Extrusion Technology: Innovative Solution for Instant Food Production

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ABSTRACT

Extrusion technology is emerging as a preferred method in agro-food processing, leveraging mixing, forming, texturing, and cooking to develop innovative food products. Extrusion cooking is a high-temperature, short time process that effectively inactivates enzymes and minimizes microbial contamination. The preference for extrusion cooking stems from its ability to achieve high productivity while preserving nutrients more effectively than conventional cooking techniques. The food processing sector has come to rely on extrusion technology due to its numerous benefits, which surpass those of other processing techniques. As a cost-effective approach, it provides a flexible platform for processing various food products from different groups, enabling adjustment to ingredients and processing parameters. Extrusion technology is employed in the food processing industry for the manufacture of various food products, such as snacks, pasta, breakfast cereals, pet foods, supplementary foods, and textured foods. It is an economically viable method for recovering and reutilizing food processing by-products and residues, thereby reducing waste and enhancing food security. The adaptability of extrusion technology facilitates the development of nutritionally enhanced products and value-added products through the strategic combination of cost-effective raw materials. Extruded products exhibit reduced moisture content, extended shelf-life, and enhanced microbiological safety. This technology offers several advantages, including product versatility, superior quality, enhanced productivity, and minimized processing time.

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INTRODUCTION

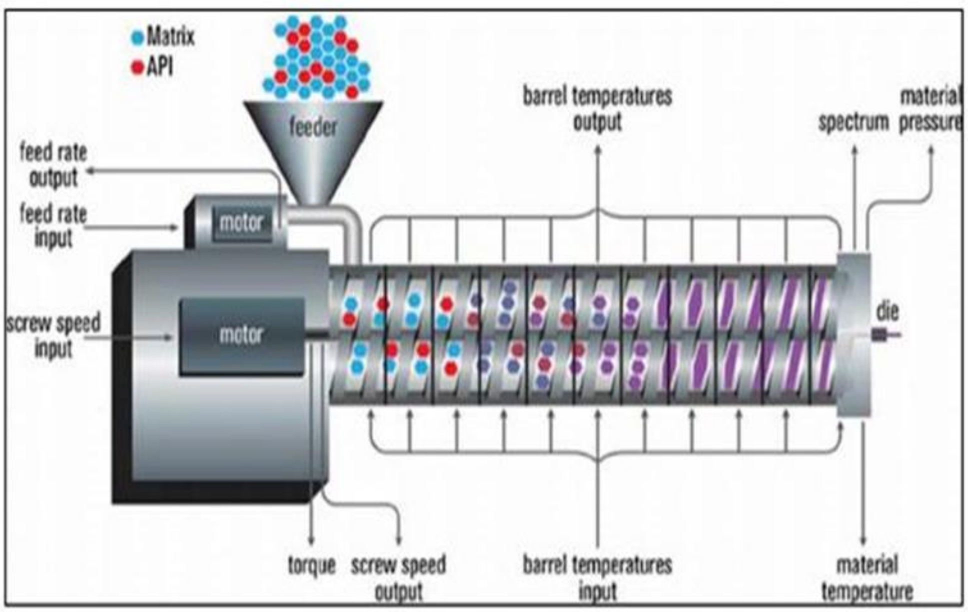
The application of extrusion technology, high-temperature, short-time processing method is becoming increasingly prevalent in the food industry, facilitating the development of innovative products, including cereal-based snacks enriched with dietary fibre, baby foods, breakfast cereals, and modified starch derived from cereal (Pardeshi and Chattopadhyay, 2014).

The high-temperature short-time characteristics of extrusion processing reduce microbial contamination and enzyme activity and the resulting low water activity (0.1-0.4) of the product serves as the primary preservation method for both hot and cold extruded foods, as observed by Bordoloi and Ganguly (2014). The thermal energy produced by viscous dissipation, combined with the shearing effect, cooks the raw mixture during extrusion, inducing physicochemical changes in the biopolymers that alters the properties of the material (Thymi *et al*., 2005).

Extrusion induces gelatinization of starches, denatures proteins and decreases the levels of oxidized and anti-nutritional factors, thereby enhancing the nutritional quality of the final product (Pansawat *et al*., 2008).

Principle of extrusion process

The principles of operation in extrusion include raw materials being are fed into the extruder barrel and the screw(s) then convey the, reconstituted food along it. Further down the barrel, smaller flights restrict the volume and increase the resistance to movement of the food. As a result, it fills the barrel and the spaces between the screw flights and becomes compressed. As it moves, further along the barrel, the screw kneads the material into a semi-solid, plasticized mass. If the food is heated above 100 oC, the process is known as extrusion cooking or hot extrusion. Here frictional heat and any additional heating that is used cause the temperature to rise rapidly. The food is then passed to the section of the barrel where pressure and shearing is further increased due to smaller flight. Finally, it is forced through one or more restricted openings (dies) at the discharge end of the barrel as the food emerges under pressure from the die, it expands to the final shape and cools rapidly as moisture is flashed off as steam. A variety of shapes, including tubes, rods, spheres, strips, doughnuts, squirls or shells can be formed. Typical products include a wide variety of low density, expanded snack foods and ready-to-eat (RTE) puffed cereals. Cold extrusion, in which food temperature remains at ambient is used to mix and shape foods such as pasta and meat products. Low pressure extrusion, at temperatures below 100 oC, is used to produce, for example fish pastes, surimi, liquorice and pet foods (Bordoloi and Ganguly, 2014).



Source: Skarma *et al*. (2020)

Extrusion and its classification

Extruder is an equipment which is used for extrusion processing. 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 (Altan *et al*., 2015). Extruders are composed of five main parts: the pre-conditioning system, the feeding system, the screw or worm, the barrel, the die and the cutting mechanism. They can vary with respect to screw, barrel and die configuration (Riaz, 2000). The selection of each of these items will depend on the raw material used and the final product desired (Riaz, 2000).

Types of Extrusion System

The use of thermoplastic extrusion in food processing is facilitated by the dynamism of extruders, which can be divided into two types: single-screw and twin-screw extruders (Riaz, 2000). A variety of extruders with different configurations and performances have been developed and they are categorized based on their applications, design and configurations. Figure above shows the schematic representation of an extruder including its main parts and zones. The food (melt) is fed at one end of a tubular structure housing the screw. Inside this housing the melt is worked upon to form a semi solid mass. The semi -solid mass is forced through a restricted opening (die) at discharge end of the screw. The food comes out expands as it touches the atmosphere. This expansion is because of the bubble growth in the semi-solid mass because of the moisture that it contains (Kokini *et al*., 1992). The expanded product is the extrudates can be consumed as it is, or after desirous processing.

Single-screw extruders are the most common extruders applied in the food industry. The classification of single-screw extruders can be defined based on process or equipment parameters such as: moisture content (dry or wet) conditioning, solid or segmented screw, desired degree of shear and heat source. In practical terms, the main classification used considers the degree of shear and the heat source (Riaz, 2000). The screw configuration comprises there are screws made up of only one piece or screws of multiple pieces.

Twin-screw extruders are composed of two axis that rotate inside a single barrel, usually the internal surface of the barrel of twin-screw extruders is smooth. Depending on the position of the screws and their direction of rotation, four different types of configurations are possible: (i) co-rotating intermeshing screws; (ii) co-rotating non-intermeshing screws; (iii) counter-rotating intermeshing screws; and (iv)counter-rotating, non-intermeshing screws. Although intermeshing screws result in greater residence time of the material in the extruder, non-intermeshing screws cause greater degrees of shear, especially if they rotate in opposite directions. However, twin screw type of extruder is little used in the food industry, even though they present more efficient displacement properties (Steel *et al*., 2012).

Extruder Variables

Screw speed, barrel temperature, screw and barrel configuration, die opening and feed rate are some of the parameters that affect the extruded performance. Extruder operation depends on pressure build up in the barrel (prior to exiting the die), slip at the barrel wall (transportation), and the degree of filling. The screw speed is responsible for the rate of shear development and the mean residence time of the feed. The heat dissipation from the mechanical energy input to dough depends on screw speed, which in turn influences dough viscosity. The feed zone temperature must be low to avoid plugging and back flow of material travel down the screw (Muthukumarappan and Karunanithy, 2012). The barrel temperature has positive effect on the degree of starch gelatinization and extruded expansion whereas it has a negative effect on product colour especially at elevated temperature. Several studies have indicated that elevated temperature leads to more moisture evaporation when exiting the die and thus results in more expanded products (Muthukumarappan and Karunanithy, 2012). Extruder feed-rate depends on the types of screw element, screw speed, type of feeding element and feed moisture. The federate has an influence on residence time, torque requirement, barrel pressure and dough temperature.

Feed Ingredient Variables

Feed composition, moisture content and particle size have the greatest effect on extrusion. The typical composition of any blend consists of starch, protein, - lipid/fat and fiber which contribute the product quality. The starch degradation usually reduces products expansion. The infant and weaning foods have high starch digestibility which is largely dependent on full gelatinization (Camire, 2000). The lipid levels over 5- 6% acts as a lubricant, reducing the slip within the barrel and resulting in poor product expansion. The fibers are the noninterracting component that contributes to low expansion, cohesiveness, durability and water stability. Higher fiber content usually results in high screw wear.

The moisture is critical variable that has multiple fractions in starch gelatinization, protein denaturation, barrel lubrication and the final product quality. A dry extruder can process materials with 8- 22% moisture with no additional drying of extrudates. Most extrudates snacks have moisture content between 8-12% and require additional drying to impart desired texture and mouthfeel (Rokey, 2000).

General rule of thumb that the extruder feed should not have particles larger than one third the diameter of die holes. Particle size also plays an important role in moisture distribution, heat transfer, viscosity and final product. Quality course ingredient particles have more effect on wear than fine particles. A product composed of fine particles will have good water stability, water absorption index, expansion (Riaz, 2000).

Sources of Raw Material in Extrusion Cooking

The most used raw materials in the extrusion process are starch and protein-based materials. This technique has been widely used with raw materials such as corn, wheat, rice and soybean, potato, cassava etc. Natural biopolymers of raw materials such as cereals or tuber flours are rich in starch, or oilseed legumes and other protein rich sources. Most commonly used materials are wheat and corn flours, but many other materials are also used such as rice flour, potato, rye, barley, oats, sorghum, cassava, tapioca, buckwheat and pea flour (Guy, 2001). The protein rich materials such as pressed oilseed cake from soya, sunflower, rape, field bean, fava beans or separated proteins from cereals such as wheat (gluten) (Guy, 2001). Expanded (Ready to Eat) RTE cereals are manufactured from mixtures of cereal flours and starches combined with small amounts of malt, fat, sugars, emulsifiers, and salt. The raw materials in the extrusion cooking processes cover various combinations of ingredients including: cereals, grains and starches, tubers, legumes, oil seeds, cereals as well as animal fat and proteins (Guy, 2001). The main characteristics of the raw material for extrusion cooking are type of material, moisture content, physical state, chemical composition (quantity and type of starch, proteins, fats and sugars) and pH of the material. Most raw materials used in food extrusion are solid (Steel *et al*., 2012). The structure of the extruded products may be formed from starch or protein polymers. Most products, such as breakfast cereals, snacks and biscuits are formed from starch, while protein is used to produce products that have meat-like characteristics and that are used either as full or partial replacements for meat in ready meals, dried foods and many pet food products (Guy, 2001). Typical raw materials used in the popular extruded products, each of which offers a wide variety of functions: structure-forming, facilitating physical transformation during the extrusion-cooking, affecting the viscosity of the material and its plasticization, facilitating homogeneity of the dough ingredients, accelerating starch melting and gelatinization and improving the taste and colour of products (Moscicki, 2011). Further, ready to eat breakfast was successfully developed using the low amylose rice flour incorporated with seeded banana powder in a single-screw extruder (Borah *et al*., 2015). Dhumal *et al*. (2014) developed cold extrudate, microwave puffed and oven toasted low fat ready to eat fasting foods successfully using potato and barnyard millet.

Role of Starch in Extrusion Cooking

Extrusion cooking may have both beneficial and undesirable effects on nutritional value. Beneficial effects include gelatinization of starch, destruction of anti-nutritional factors, increased soluble dietary fibres, reduction of lipid oxidation and contaminating microorganisms and retains natural colours and flavours of foods (Nikmaram *et al*., 2015). Among all flour components, starches play a key role during extrusion cooking. Starch undergoes several significant structural changes, which include gelatinization, melting, and fragmentation (Lai and Kokini, 1991). Starch is a carbohydrate composed of chain of glucose molecule. Potato, corn and rice are the major sources for starch but they are also used as a food (Karmakar *et al*., 2014). Roots contain starch ranging from 73.7 to 84.9 % of the root dry weight. Starch is one of the most important raw materials in the food industry because of its properties are a low gelatinization temperature (71°C), a low tendency to retrograde, no residual proteinaceous materials or soil residues, non-cereal flavor, high viscosity, high water binding capacity, bland taste, translucent paste and relatively good stability (Sriburi *et al*., 1999). Native starch undergoes substantial changes leading to greater molecular disorganization during extrusion cooking. Most importantly from the perspective of finished product texture, the starch loses its relative crystallinity, undergoes molecular fragmentation, and often complexes with lipids in the feed texture. The role of shear, temperature, moisture and feed composition are significant in the transformation of starch by extrusion (Gonzalez and Perez, 2002). The starch granule consists of two different glucose polymers: amylose and amylopectin, which are responsible for its physicochemical and functional properties. Inside the extruder, starch undergoes through several stages. First, the initial moisture content is very important to define the desired product type. Inside the extruder have relatively high temperatures, the starch granules melt and become soft, besides changing their structure that is compressed to a flattened form (Guy, 2001). The application of heat, the action of shear on the starch granule and water content destroys the organized molecular structure, also resulting in molecular hydrolysis of the material (Mercier *et al*., 1998). The final expanded product presents air cells that are formed due to superheated water vapour pressure. When the temperature of the extrudate is reduced below its glass transition temperature, it solidifies and maintains its expanded form (Riaz, 2000). The main parameters that influence these reactions, such as shear forces, residence time and shear rate. They defined by the geometry of the extruder as well as the processing variables, such as temperature, screw speed, feed composition (such as amy1ose: amylopectin ratio) and moisture content. Order-disorder transitions usually occur over a range of temperatures. As dough's temperature exceeds the transition threshold temperature, the starch molecules begin to undergo various disordering reactions that affect their size and shape. Since rheological properties are related to the size and shape of a fluid's molecules. It seems logical to assume that these molecular changes within starch will greatly affect their rheological properties (Lai and Kokini, 1991).

Role of Ingredients in Development and Formulation of Structure and Texture in Extruded Product

In extrusion cooking, changes in ingredients such as sugar, salt, fibre or processing parameters like screw speed and temperature can affect extrusion system variables and product characteristics such as texture, structure, expansion and sensory attributes. The most commonly used cereals in extruded are rice, wheat, oats and corn. For formulation of extruded mixture of these cereals can be used, in the form of flours, grits and whole grain flours. They can also be mixed with other ingredients such as starches, sugar, salt, malt extract or other liquid sweeteners, heat stable vitamins and minerals, flavorings, colorants and water, to vary appearance, texture, taste, aroma and other product characteristics (Riaz, 2000). Traditional snacks or breakfast cereals can be enhanced by the addition of extra fibres or whole grain flour as ingredients during extrusion, transformed into palatable cereal-based products that also promote beneficial physiological effects. Functional ingredients such as soy, and botanicals (fruit, vegetables, cereals, etc.) that present high amounts of bioactive compounds can be used in the extrusion process to develop novel products with phytochemicals and other healthful food components (Steel *et al*., 2012).

Applications of Extrusion Technology in Instant Food Products

Extrusion technology has revolutionized the food industry by enabling the production of a wide range of instant food products with enhanced nutritional value, texture, and shelf stability. This high-temperature, short-time (HTST) process is widely used in the development of RTE cereals, instant noodles, snack foods, and fortified food products (Singh *et al*., 2020) The ability of extrusion to modify raw materials which ensures energy efficiency and product consistency makes it an essential technology in modern food processing (Riaz, 2000). According to Rokey *et al*. (2010), extrusion allows the incorporation of various functional ingredients, such as proteins, dietary fibre and micronutrients without compromising product quality. This is particularly beneficial in developing instant foods that require minimal cooking or rehydration. Extrusion is widely used in the development of instants foods, providing benefits such as rapid preparation, extended shelf-life and enhanced sensory properties (Bhandari and Zhang 2022). Ready-to-Eat Breakfast cereals, instant noodles and pasta, extruded snack foods, instant soups and porridge fortified and functional instant foods are commonest products that has emerged through extrusion technology (Guy, 2011).

Quality Control in Extrusion Processing

Extrusion processing is widely used in the food, plastic, pharmaceutical, and metal industries to create products with specific shapes, textures, and functionalities. Quality control in extrusion is essential to ensure consistent product performance, safety, and compliance with industry standard (Harper, 2013). The quality of extruded products depends on factors such as raw material composition, processing parameters and equipment performance. Effective quality control measures help maintain uniformity, reduce waste and effective process efficiency (Riaz, 2000).

Key Quality Control Parameters in Extrusion

Raw Material Quality: Raw materials play a critical role in extrusion performance. Variation in ingredient composition can affect processing behavior and final product characteristics (Bhandari and Zhang 2022). Essential quality control measures for raw materials include: moisture content, particle size distribution, chemical composition contaminant testing.

Processing Parameters Control

Maintaining precise control over processing conditions is critical to achieving desired product properties. Key parameters include; temperature, screw speed, feed rate, pressure and torque monitoring,

Physical and Structural Quality Control

Extruded products must meet specific physical and structural requirements such as: expansion ratio, density, porosity, cell structure, hardness and crispness (Singh *et al*., 2020).

Chemical and Nutritional Quality Control

Chemical and nutritional attributes must be maintained throughout the extrusion process to ensure product safety and functionality. Key measures include: nutrient retention, fat and oil stability, colour and flavor stability, moisture content (Riaz, 2000).

Microbiological and Contaminant Control

Food safety regulations require stringent monitoring of microbial and chemical contaminants in extruded products (Singh *et al*., 2020). Essential tests include: microbial testing, mycotoxin analysis, heavy metal screening.

Quality Control Techniques in Extrusion Processing

Several techniques are used to assess and maintain quality in extrusion processing such as; Differential scanning Calorimetry, Fourier Transform Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM), Near-Infrared Spectroscopy, image processing system, Automated Torque and pressure sensors (Singh *et al*., 2020).

Challenges in Extrusion Technology

Despite its versatility, extrusion technology encounters several limitations that affect efficiency, product quality and economic feasibility. Some of these limitations are; raw material variability, high energy consumption and process inefficiencies, nutrient losses in food extrusion, environmental concerns and waste management, equipment wear and maintenance issues (Harper 2013).

Future Trends in Extrusion Technology

To address current challenges, future advancements in extrusion focus on efficiency, sustainability and innovative applications. Smart extrusion systems and process automation in the form of artificial intelligence, machine learning and real-time monitor system can be adopted (Bhandari and Zhang, 2022). Development of high-protein and functional ingredients can meet up with such demands (Harper, 2013). In response to environmental concerns, extrusion is being adapted for biodegradable plastics, recycled polymer extrusion and edible packaging are innovative supports the circular economy by reducing waste and carbon footprint in extrusion manufacturing (Bhandari and Zhang, 2022).

CONCLUSION

Extrusion processing offers a flexible and efficient means of developing food products that are not only cost-effective but also possess high nutritional value and convenience. The extruded products exhibit significant potential in replacing traditional snack foods characterized by low nutritional content. Furthermore, the extrusion process has been shown to enhance the nutritional profile of food product, by reducing anti-nutritional factors, improving protein digestibility, and augmenting antioxidant activity. Consequently, this technology assumes a vital role in the production of a diverse array of food products and ingredients, owing to its numerous benefits, including the destruction of anti-nutritional factors, increased soluble dietary fibres, reduced lipid oxidation, and elimination of contaminating microorganism.

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