Extrusion technology and its effects on Nutritional values

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Abstract: Food production uses extrusion technology and has done so for many years. Extrusion cooking can be used to produce food items such as ready-to-eat cereals, a few snacks, dry or semi-moist pet feeds, confectionery goods, macaroni products, and goods containing texturized soy protein. In food manufacturing, extrusion entails pressing soft, combined ingredients through a hole in a perforated plate or die intended to create the desired form. The meal is extruded and then chopped using blades into desired sizes. The device that pushes the mixture through the die is called an extruder, and the mixture is referred to as extrudate. Typically, the extruder consists of a sizable revolving screw that is fitted securely inside a stationary barrel with a die at the end. The effects of extrusion cooking on food items' nutritional quality are debatable since extrusion may alter the extrudate's carbohydrate, dietary fibre, protein and amino acid profile, vitamins, and mineral content in ways that are either advantageous or detrimental. Extrusion at a high temperature for a brief period of time "minimises losses in vitamins and amino acids." Extrusion makes it possible to produce some foods in large quantities and "denatures antinutritional elements," such as eliminating poisons or eradicating bacteria. Moreover, it affects the product's "protein quality and digestibility" and form, texture, colour, and flavour.

Keywords: extrudates, lysin retention, protein digestibility, starch gelatinization, total phenolic content
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1. Introduction

Extrusion processing is defined as the process by which moistened, starchy and proteinaceous food materials are plasticized through a die by a combination of moisture, pressure, heat and mechanical shear (Maurya & said, 2014). Food extrusion involves the process of forcing food materials to flow under a variety of operations, including kneading, melting and/or shear, through an orifice (die) which is specifically designed to shape and/or expand the material (Steel et al., 2012). It is a high temperature and short time (HTST) process which inactivates enzymes and reduces microbial contamination. As it is a HTST process, which reduces microbial contamination and inactivates enzymes, the main method of preservation of both hot and cold extruded foods is by the low water activity of product (0.1-0.4) (Bordoloi and Ganguly, 2014). Comparatively speaking, the procedure uses less moisture than traditional baking or dough processing. On a wet weight basis, the typical moisture levels are in the range of 10 to 40%. This technology has some unique positive features compared with other heat processes, because the material is subjected to intense mechanical shear. Extruders uses pressures ranging from 15 to over 200 atmospheres to regulate shape, maintain water in a super-heated liquid condition, and boost shearing forces in specific screw types.

The most difficult and demanding field now, and it will remain so in the future, is health and nutrition. Research on preserving and improving food's nutritional value while it is being processed is always vital. A difficult issue with most conventional cooking techniques is the nutritional quality degrading at high temperatures. Extrusion cooking is preferable to other food-processing techniques in terms of continuous process with high productivity and significant nutrient retention, owing to the high temperature and short time required (Guy, 2001). Food extruders may be designed to perform several unit operations concurrently, including mixing or homogenization, shearing, starch gelatinization, protein denaturation, texturization, enzyme inactivation, thermal cooking, pasteurization, dehydration, shaping and size reduction (Akhtar et al., 2015; Fellows, 2000).

The hectic kind of life we lead nowadays has greatly altered how we behave when it comes to food. So, a lot of consumers are forced to adjust for ready-to-eat and ready-to-cook food that is nutrient-rich and therapeutic. Hence, extrusion technology is employed to satisfy consumer demand.

Extrusion cooking has gained in popularity over the last two decades for a number of reasons:

1. **Versatility**: a wide range of products, many of which cannot be produced easily by any other process, is possible by changing the ingredients, extruder operating condition and dies
2. **Cost**: extrusion has lower processing costs and higher productivity than other cooking and forming processes
3. **Productivity**: extruders can operate continuously with high output
4. **Product quality**: extrusion cooking involves high temperatures applied for a short time, retaining many heats sensitive components of a foods
5. **Environmentally**-Friendly: as low - moisture process, extrusion cooking does not produce significant process effluents, reducing water treatment costs and levels of environmental pollution,

2. History

As early as 1797, the first extrusion process was patented by Joseph Bramah for metal alloys. Food extrusion has a long history. It started as early as the 1870s with meat extruders that were used to make sausages. In the 1930s, the mass production of extruded dry pasta and breakfast cereals was implemented and adopted by many bakeries. Since then, food extrusion technology has become popular in many food-processing industries such as confectionery, breakfast cereals and porridges, bakery products, instant drinks, meat processing and many others (Egal & Theron, 2019).

The origin of extrusion process is closely associated with polymer science and technology. In the midth-1850s, extrusion was used to produce the first seamless lead pipe. The first man-made thermoplastic, celluloid, was manufactured in 1860s based on a reaction between cellulose and nitric acid. The manufacturing of Bakelite in 1907, and the protective coating resin, glyptal, in 1912, was dependent on extrusion processing. Formal applications of extrusion processes to foods began in the 1930s and evolved over the following 50 years, as equipment for extrusion processing increased in capabilities and complexity. Extrusion cooking was first introduced in food and feed processing in the late 1950s (Caroline et al., 2012). The first patent on an application of twin-screw extrusion technology was filed in the mid-1950s. The word “extrudate” emanates from the Latin word “ex” (out) and “trudere” (to thrust) (Adekola, 2016). Since then, the application of extrusion technology in food processing has advanced, widened and grown dramatically (Rao and Thejaswini, 2015).

3. Extruder

An extruder is a device which pushes or pulls a material through a shaped die to form a continuous length of product with a predetermined cross section. It is used to make a variety of food of different shape Food extruders may be designed to perform several unit operations concurrently, including mixing or homogenization, shearing, starch gelatinization, protein denaturation, texturization enzyme inactivation, thermal cooking, pasteurization, dehydration, shaping and size reduction (Akhtar et al., 2015).

The use of thermoplastic extrusion in food processing is facilitated by the dynamism of extruders, which can be divided into two types: single-screw and twin-screw extruders (Riaz, 2000). Extruders have been produced in a range of configurations and performances, and they are grouped according to the uses, designs, and configurations for which they are most suited.

Extruders consist of five major components:

(i) the preconditioning system
(ii) the feeding system
(iii) the screw or worm
(iv) the barrel
(v) the die and the cutting mechanism.

Principle and Working of an Extruder

The raw materials are introduced into the screw(s), which then transports the food. Smaller flights that are farther down the barrel limit the volume and stiffen the food's resistance to movement. It consequently becomes squeezed and fills the barrel as well as the crevices between the screw flights. The material is kneaded by the screw as it advances up the barrel, forming a semi-solid, plasticized mass. Extrusion cooking is the term for the procedure where the meal is heated above 100 degrees Celsius (or hot extrusion). Here, the temperature rises quickly as a result of frictional heat and any additional heating that is applied. High operating temperatures encourage the gelatinization of starch components and the stretching of expandable components when there is water present. After pausing the meal, the pressure and shearing are increased in the barrel part with the smallest flights. At the discharge end of the barrel, it is finally driven through one or more restricted apertures (dies) as the food emerges under pressure, expands to its final shape, and cools quickly as moisture flashes off as steam. Low pressure extrusion, at temperatures below 100 degrees Celsius, is used to produce, for example fish pastes, surimi and pet foods (Bordoloi and Ganguly, 2014). The operating parameters in an extruder are:

- temperature
- pressure
- diameter of the die apertures
- shear rate

Classification of Extruders

Based on operation:

1) Hot Extruder
2) Cold Extruder

Based on construction:

1) Single Screw
2) Twin Screw
    - Counter Rotating Extruder
    - Co-Rotating Extruder

4. Cold Extrusion Technology

This procedure results in goods with a high density and humidity, such as muffins, cookies, or sweets, without raising the temperature of the meal. It is frequently used to make pasta in food processing facilities. Food is heated during cold extrusion to a maximum of 100 degrees Celsius. When food is shaped and mixed, including meat products and pasta, cold extrusion is utilised to maintain a steady food temperature. Low pressure extrusion can also be done at temperatures lower than 100 degrees Celsius. 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).

Cold extruders are appropriate for both home use and small-scale enterprise. Because they are so expensive, extruder cookers are only utilised by large-scale companies.

5. Hot extrusion technology

In this, the raw material is thermos-mechanically converted under pressure at high temperatures (HTST) in a brief period of time. This technology is used to manufacture foods including cereals that are ready to eat for breakfast, snacks, and other textured food and feed products. Food is typically heated at a temperature more than 100 degrees Celsius. To raise the temperature quickly, frictional heating and other heating processes are employed. Food is transferred to barrel sections with small flights that serve to generate shear and pressure once it has been heated. Following the final shape, the food is quickly chilled to remove the moisture present in the form of steam before being forced under pressure through the die. Products are shaped into a wide variety of shapes, including spheres, doughnuts, doughnut-like shapes, rods, tubes, shells, and squirls.

6. Single screw extruder

There is only one screw in a single screw extruder (Fig.1), and it revolves constantly inside the barrel. They are often available in several varieties. Operations like dry extrusion, which are straightforward and inexpensive to run, are used.

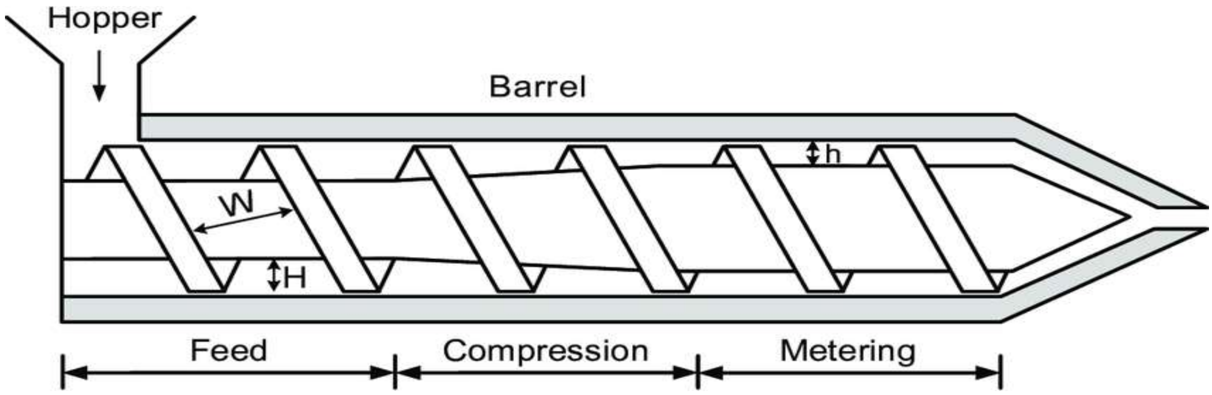

Fig.1 Single Screw Extruder (Altinkaynak, 2010)

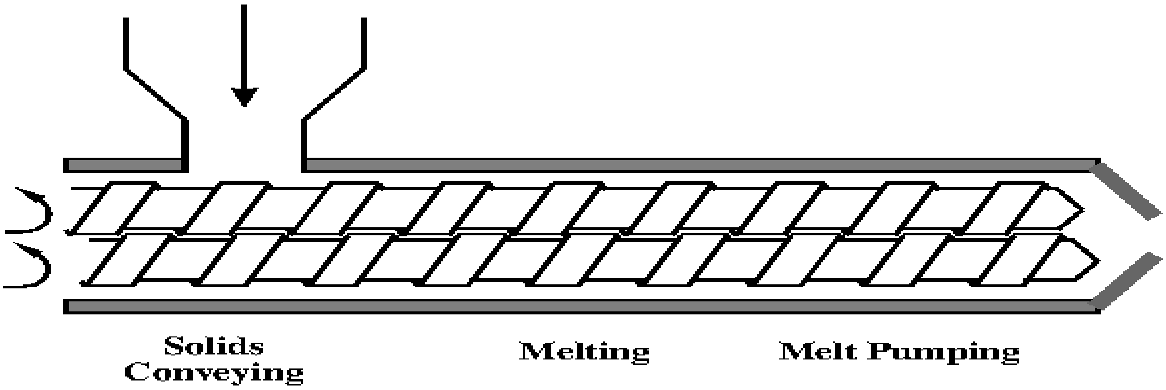

Fig.2 Twin Screw Extruder (Patil et al, 2005)

7. Twin screw extruder

Two revolving parallel screws (Fig.2) with the same dimension are present inside the barrel of a twin screw extruder. While being more complicated than single screw extruders, twin screw extruders offer significantly better control and more variety. For the same capacity, twin-screw extruders are often more expensive than single-screw machines. The flow of product will be uniform throughout the barrel as a result of positive pumping of screw flights. (Adekola, 2014).

8. Raw Material used in Extrusion Cooking

<u>CEREALS</u>

The most important source of overall food consumption in terms of calories is cereal grains, which are common staples and offer more food energy than any other food category. Cereals have relatively similar overall composition, which is often low and high in protein and carbohydrates, respectively, with the exception of oats and maize which contain comparatively higher amounts of lipids (7-9 %), compared to 1-2 % in other cereals (Riaz, 2010). Apart from breakfast cereals and snacks, other extruded cereal-based products include pasta, breads, soup bases and modified starches, biscuits, croutons, and confectionary (Ilo et al., 2000). There are two varieties of breakfast cereals: ready-to-eat cold cereals and heated cereals (traditional cereals). The RTE cereals are usually cooked and modified by flaking, toasting, puffing, shredding or extruding (Varsha and Pavani, 2016). Wheat bran, a by-product from the milling of wheat, has been used with plant proteins to produce expanded snacks and breakfast cereals of improved nutritional and fibre value (Onipe et al., 2015). Granola are RTE cereals made from oats mixed with added ingredients including vegetable oils, sweeteners (brown sugar, honey), flavours (cinnamon, malt extract, nutmeg, dried fruits) and protein (dried milk) (Neulicht and Shular, 1995). This blend is subsequently toasted in an even layer 8 until it browns, and a low moisture is attained, after which it was broken into smaller pieces (Tribelhorn, 1991). Rice flour is extensively used in infant food formulations, and may also serve as an important alternative to wheat for gluten-intolerant individuals (Rosell and Collar, 2007).

<u>ROOTS AND TUBERS</u>

They have a lot of promise for the creation of extruded items, especially given how much starch they contain. They are the second most significant source of carbohydrates in the world after grains. Major root and tuber crop common to the tropics include cassava

(*Manihot esculenta Crantz*), yam (*Dioscorea spp*.), sweet potato (*Ipomoea batatas L*.), potato (*Solanum spp*.), and cocoyam (*Colocasia spp. and Xanthosoma sagittifolium*) (Chandrasekara and Kumar, 2016). Among these, potato and cassava are the most commonly used in extruded snacks, as flour, granules, starch or flakes (Ilo et al., 2000). Potato starch may contain amylose (20-25 %), and a low lipid (0.1 to 0.2 %) content (Guy, 2012; Riaz, 2006), and could be incorporated into extruded snacks to provide additional expansion and improved functional properties (Guy, 2012). Extrusion of flours from root and tuber crops has enabled the production of a range of snacks and pre-gelatinized flours, thereby providing an economic means of diversifying the utilization of such crops (Akinoso and Abiodun, 2016).

PULSES AND OILSEEDS

Legumes contain compounds such as lectins, saponins, cyanogenic compounds, trypsin and chymotrypsin inhibitors, which exert anti-nutritional effects upon ingestion (Berrios, 2016). Simple extruded products such as RTE snacks and pasta have been formulated from blends of legume flours and other components, especially cereal flours and starches (Hulse, 2012). Despite the wide range of legumes available, soybean protein 14 is considered the best choice for processing texturized products. Defatted soy flour traditionally used in texturized products usually has a minimum protein content of 50 %, and protein dispersibility index (PDI) of 60 to 70, however, general raw material specifications for extrusion of texturized proteins include 20-80 PDI, 0.5-6.5 % fat, up to 7 % fibre, and up to 8 mesh particle size (Kearns et al., 2013). Vegetable oils are a valuable resource with several uses in food, and the process used to extract them from oilseeds is crucial in determining the oil's quality. Oilseeds include legumes such as soybean and peanuts primarily grown for oil extraction, and non-leguminous oil crops such as linseed, cottonseed, sunflower, safflower, sesame, rapeseed, mustard seed, melon seed, hempseed, among others (Yadava et al., 2011).

ANIMAL PRODUCTS

Animal products including fish flour/powder, minced fish and fish pastes, egg white powder, meat, milk powder, and cheese, which are excellent sources of proteins and other nutrients, have also found useful application in extrusion processing of novel food products (Dileep et al., 2010; Dubey, 2011). Several extruded goods using these culinary ingredients have been successfully developed. These components are added to extruded goods for a variety of reasons, including increased nutritional value, new product development and market expansion, taste innovation, and ingredient diversification. Incorporation of under-utilized seafood has garnered recent research interest, and incorporating these high protein fractions into extruded products creates value for low-cost and underutilized seafood, thereby enhancing their utilization (Surasani, 2016). In chicken meat noodles from whole wheat flour and meat at inclusion levels of 0, 30, 40 and 50 %, increased meat levels led to reduced crude fibre, yield, water solubility index, volume increase and cooking loss, however, fat, protein, ash and water absorption index significantly increased with higher meat inclusion levels (Verma et al., 2014), and the most desirable noodle product was that which contained 30 % meat. Also, extruded snacks were formulated from 50:50 rice flour: meat, 50:50 corn flour: meat and 60:40 wheat flour: meat blends, and although the product which contained 100 % meat had higher pH, bulk density, moisture, protein and fat than all the blends, it had lower hydration ability, water solubility and water absorption index (Anandh, 2013). Nutrient-rich RTE snacks developed from croaker fish flour (Johnius dussumieri) and blends of rice flour, corn flour and soybean flour, using a twin-screw extruder gave the most desirable product, in terms of quality and acceptability, when formulated from 18 % fish flour, 45 % rice flour, 30 % corn flour, and 5 % soybean flour, while the product containing less fish flour (12 %) had better expansion (Mulye and Zofair, 2015).

Legume type	Extruder type	Temperature of die zone	Feed moisture (%)	Screw speed (rpm)	Result
Faba bean	Twin screw	140	-	300	Less dense less hard extrudates
Cowpea	Single screw	180	16	200	
Chickpea	Twin screw	140	17	434	
Lentil	Twin screw	160	18	200	

Table 1 Optimum Value of parameters for legume based extrudates

Source	TPC content in input raw material (mg/100gm)	TPC content in output extrudates (mg/100gm)	Type of extruder	Retention (%)
Glutinous rice flour	36	7-12	Co-rotating twin screw	34-85
Ground wheat	266	210	Single screw	79
Millet	295	455	Twin screw	154
Oat flour	158	146	Single screw	92
Rice flour	123-402	51-741	Twin screw	92
Soyabean	540	652-660	Twin screw	120-122
Wheat flour	340	220	Co-rotating twin screw	65

Table 2 TPC content of extrudates after extrusion

9. Effect of extrusion on nutritional values of food

Change in Total Phenolic Content of extrudates

Polyphenols are secondary metabolites of plants that are used in their defence against severe environments, such as ultraviolet radiation or attack by pathogens (Shahidi et al, 2016). These compounds are generally classified as flavonoids, phenolic acids, lignans, and stilbenes. They are widely distributed in plant-based food products and influence the Maillard reaction (Eskin et al, 2013). Phenolics are linked to several health benefits, including antioxidant, antibacterial, antiglycemic, antiviral, anticarcinogenic, anti-inflammatory, and vasodilatory properties (Osakabe et al, 2004). The TPC data of one-component extrudates from sources is given in Table 2

Protein digestibility

A series of amino acids are used to create the exceedingly complex chemical molecules known as proteins. Isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine are regarded as essential amino acids among the twenty-two amino acids that make up the majority of proteins. The amount, digestibility, and accessibility of the necessary amino acids all affect how nutrient-dense a protein is. The best indicator of protein quality is thought to be digestibility. Protein digestibility in non-extrudates is higher than extrudates due to denaturation of protein and inactivation of antinutritional factors that impair digestion.

Extrusion (300-r.p.m. screw speed, 27 kg/h feed rate, 5/32 inches die size and 93–97degree Celsius outlet temperature) causes complete destruction of trypsin inhibitor activity in extruded blends of broken rice and wheat bran containing up to 20% wheat bran (Singh et al., 2000). Nevertheless, it was discovered that by heating the fully ingested seed for 5 minutes at 100 C, the lectin activity could be totally eliminated, as was the case with kidney bean. Legume flour's lectin activity has been demonstrated to be significantly reduced or eliminated by extrusion. Extrusion has been shown to be very effective in reducing or eliminating lectin activity in legume flour (Alonso et al., 2000a) Researchers found behaviour of molecular aggregation and chemical cross-linking of soybean protein at both low and high moisture content during extrusion. The results showed that, hydrophobic interactions, hydrogen bonds, di-sulphide bonds, and their interactions collectively hold the structure of protein extrudate regardless of the location and moisture level in the extruder and the contribution of non-covalent bonds during process also exceeds covalent bonds to bring about the change (Chen et al, 2011). The inhibition of antitrypsin activity in extruded snacks improves the enzyme hydrolysis of protein during extrusion heating. Pepsin's greater affinity for protein than trypsin's further supported the possibility of antitrypsin action. The improvement in pepsin hydrolysis might be the result of the denaturation of proteins during extrusion cooking, rendering them more susceptible to pepsin activity. This suggests that extrusion considerably improved the nutritive value of proteins (Singh et al., 2000).

Lysin retention

Lysine is the scarcest necessary amino acid out of all the essential amino acids found in cereal-based goods, which make up the bulk of extruded products. Hence, it is crucial to concentrate on lysine retention throughout the extrusion process. The available lysine in the extrudates of defatted soy flour and sweet potato flour mixture ranged from 68 to 100% (Iwe et al., 2004). Increase in screw speed (80– 140 r.p.m.) and a reduction of die diameter (10–6 mm) enhance lysine retention. Although while an increase in screw speed causes shear to increase and the circumstances to become more severe, the shorter residence time that results from the increase in screw speed shortens the period that materials are subjected to heat treatment, which leads to high lysine retention.

Animal proteins (egg and milk proteins at 10 and 30% levels) and reducing sugars (fructose and galactose at 0, 2 and 8% levels), with pregelatinized wheat flour, were extruded at 110- and 125-degree Celsius product temperature and feed moisture of 19 and 23.5% for egg protein and 13.5 and 16% for milk protein. Lysin showed the lowest retention (up to 40%). Retention of other essential amino acids varied from 80 to 100% in most situations. Increased protein and sugar levels resulted in significant degradation of lysin. Greater lysin retention was found at a lower temperature and higher feed moisture (Singh et al, 2007).

Starch Gelatinization

In the presence of water and heat, the intermolecular connections between starch molecules are broken down, allowing the hydrogen bonding sites (the hydroxyl hydrogen and oxygen) to engage additional water. This process is known as starch gelatinization. Starch gelatinization does not alter total starch content but may cause some degradation and influence the digestibility of the product (Bao and Bergman, 2004). Major sources of starch in extruded products are cereals and root or tuber crops (Riaz, 2006). The features of starch granules vary depending on the source and type, and the two components of starch, amylose and amylopectin, have various physical and chemical characteristics and change in these components after the overall starch content of extrudates. The effect of their ratio has been comprehensively studied by many researchers. Amylose adds lightness and flexibility to goods, however with a sticky surface, whereas amylopectin generates harder extrudates with less extension. For products with good texture and hardness, 5 to 20 % amylopectin content is recommended in feed materials (Moscicki et al., 2013). Gelatinization temperature is specific for starch granules from different sources and some typical ranges include 62–80 degree (maize), 52–85 degree (wheat), 58–65 degree (potato), and 52–65 degree for tapioca (Moscicki et al., 2013). The functioning of the starch has a significant impact on the end product's quality characteristics, such as moisture content, viscosity, texture or consistency, taste, and shelf life. Expansion of a product following its release from the die is controlled by gelatinized starch, cellulose complex and cellular proteins, and the final product structure is irrevocably changed.

ADVANTAGES OF EXTRUSION

- Adaptability: It may change to meet the need of customers for new meals. Extrusion may be used to create a wide range of conventional/traditional meals, convenience foods, and snacks that are sold in India.
- Product characteristics: Products can be made in a range of sizes, forms, textures, colours, and appearances. The other production techniques cannot produce them.
- Good product quality: As extrusion is a high temperature, quickly heating process, it is possible to obtain products of a high quality and consistency. It eliminates the anti-nutritional elements in food and increases the digestion of proteins and carbohydrates.
- Reduced cost: Extrusion uses fewer raw materials, requires less labour, and requires less capital investment. It operates in a smaller space and uses less manpower and energy.
- No waste or effluent generation: There are no disposal issues or waste or effluents produced by extrusion.
- Novel foods: Extrusion may alter the proteins and carbohydrates of both animal and plant sources to create interesting treats.
- Foods with low-calorie, high-fibre, high-protein, and nutrient-dense food supplements can be developed.

LIMITATIONS OF EXTRUSION

- Loss of vitamins, proteins and amino acids: The high temperature during the puffing process causes some of the reducing sugars in raw materials to undergo Maillard reaction with free amino acids, which reduces the utilization of some proteins. Excessive heating, especially in the case pf high pH, can make some amino acids racemize to produce D-type amino acids, which makes the protein, the digestibility is greatly reduced. Temperature, pressure, fiction and moisture also causes the loss of vitamins
- Fading of product color due to expansion on excessive heat: Due to elevated temperature and low moisture conditions used, different chemical reactions such as the non-enzymatic browning and caramelization can take place.
- Temperature treatment of food material containing proteins and reducing sugars usually leads to a deterioration of the nutritional characteristics of proteins(lysine).

10. Conclusion

We can conclude by saying that it is a commonly used manufacturing process and is highly consistent and has higher accuracy. According to the research analysed, this technology has the potential to generate highly nutritious and ready-to-eat food products which is highly needed nowadays. Nowadays consumers do choice for convenient and ready to cook and eat food with nutritionally rich and therapeutic benefits. This technology can be used to make various variety of quality food with many nutritional benefits. The extrusion process has the potential and is likely to continue to develop and used widely in the future to meet the increasing demands of consumers.

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