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Gaurav A Shelar

MIT College of Food Technology,

MIT-ADT University, Loni

Kalbhori, Pune, Maharashtra,

India

Sandip T Gaikwad

MIT College of Food Technology,

MIT-ADT University, Loni

Kalbhori, Pune, Maharashtra,

India

Extrusion in food processing: An overview

Gaurav A Shelar and Sandip T Gaikwad

Abstract

Extrusion processing plays the important role in food processing for the manufacturing of pasta, textured vegetable protein (TVP), ready to eat products such as snacks produced from cereals, in which baby foods, breakfast cereals, dietary fibre, pet foods, cereal based modified starch and traditional products. Extrusion technology is a food processing operation which is carried out by the combination of different operations such as mixing, shaping, kneading, forming and cooking. Extrusion cooking helps to lower the microorganism activity and helps in enzyme inactivation. Extrusions have impact on the qualities of food products due to high temperature. The major impact is on nutritional qualities along with physicochemical properties. As the nature of protein, starches and other constituents will be changed due to alteration in chemical structure. Various types of extruder are utilised for production of extruded items. The extrusion is classified according to two basis i.e. operation and construction. On the basis of operation extruder is classified as hot extruder and cold extruder and on the basis of operation it is classified as twin screw and single screw. The extruder is a machine which passes mixed ingredient through a specific type of die or orifice and formed material by the extruder is known as extruded. The rotating screw present in the extruder is fitted within a barrel which has the die at the end. This article focuses on the extrusion in food sector along with extrusion type and impacts of extrusion on different properties of food products.

Keywords: Extrusion system, extruded foods, extruder, extrusion cooking

Introduction

Extrusion is defined as a system of pushing mixed ingredients out through a small opening, called a die, to form and to shape the materials ^[1]. In food extrusion involves the both physical and chemical processes. Extrusion technology is mostly utilised in the modern food industry due to its product quality, multifunction, versatility, low cost, high productivity energy and environmentally-friendly. In extrusion cooking, starchy, moistened and proteinaceous food material are processed through the application of using of mechanical shear, heat and pressure. This process is done through the barrel and screw mechanism. The major impact is on nutritional qualities along with physicochemical properties. As the nature of protein, starches and other constituents will be changed due to alteration in chemical structure ^[2]. Extrusion cooking is the HTST (High temperature short-time) method, developed for the manufacturing of innovative value added ready to eat products such as produced from cereals, in which baby foods, breakfast cereals, dietary fibre, pet foods, cereal based modified starch and traditional products ^[3, 4, 5]. The extrusion process is carried out by two parameters, under high temperature and pressure or it is simple a non-cooking method, forming process. By the using of numerous raw ingredients extrusion cooking produces a large variety of food products. Food extrusion technology has become more vital in the food production industries as effective production process. By the using of different types of basic and raw ingredients, the extrusion cooking technology produces the number of food items for human consumption for their diet with various textures, shapes, flavours and colours. Extrusion process helps in producing snacks food, pet foods and transferring and accommodating liquefied shapes of pastes and doughs types of prepared basic material. Extrusion cooking is a HTST process, it brings inactivation of raw enzymes, lower the microorganism level from the finished product, deactivation of naturally occurring toxic substances, denaturation of protein, modification of lipids and gelatinization of starch. Extruded food products have lower water activity (0.1-0.4) and due to the lower water activity of cold and hot extruded food product are preserved for long time ^[6]. Quality parameters and predominant perception as convenience food these two factors reserve the place of extruded food products in human diet. The extruded food products are digestible, palatable and safe to consume. Classification of extruded food products are distinguished into animal consumption products, human consumption products, non-consumable materials and biodegradable.

Correspondence

Gaurav A Shelar

MIT College of Food Technology,

MIT-ADT University, Loni

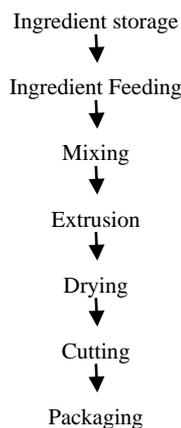
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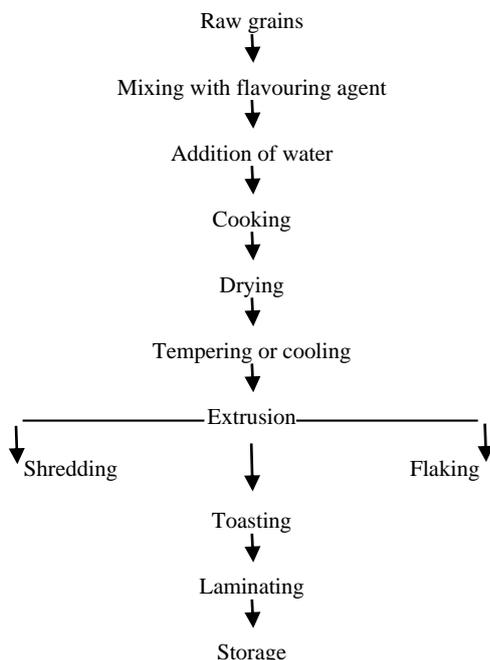
Extruded food products for human consumption are categorised into 7 types are as follows

- 1) Co-extruded
 - 1) Jelly filled cores
 - 2) Fruit based cereal
- 2) Directly Expanded
 - 1) Corn curls
 - 2) Breakfast cereals
- 3) Unexpanded
 - 1) Pasta
- 4) Modified
 - 1) Fat mimics
 - 2) Starches
- 5) Half products
 - 1) Potato pellets
- 6) Candy
 - 1) Liquorice
 - 2) Chewing gum
- 7) Texturized
 - 1) Meat analogues

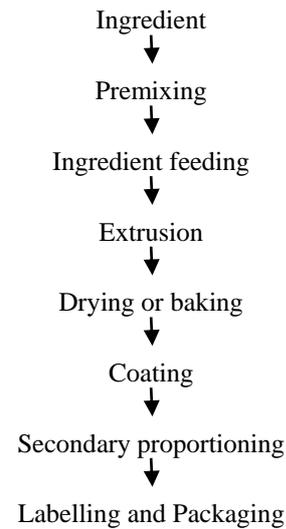
Processing flowcharts of some extruded food products
Pasta processing



Breakfast cereal processing



Snack food processing



Process

In extrusion method, ingredients used for product preparation are firstly grinded at the coarse flour consistency to the optimum particle size. From the pre-conditioner the processed raw material is passed, based on the final product and other ingredients are added to the processed raw material. To begin the cooking process steam is inserted and the processed raw material (extruded) from the pre-conditioner is processed through the extruder. The large rotating screw present in the extruder is strongly fitted within a barrel which has the die at the end. The extruded material passes from the die because of the large rotating screw present in the extruder forces the extruded material towards the die. The time spend by the material inside the extruder is referred as the residence time. The texture of extruded products like puffs changes there structure due to impact of heat and moisture release along with reduction of forces. The texture changes happens and it have different quantity. The ration of the change is considered as expansion ratio. The output from the extruder that is extruded is cut into the specific length by the using of blades, at a uniform speed which rotate about openings of die. During maintaining the porosity, the products become rigid after the cooling and drying. Due to the pressure generation (10-20bar) in the extruder product produces its own heat and friction and in the extruder cooking process is take place. Based on parameters and inputs, starch gelatinization and protein denaturation can cause in this process. HTST or high temperature short time methods involve in the many food extrusion processes. Dampness, extruded composition, speed of the blade, rotating speed and length of screw, temperature of barrel and shapes of die this are the important factor of the extrusion process. These are controlled dependent on the ideal item to guarantee consistency of the yield. From these factors of the extrusion process, moisture is the main factor which acting on plasticizing the extruded and affecting the mixing viscosity. Product temperature, torque and viscosity decreases when the moisture increases and bulk density increases. Due to this die pressure is also decreases. Food processing from the many extrusion processes required to control the moisture level from low to intermediate moisture level that is beneath to 40% moisture. The process in which the high moisture extrusion is carried out called as wet extrusion, after the introduction of twin screw extruder the wet extrusion is mostly used, which is having an increasingly proficient

passing on ability. Temperature is the most important rheological factor of high starch extruded in the wet extrusion. The level of salt of some extruded products will decide the texture and colour of extruded. Salt concentration of extruded product responsible for the airiness and expansion ratio of the product, perhaps because of starches and salt concentration present in the extruded which causes the chemical reaction. Salt concentration changes the colour of extruded this is due to the, "water activity of extruded item is changes by salt and subsequently browning reaction rate also change". Minor ingredients including flavours and food colours are distributed by the use of salt. After extrusion; these are all the more equally circulated over the item's surface in the wake of being blended with salt. In 1870, to manufacturing of sausage the first extruder was developed. Since 1930, by the using of extrusion technology breakfast cereal and packaged dry pasta have been developed, and in 1950 extrusion method is used for the production of pet food.

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

Extrusion has picked up in fame for the following reasons

- **Versatility:** Various types of food products are produced by changing the die shape, working state of the extruder and processed raw material.
- **Reduced costs:** Extrusion cooking lowers the handling costs and increases profitability than forming or cooking methods. Many conventional procedures such as cornflakes production and hotdogs are increasingly proficient and less expensive when supplanted by extrusion.
- **Higher productivity and automatic operations:** Extruders work persistently and have high outputs.
- **Quality of product:** Extrusion cooking is the HTST method and required low heats for processing therefore loss of heat sensitive compound are prevented.

Extruder

Extruder is a device which is used to give shape by pushing material from a specific type of die or orifice. An extruder is a thermodynamic unit. To operate the rotating screw of the extruder, it consists of a power supply, and rotating screw is surrounded by the barrel and feeder raw material. The rotating screws transfer the processed raw material to the orifice or die that gives the shape to the product. Heating, mixing, conveying of pre-ground and conditioned ingredient is done by a variety of processes which enter through the screw. The item leaves the extruder through a kick the bucket where it generally puffs and changes surface from the arrival of steam and ordinary powers. Grain processing utilizing an extruder offers great open doors for little scale organizations in India since raw materials are promptly accessible, extruders are sensibly moderate and if the items are picked accurately, they have a decent interest and can be productive. The preparing units have developed from straight forward passing on gadgets to end up exceptionally modern in the most recent

decade [7].

Major Parts

1. The pre-conditioning system
2. The barrel
3. The die and the cutting mechanism.
4. The feeding system
5. The screw or worm

There are various types of parts of extruder according to the die configuration, screw and barrel. The use of every part of the extruder will rely upon the raw material utilised and type of final product [8]. In the barrel of the extruder there is rotating screws which transfer the material through the barrel and uniformly mix the material into different types. In cold extrusion method heat is not required it only shapes the food into different forms by applying pressure material is discharged from the barrel through the specific type of die. In the extruder cooker the material present in the barrel is warmed by friction and it rises up and passes from the die on pressure. Some breakfast products have crisp and light texture and they extend quickly due to the steam is releases because of the pressure when the material rises up through die.

Classification of Extruders

Classification of extruder based on two categories, Operation and Construction.

Based on operation

1. Hot Extruder
2. Cold Extruder

Based on Construction extrusion can be classified as

1. Twin screw extrusion
2. Single screw extrusion

Cold Extrusion

The elevated cooking temperatures used in normal extrusion lead to discoloration of whey proteins from the Millard reaction, racemization of protein during cross-linking, destruction of the sulphur-containing amino acids, cysteine and methionine, and other problems [9]. In cold extrusion heating of food is carried out up to 100 °C called cold extrusion. In Cold extrusion, food temperature is constant which is used to shaping and mixing of food including meat products and pasta. Temperature less than 100 °C is also used for low pressure extrusion. Ex. Pet Foods. Chilling, baking or drying methods are used for the preservation of cold extruded products. While extrusion cooking eliminates contaminating micro-organisms and preserve the dry food products for longer period. Packaging of dry products prevents the oxidation and moisture absorption while storage. Cold extruders are appropriate for small scale industry and also for household use. Extruder cookers are used by only large scale industries because they are high in cost. The primary use of cold extruders is in pasta creation, albeit comparable machines are utilized to frame roll batter into various shapes. A pasta extruder (Figure 1) is utilized to make a wide range of pasta utilizing mixture produced using durum wheat flour (or 'semolina') and eggs. By adding tomato purée or spinach paste coloured paste also made.



Fig 1: A pasta extruder

There are various types of extruder are available which are used in small scale manufacturing and food outlet from manual operating to fully automatic machines. The pasta extruder has different parts such as die, extruder barrel and mixing chamber which are used for making of specific shape of paste. Many equipment manufacture companies make the die from plastic, stainless steel or preferring bronze, which they guarantee that it gives harsh surface to the pasta that, holds sauce superior to any pasta made by different techniques. They are cut into specific size and shape after the rise up out from the die. Rigatoni is firstly extruded and then cut into specific size (straight for rigatoni or angled for penne rigati). Pasta is not only immediately cooked but also dry for retail sell. Pasta is also preserved up to six months.

Hot extrusion

Hot extrusion is also known as extrusion cooking in which heating of food is carried out at more than 100 °C. Frictional heating and other heating methods is used to increase the temperature quickly. After the heating of food it is passed to barrel sections which have a small flight which helps to increase the shear and pressure. At last, food is passed from the die under pressure, after the final shaping food is cooled quickly to remove moisture in the form of steam. Product is formed into many type of shapes such as shells or squirrels, doughnuts, strips, rods, tubes and spheres. Different types of food product are formed by extrusion cooking including puffed cereals (RTE), expanded snack foods etc. Extruders are the single screw or twin screw equipment. Twin screw extruder are not affordable by small scale industries because they have high maintenance and capital cost as compare to single screw extruder. Single-screw extruder (Fig. 2) and Twin screw extruder (Fig. 3) is described as follows.

Single screw extruder

Single screw extruder contain one screw which continuously rotate in barrel of single screw extruder, and these come in different types. The regularly utilized single screw extruders have a consistent pitch.



Fig 2: Single-screw extruder

Used process raw material and working state in the barrel are the main factor that control the quality and type of extruded food product that are manufactured by the hot extrusion method.

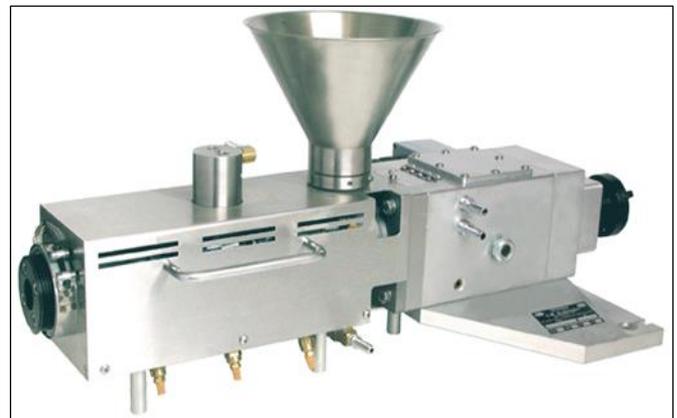


Fig 3: Twin-Screw extruder

Two rotating parallel screw having same length are present in barrel of twin screw extruder. Twin screw extruder entangled than single screw extruders, and yet gives substantially better control and more adaptability. The flow of product will be uniform through barrel as a result of positive pumping of screw flights.

Types of extruded food products

1. Starch based products
2. Sugar based products
3. Cereal based products
4. Protein based products

Extrusion technology having special significance in food processing due to its applications in food production, low cost, higher productivity, flexibility and product quality as to other methodologies [10, 11, 12].

Effect of Process Parameters of Extrusion on Quality of Extruded

Extrusion technology permits the production of food product through a nonstop, economical process which gives qualitative consistency of the finished product. It is done through dominating numerous parameters of the extrusion technology. Extrusion technology also developed new quality food product and redevelop several snack producing methods. The reactions happens in different chemicals inside the

extruder is result of extrusion process. This reactions happens majorly at the end of die and extruder barrel.

Effect of extrusion technology on food product

1. Raw enzyme inactivation.
2. Naturally present toxin destruction.
3. Lower the microbial load of finished product.
4. Increases the bioavailability of iron.
5. Loss of EAA that is lysine.
6. Extrusion processes convert the complex starches into simple form.
7. Effect on tooth (rot).
8. Extrusion method increases the glycaemic index of food products.
9. Loss of vitamin A.

Nutritional Properties

Effect on protein and amino acid

Protein absorbability of the extruded food product is expanded by the extrusion cooking technology. The extruded food products prepared from cereals are rich in essential amino acid that is lysine. Subsequently an emphasis on safekeeping of lysine during extrusion method is of specific significance ^[13].

Carbohydrates

Sugar

Sugars including sucrose, fructose and lactose are the good source for instant energy. Sugar impart the sweet taste of the food product. Sugars are responsible for the some chemical reactions occurs in the extrusion process. It is necessary to control the sugar in the extrusion process to maintain the nutritional and organoleptic properties of extruded food product. Extrusion process results in loss of some sugar. It is due to the sucrose get converted into the fructose and glucose and maillard reactions with protein and sugar. The quality of some legume based extruded food product is increased by obliteration of some oligosaccharides ^[14].

Starch

In the extrusion process starches are exposed to heat, mechanical shear and pressure up to 103 psi ^[15]. Starch is comprised of glucose units connected by glycosidic bond. Amylopectin and amylose are the starch molecules. Amylopectin and amylose responsible for the viscosity and gelatinization of the cooked paste. The atomic weight of starch molecules of the wheat flour is decreased by the feeding moisture and low temperature of die.

Dietary Fibre

Water solubility of sugar beet product is increased by extrusion due to it lessens the sub-atomic weight of hemicellulose and pectin particles. Processing of product by twin screw extruder alter the content of dietary fibre. It was found that the higher temperature will; result in higher dietary fibre content of wheat. Extrusion cooking have also increased the amount of dietary fibre in extruded barley. Soluble dietary fibre of waxy barley is increased by increasing total dietary fibre ^[16].

Lipids

The extrusion process is helped with presence of lipids, these lipids may be present in ingredients as well as they can be added externally. The torque is reduced as the lipid will

decrease slip in the barrel. This will lead to poor product expansion as result of insufficient pressure. During extrusion the temperature is high which will result in lipid release. Lipid will also be released during extrusion due to mechanical disruption of cell walls.

Functional Properties

Extrusion is very much depends on the starch, its type and quantity will effect overall extrusion. Moisture content of extrusion is between 25-30% with 30 to 90 s residence time ^[17]. The moisture content and residence time changes the physiochemical properties of extruded along with nutritive value and organoleptic parameters, thus quality of product also changes. Bulk density, colour, expansion ratio, Water Solubility Index (WSI), hardness, Pellet Durability Index (PDI) and Water Absorption Index (WAI) are the physical properties of extruded ^[18].

Expansion Ratio

As the moisture content of feeding material decreases, the rotating speed of screw, expansion ratio and temperature of barrel is increases. Expansion ratio of extruded food product is sharply decreases when increase in feed moisture ^[19]. The barrel temperature, screw speed along with moisture content will influence the expansion ratio of about all extruded products. Higher moisture content of inputs will result in significant decrease in expansion ratio ^[20]. Increasing in rotating speed of screw and barrel temperature result in high expansion and low expansion due to the increase in moisture content ^[21].

Bulk Density

The density of extruded food product affected by the free factor such as moisture content, temperature and screw speed which is inversely to the expansion ratio. Rise in rotating speed of screw and barrel temperature causes the lower bulk density of extruded food product. High moisture content of the extruded food product also affected the bulk density of extruded. The value of bulk density of texturized rice is increases because of the gelatinization of starch and low speed of rotating screw that is in between 20.1 to 32.6 RPM ^[22]. Sahagun and Harper (1980) also observed the same result when researching on the Corn and Soybean. They have found screw speed along with feed Temperature will have impact on bulk density of the extruded product.

Water absorption index (WAI)

The higher gelatinisations lead to higher expansion of extruded products. High mechanical share it also have impact on WAI. The high temperatures increase the dextrinization which may lead to increase in WAI. Higher the amount of moisture content in the product lower will be WAI as the water is present in product is will not absorb more water. Barrel temperature and screw speed will also have positive impact on the WAI. Positive impact of increased barrel temperature on WAI is mostly due to higher amount of starch degradation.

Water solubility index (WSI)

The water solubility index of extruded is decreases when the moisture of the extruded is increases and increasing as the temperature and rotating speed of screw increases. As the temperature of barrel increases, it bring down the water solubility index. Starch gelatinization is increased by

temperature which increases the quantity of soluble starches that causes the rise in WSI. Ding *et al.* (2005) additionally accomplished the relationship between temperature and water solubility index in extruded food products.

Hardness

Higher hardness due to the rise in temperature of barrel and lower hardness due to the increase in rotating speed of screw. Rise in moisture content brought about bring down hardness. Ding *et al.* (2006) reported that lower melt density causes the increasing in rotating speed of screw with bring down hardness Altan *et al.* (2008) observed that high expansion at raised temperature causes the effect on hardness due to temperature.

Product moisture

The product moisture is depend on many factors among them initial moisture content of the input is major factor. It is directly proportional to the product moisture content. It was also observed that the temperature used for extrusion is inversely proportional to the moisture content of final product. Higher extrusion temperature will reduce the moisture content of final product ^[23, 24]. The crispness of the food product is totally depend on the moisture content of the food product. The dried extruded food products have low water activity ranging from 0.1-0.33 which helps to lower the microbial load and increases the shelf life of the food product. Quality parameters of the food product including degree of cooking and expansion ratio are induced from digestibility and absorption are specifically related with product moisture ^[25]. Melt temperature is reduced by the moisture present in the extruder. Less viscosity of the product causes increase in pressure due to the decrease in melt temperature. High shear extrusion and raised shear rate decreases the impact of moisture content on product but results in instability of product. High moisture content of puffed food products causes the thick cell wall and increases hardness ^[26]. Moisture affected the expansion ratio and water holding limit of extruded items ^[27].

Conclusion

Among many valuable methodologies used for the food processing extrusion is having special significance. It was observed that this innovative technology is used for processing of many snack foods which is generally prepared from breakfast cereals. This method is used because of many advantageous effects i.e. anti-nutritional factor destruction, lipid preservation, killing of contaminated microbes and increase in many soluble dietary fibres. The extrusion have two different methods among them cold extrusion is better as the nutrient loss is less, due to less temperature. The extrusion technologies have great potential to be used in food processing sector. Further research is required in the context of nutritional quality of extruded product and efficiency of extrusion.

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