxidation and moisture absorption during storage. Cold extruders are suitable for small scale industry and also for household usage. Extruder cookers are used only by the large scale industries because they are very high in cost. The main use of cold extruders is in pasta production, although comparable machines are used to frame, roll batter into various shapes. A pasta extruder (Fig. 1-a) is used to make a wide range of pasta using the mixture produced using durum wheat flour (or 'semolina') and eggs. Also by adding tomato purée or spinach paste in it different types of coloured paste also made.

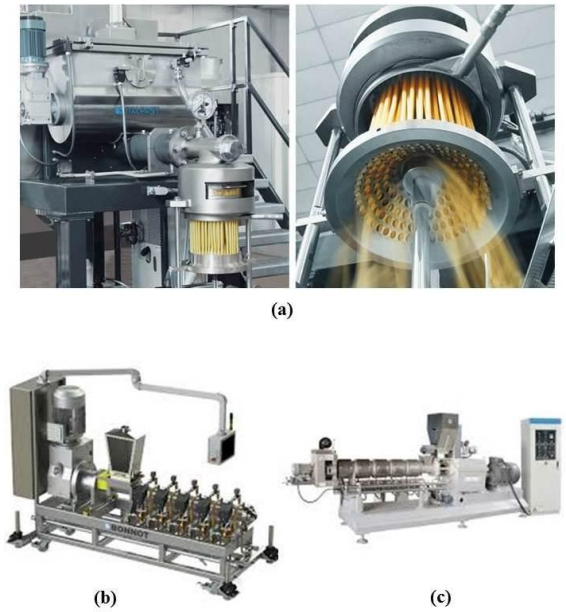


Fig 1: (a) pasta extruder, (b) pet food extruder, (c) puff snack extruder

There are several types of extruder are available which is used in small scale manufacturing and food outlet starting from manual operating to fully automatic machines. The pasta extruder has many different portions such as die, conveying screw, extruder barrel, and mixing chamber which are used for production of precise shape of paste. Many equipment manufacturing companies make the die from different materials like plastic, stainless steel or preferring bronze, which they assurance that it gives harsh surface to the pasta that, holds sauce superior to any pasta made by a variety of different techniques. They are cut into specific size and specific shape after they rise up out from the die. Pasta is immediately cooked but and dried for retail sell and it also preserved up to six months.

8.1.2 Hot extrusion technology

Hot extrusion is also known as extrusion cooking in which heating of food is usually carried out at more than 100 degree Centigrade. Frictional heating and other heating techniques is used to increase the temperature rapidly. After the heating of the food, it is passed to barrel sections which have a small flight which helps to increase the shear and pressure. Finally, food is passed through the die under pressure, after the final shaping the food is cooled rapidly to remove the moisture present in the food in the form of steam. Product is formed into many different type of shapes such as shells or squirls, rods, tubes, doughnuts, strips, and spheres. Different types of new food product are formed by extrusion cooking which includes puffed cereals (RTE), expanded snack foods and etc. Extruders are the single screw or twin screw equipment. Twin screw extruder equipment is not affordable by small scale industries because of its high maintenance cost and capital cost as

compare to single screw extruder. Single-screw extruder equipment (Fig. 2) and Twin screw extruder equipment (Fig. 3) is described as follows.

8.2.1 Single screw extruder

Single screw extruder contain only one screw which continuously rotates inside the barrel of single screw extruder, and usually these comes in different types. It works on simple and cheap to run operations such as dry extrusion (Wilson & Tribelhom, 1979). The regularly used single screw extruders have a consistent pitch (Harper, 1981). It was in 1946 that single-screw extruders were used for the extrusion cooking and expansion of corn snacks (Wiedman & Strobel, 1987).

Fig 2: Single-screw extruder

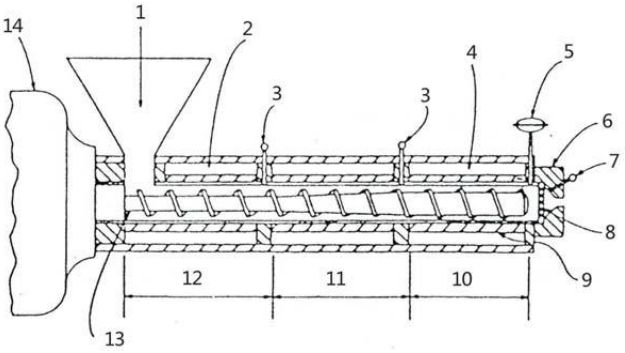


Fig. 2.1: Mechanical sections of a single-screw extruder.

1. Feed hopper; 2. Cooling water jacket; 3. Thermocouples; 4. Barrel steam jacket; 5. Pressure transducer; 6. Die; 7. Discharge thermocouple; 8. Breaker plate; 9. Barrel with hardened liner; 10. Metering section; 11. Compression section; 12. Feed section; 13. Screw with increasing root diameter; 14. Drive, gear reducer and thrust bearing.

In single screw extruder, the used process raw material and working state in the barrel are the key factors that control the quality and the type of extruded food product that are manufactured by the hot extrusion method.

8.2.2 Twin screw extruder

Fig 3: Twin-Screw extruder

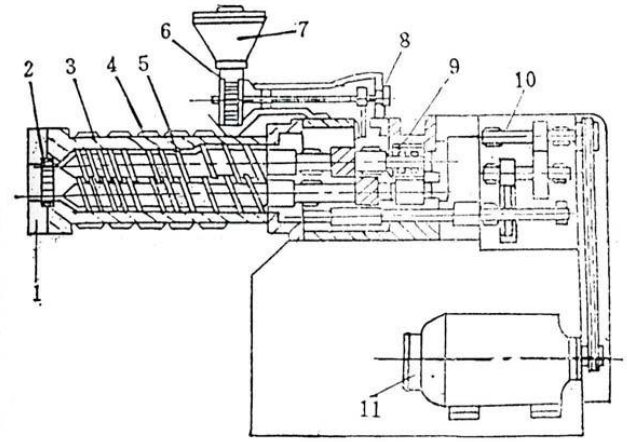


Fig. 3.1: Mechanical sections of a twin-screw extruder.

1. Die housing; 2. Die plate; 3. Extruder barrel; 4. Heater; 5. Twin screw; 6. Feed gage; 7. Hopper; 8. Feed metering device; 9. Bearing; 10. Gear box; 11. Electric motor.

In twin screw extruder, two rotating parallel screw having same dimension is present inside the barrel. Twin screw extruder is entangled than single screw extruders, and yet gives considerably better control and more versatility. Twin-screw extruders are typically more expensive than a single screw machine for the identical capacity (Lusas & Riaz, 1994). The flow of product will be uniform throughout the barrel as a result of positive pumping of screw flights. (Adekola, 2014)

9. Different types of extruded food products along with some examples

1. Starch based products	•corn snack foods •potato snack foods
2. Protein based products	•Textured Vegetable Protein (TVP) •Sausage products, Frankfurters, hot dogs
3. Cereal based products	•Expanded snackfoods •Pasta products
4. Sugar based products	•Chewing gum •Liquorice

Extrusion technology is having an special importance in food processing field because of many advantages like easy applications in food production, low cost, flexibility, higher productivity, and product quality as compare to other methodologies (Fellows, 2009).

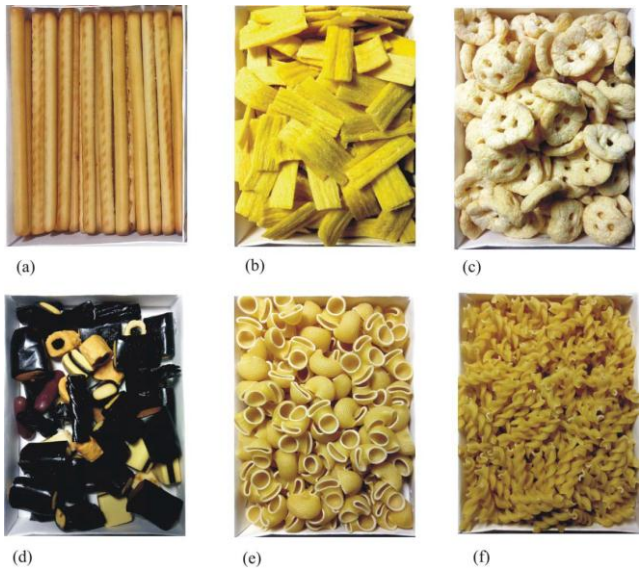


Fig 4: Extruded food products made up of different raw materials (a) Milk stick biscuits (b) Extruded wheat snacks (c) Wheat flour chips (d) Liquorice (e) Pasta (Escargot) (f) Pasta (Torsades)

10. Effect of Process Parameters of Extrusion on Quality of Extruded

Extrusion processing permits the production of food products through a continuous, economical process which gives a qualitative reliability of the finished product (Harper, 1981). It is done through dominating many factors of the extrusion technology. Extrusion technology has also developed new quality food product and improved several snack producing methods. The reactions takes place in different chemicals inside the extruder is the result of extrusion process. This reaction happens especially at the end of die and the extruder barrel (Riaz, 2000).

11. Effect of extrusion technology on food product

1. Inactivation of raw enzymes.
2. Destruction of naturally present toxin.
3. Reduce the microbial load in finished product.
4. Increase the bioavailability of iron.
5. Loss of EAA present in the food that is lysine.
6. Extrusion process converts the complex starches into simple form.
7. Effect on the tooth (rot).
8. Extrusion process increases the glycaemic index of food products.
9. Loss of vitamin- A.

12. Nutritional Properties in Extruded foods

12.1 Effect on protein and amino acid

In extrusion cooking technology, the protein absorbability of the extruded food products is expanded. The nutritional value of protein is depends on the quantity, digestibility and accessibility of essential amino acids (Singh *et al.*, 2007). The extruded food products prepared from the cereals are rich in essential amino acid (lysine). Consequently an importance on protection of lysine during extrusion method is of specific significance (Iwe *et al.*, 2004).

12.2 Effect on Carbohydrates

12.2.1 Sugar

Sucrose, fructose and lactose present in sugar are the noble source for instant energy. Sugar conveys the sweet taste of the food product. Sugars are also responsible for the some chemical reactions which take place in the extrusion process. It is necessary to control the sugar in the extrusion process to sustain the nutritional and organoleptic properties of extruded food products. Extrusion process will results in loss of some sugar. It is mainly due to the sucrose getting converted into the fructose and glucose which also includes maillard reactions with protein and sugar molecules. The superiority of some legume based extruded food product is enhanced by obliteration of some oligosaccharides (Singh *et al.*, 2007).

12.2.2 Starch

Starch is the chief component and it provides the fundamental structure (Guy, 2001).The starches are exposed to heat, mechanical shear and pressure up to 100- 103 psi in extrusion processing (Lai & Kokini, 1990; Davidson *et al.*, 1984). Starch is made up of glucose units connected by glyosidic bond. Amylopectin and amylose are the starch molecules. Amylopectin and amylose are the main reason for the viscosity and gelatinization of the cooked paste. The atomic weight of starch molecules present in the wheat flour is decreased by the feeding moisture and low temperature of the die (Jaybhaye *et al.*, 2014).

12.2.3 Dietary Fibre

Water solubility of the sugar beet product is increased by the extrusion due to it reduces the sub-atomic mass of hemicellulose and pectin particles. Processing of product by twin screw extruder changes the content of dietary fibre. The high temperature will results in higher dietary fibre content of the wheat. Extrusion cooking has also increased the quantity of dietary fibre in extruded barley. Soluble dietary fibre of waxy barley is increased by increasing the overall dietary fibre (Vasanthan *et al.*, 2002).

12.3 Effect on Lipids

The extrusion process is carried out with the presence of lipids, these lipids possibly will be present in the ingredients as well as they can be provided externally. The torque produced in the barrel will be reduced as the lipid will decrease slip in the barrel. This will leads to poor product expansion as a result of inadequate pressure (Yu, 2011). During extrusion process the temperature is high which will leads to lipid release (Serrano, 1997). Sometimes lipid will also be released during extrusion due to mechanical disruption of cell walls present in the food materials. The level of hydrogenation and cis-trans isomerization of the fatty acids which takes place during extrusion is very minor to be nutritionally vital (Camire *et al.*, 1990).

13. Functional Properties of extruded food

Extrusion process mostly depends on the starch, the type of starch and quantity of the starch will affect the overall extrusion. Moisture content of extrusion is between 25%-30% with 30 to 90 s residence time (Huber, 2001). The moisture content and residence duration modifies the physiochemical properties of extruded foods alongside with nutritional value and organoleptic parameters, thus the standard of product also changes (Thymi et al., 2005). Bulk density, colour, Pellet Durability Index (PDI), expansion ratio, hardness, Water Solubility Index (WSI), and Water Absorption Index (WAI) are the physical properties of extruded food products (Muthukumarappan & Karunanithy, 2012).

13.1 Expansion Ratio

The expansion is categorised on cooled and dimensionally steady-and-stable products (Della *et al.*, 1996). For instance the moisture content of feeding material decreases, then the expansion ratio, rotating speed of screw, and temperature of barrel is increases. Expansion ratio of the extruded food products will abruptly decrease during increase in feed moisture (Pathania *et al.*, 2013). The barrel temperature, screw speed along with moisture content will impact the expansion ratio of all extruded products. More moisture content in inputs will result in significant decrease in expansion ratio (Oke *et al.*, 2013). Because of rise in rotating speed of the screw and barrel temperature, it will result in high expansion ratio and low expansion ratio due to the rise in moisture content (Kothakota *et al.*, 2013). The lower limit of starch content for decent expansion is 60%–70% (Conway, 1971).

13.2 Bulk Density

The density is affected by the free factors such as temperature, moisture content, and screw speed which are inversely proportional to the expansion ratio. Increase in rotating speed of screw and barrel temperature will result in lower bulk density of extruded food product (Kothakota *et al.,* 2013). High moisture content of the extruded food product will also affect the bulk density of extruded. The rate of bulk density of texturized rice will increases because of the gelatinization of starch and low rotating speed of the screw that is in between 21.10 to 32.60 RPM (Hagenimana *et al.*, 2006). Harper and Sahagun (1980) also observed the same while researching on the Corn and Soybean. They had found that the screw speed along with feed Temperature will have impact on the bulk density of the extruded food product.

13.3 Water absorption index (WAI)

When the gelatinisation is high it leads to higher expansion of extruded products. High mechanical shear will also have an impact on WAI. The high temperatures increase the dextrinization which may leads to rise in WAI. When the amount of moisture content is high in the product then the WAI will be lower as the water is present in product is will not allow to absorb more water. Barrel temperature and screw speed will also have a positive impact on the WAI (Mercier & Feillet, 1975). The positive impact of high barrel temperature on WAI is mainly due to higher amount of starch degradation.

13.4 Water solubility index (WSI)

The water solubility index of extruded products will decreases when the moisture content of the extruded products is increases and increasing when the temperature and rotating speed of screw increases. For instance the temperature of barrel increases, it brings down the water solubility index. Starch gelatinization is increased by the temperature which increases the amount of soluble starches that causes the rise in WSI. Ding *et al.* (2005) moreover accomplished the relation between the temperature and water solubility index in extruded food products.

13.5 Hardness

Higher hardness is a result of rise in temperature of barrel and lower hardness is a result of increase in rotating speed of screw. Increase in moisture content is brought about bring down the hardness. Ding *et al.* (2006) defined that lesser melt density grounds the increasing in rotating speed of the screw with bringing down the hardness Altan *et al.* (2008) detected that high expansion at the raised temperature causes the effect on hardness due to the temperature.

13.6 Product moisture

The product moisture in extruded products is depend on many different factors among them initial moisture content of the input is one of the major factor. Initial moisture content is directly proportional to the product moisture content. It was also detected that the extrusion temperature is inversely proportional to the moisture content of the final product. Higher extrusion temperature will decrease the moisture content of final product (Maurice *et al.*, 1988). The crispness of the extruded food product is completely depending on the moisture content of the food product (Richard *et al.*, 1988). The dried extruded food products have low water activity in the range of 0.10-0.33 which helps to reduce the microbial load and increases the shelf life of the extruded food product (Nikmaram *et al.*, 2015). Some of the quality parameters of the extruded food product including degree of cooking and expansion ratio are brought from digestibility and absorption are exactly related with the product moisture (Kirby *et al.*, 1988). Melt temperature of the extruded products is reduced by the moisture present in the extruder. Low viscosity of the product will cause increase in pressure due to the decrease in melt temperature of the extruded products. High shear extrusion and raised shear rate reduces the effect of moisture content on the product but results in instability of product. High moisture content of the puffed food products causes the thick cell wall and increases hardness of the extruded products (Mercier, 1979). Moisture affects the expansion ratio and water holding capacity of the extruded products (Bhattacharya & Hanna, 1987).

14. Conclusion

Among many different valuable methodologies used for the food processing, extrusion technology is having special importance. This novel technology is used for processing of many snack foods which is commonly prepared from breakfast cereals. This extrusion technology is used because it has many advantages like anti-nutritional factor destruction, killing of contaminated microbes, lipid preservation, and increase in many soluble dietary fibres. The extrusion can be practised by two methods among them cold extrusion is healthier as the nutrient loss is less, due to less temperature. The extrusion technologies have a great potential in food processing sector.

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