INTERNATIONAL JOURNAL OF RESEARCH AND INNOVATION IN APPLIED SCIENCE (IJRIAS)
ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue III March 2026

Extrusion Cooking Technology in Food Applications: A Mini Review

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DOI: https://doi.org/10.51584/IJRIAS.2026.11030099

Received: 10 February 2026; Accepted: 16 February 2026; Published: 16 April 2026

ABSTRACT

Extrusion cooking is a contemporary and sustainable approach in food industries used to produce a wide range of improved products such as ready to eat breakfast cereals, confectionary snack products, meat analogue, dairy products and pet food among others. During extrusion cooking, modification in the structure of raw materials occurs such as starch gelatinization, protein denaturation, destruction of anti-nutritional factors and microorganisms using cold or hot extrusion operating as single or twin screw design. Basically raw materials are fed into the extruder barrel and the screw(s) then convey the food down it. Further along the barrel, lesser 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 along the barrel, the screw cooks the material into a semi-solid, plasticized mass. The food is then passed to the section of the barrel having the negligible flights, where pressure and shear force is further increased. Finally, it is forced through an opening die at the discharge end of the barrel. In comparison with other processing techniques it was reported that extrusion cooking has low cost of production with little energy consumption, high versatility and production output with minimum time and nutrient retention ability as well as bioavailability of bioactive compounds. The work intends to review from past studies the production of innovative, sustainable and diverse food products. The review highlights the mechanisms of operation of extruders, types of extruders, extrusion cooking ingredients, variables and extrusion cooking applications in food.

Keywords: Anti nutritional factors, denaturation; extrusion; food nutrients; gelatinization

INTRODUCTION

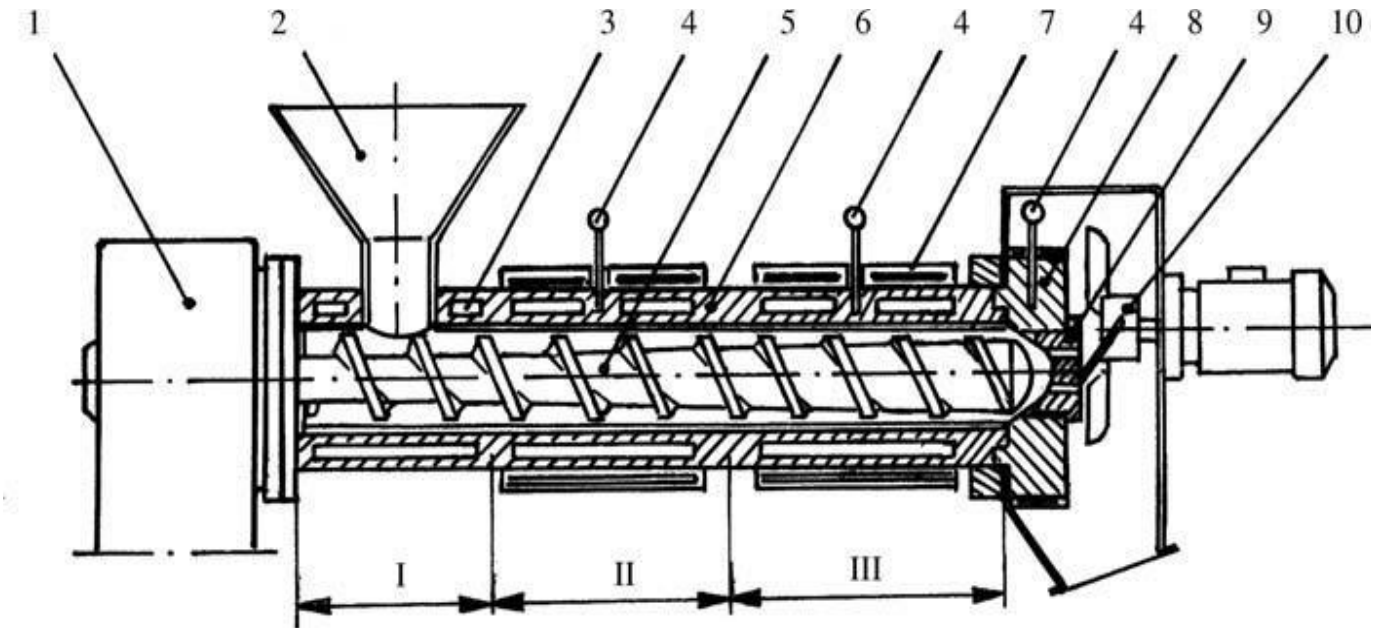
Food manufactures are producing novel and sustainable food products that are nutrient dense and are suitable to use lately. Extrusion cooking can be used to make such products. Extrusion cooking enables the production of underutilized accepted food products that are convenient for human consumption. Thus extrusion cooking has ability to increase digestibility of starch and protein by gelatinizing and denaturing, solubilizing dietary fiber, reduces anti-nutritional factors, undesirable enzymes, microorganisms, contaminants and toxins (Yu *et al.*, 2013). It is a modern food processing technology used to produce a wide variety of products. Extrusion cooking as defined by various authors is a thermo-mechanical process used to force food materials in a granular or pulverized form to flow under specific variable conditions through an outlet called die to produce different varieties of products which are cut into definite shapes by blades (Chandresh and Priya, 2020, Dendegh *et al.*, 2021, Okorie, 2021 and Sanusi *et al.*, 2023). The entire process is uninterrupted and capable of happening within short period of time. Today extrusion cooking technology can be applied in confectionary products, snack foods, breakfast cereals, dairy products, infant food, meat analogs, oil expelling, pre-gelatinized flour etc aimed at improving the quality of food. Chandresh and Priya (2020) describe two types of extrusion based on operation as cold and hot extrusion. In cold extrusion; cooking of food is carried out at 100^{o}C and the temperature of the food is maintained constant which is used in shaping and mixing of food. The extruder has a deep screw which operates at a low speed in a smooth barrel to knead and extrude the material with little friction. Hot extrusion uses high pressure and temperature to form expanded product. The swift discharge of pressure as the food emerges from the die causes increase of steam and gas in the material to form a low density product. Hot extrusion thus is a high temperature short time (HTST) process which minimizes the loss of nutrients and reduces microbial contamination. The extrusion system encompasses multiple unit operations with high efficiency and low cost processing. Okorie, (2021) enumerated some of the advantages of extrusion cooking compared to conventional processing as:

1. Ability to produce wide range of new products
2. Lower processing cost and higher productivity,
3. Increase product quality with minimal nutrient and flavour losses
4. Eco friendly with no production of effluent
5. Energy efficiency operating at relatively low moisture while cooking food products.

The objective of the study is to review extrusion cooking technology. The review explains the mechanisms of operation of extruders, types of extruders, extrusion cooking ingredients, variables and extrusion cooking applications in food.

Parts of extruders

Extruder system is basically made of the following parts as reported by Moscicki and Zuilichem, (2011) to include: feeding system, pre conditioning system, the screw, the barrel, the die and the cutting blades as shown in plate 1 below. The various parts are grouped into sections to include transport, compression and melting and plasticizing sections.



A cross-section of a single-screw food extruder: 1 – engine, 2 – feeder, 3 – cooling jacket,

4 – thermocouple, 5 – screw, 6 – barrel, 7 – heating jacket, 8 – head, 9 – dies, 10 – cutter,

I – transport section, II – compression section, III –melting and plasticizing section

Plate 1: A Schematic View of Extrusion Machine with Various Sections

(**Source:** Moscicki and Zuilichem, 2011)

Feeding system: Materials are frequently introduced into the extruder through the hopper at a constant rate.

Pre-conditioning*:* Pre-conditioning is optional and is carried with steam or water. Pre-conditioning hydrates the material and reduces retention times within the extruder.

Screw*:* The screw enables the cooking. The role of the screw(s) is to help in imparting shear to the ingredient and forcing the dough of the mixed ingredients out from the extruder through the die. The screws impart shear through the buildup of pressure. Screws can be mono-piece (composed of a unique piece) or multi-piece (composed of various elements).

Barrel: The barrel houses the screw or a set of screws. The barrel is separated into transport section, compression section, melting and plasticizing section. The barrel is jacketed to permit circulating of steam or water for heating and cooling, thus enabling the regulation of the temperature in the various zones of the extruder. The heating can also be accomplished by providing electrical heating units on the barrel or by steam. The inner layer of barrels is often smooth in twin-screw systems while it may be grooved or fluted in single screw systems. The barrel may consist of various injection ports. Injection ports may be used for water or other liquid ingredients.

Die: The die performs two basic functions to include shaping the product and to promote opposition to material flow within the extruder causing an increase in internal pressure by holding the material in the screws thus providing time for the screws to impart shear energy onto the sample. The die can be varied greatly and come in various designs and number of orifices.

Cutting mechanism*:* A die cutter is normally used to cut the final extrudates coming out of the die. The cutting ensures uniform size of the product and is dependent on the rotation speed of the cutting blades.

Types of extruders

There are basically two types of extruders to include single screw and double screw extruders.

Single Screw Extruder

Single screw extruder is made up of a single rotating screw in a metal compartment/barrel. The raw materials are fed from the hopper situated in transport section as shown in plate 1 above and the rotating screw moves the material to the compression section. In the compression section the screw channel becomes shallower and the material is compressed resulting in rise in temperature of the material. It is further transported to the melting and plasticizing section and later pushed out through the die opening (Okorie, 2021).

Twin Screw Extruder

Twin screw extruder consist of two rotating parallel screw having equivalent dimension inside the barrel. Twin screw extruder is intertwined than single screw extruders Twin-screw extruders are generally grouped according to the direction of screw rotation and to the degree to which the screws intertwined as counter-rotating twin screw, co-rotating twin screw, non-intermeshing counter rotating. In all direction of rotation the flow of product will be uniform throughout the barrel as a result of positive pumping of the screw flights (Chandresh and Priya, 2020).

Extrusion cooking ingredients

Diverse kinds of ingredients are used in making extruded foods thus the selection of raw materials for processing is important in extrusion cooking. The most used materials components are starch and protein based (Navale *et al*., 2015).

Classification of extrusion cooking ingredients by components

Maize and wheat flours are the most commonly used materials for food extrusion. Other flours may include rice, soy, potato, rye, barley, oats, sorghum, cassava, tapioca, buckwheat, pea flours. Among all the flour samples maize flour is the most general ingredient for extruded products due to its composition, ratio of vitreous to floury endosperm, and particle size. Within optimal extruding conditions maize flour is light, highly expanded and crunchy and produces soft product. The main ingredient components that affect the properties of the final product are starch, water, protein, fiber, oil, additives and particle size (Navale *et al*., 2015).

Starch

Starch is the major component of extrusion and it provides the basic structure according to Guy, (2001). Starch granules are gelatinized and dispersed during extrusion, resulting in the formation of a continuous phase of the melt inside the extruder. Both amylose and amylopectin are desirable to give the best expansion characteristics (Huber, 2001). Starch granules undergo gelatinization and melting by the action of heat and moisture on hydrogen binding among tightly packed polysaccharide chains in the granule structure. Under conditions of excess water, hydrogen bindings in the less ordered amorphous regions of the granule are disrupted first and allowing water to combine with free hydroxyl-groups. Swelling results and further opening of the granule structure. Complete starch gelatinization was reported to be achieved at temperatures of less than 120°C, moisture of 20- 30% or even at lower moisture levels (10-20%), provided high shear and temperatures are reached during extrusion (Guy, 2001).

Water

Water is an important medium in extrusion. It is needed for starch gelatinization and ingredient dispersion. Water can be added directly to the feed, injected into the barrel, or added in the form of steam to the pre conditioner or barrel; water will also affect the temperature of the feed material according to Yu, (2011).

Protein

Soybeans, oilseeds and legumes provide a good source of protein for extrusion. During extrusion process protein denaturation and break down of high molecular weight proteins into smaller units of amino acids, thermal unfolding of globulin protein, thermal inactivation of trypsin inhibitor occurs. Disulfide bonds are also broken and undergo reorganization and polymerization. Electrostatic and hydrophobic interactions favor the formation of insoluble aggregates. Proteinous enzymes lose their activity due to high temperature and shear. Protein also loses their solubility in water and saline solution due to the temperature and mechanical energy to which the product is subjected. Texturization may occur in high protein content food (Steel *et al*., 2012). During extrusion protein helps to form a continuous structure. The Structure created by protein is similar to starch in that the proteins must be dispersed from their native bodies into a free flowing continuous mass (Guy, 2001).

Fiber

Extrusion produces structural effect on the fiber resulting in redistribution of insoluble fiber to soluble fiber. This effect is accomplished by the rupture of covalent and non covalent bonds between carbohydrates and protein molecular fragments that would be more soluble. This modification changes the type and functionality of the fiber.

Lipids

Lipids have two functions in extrusion process; they can influence the quality of the product and act as a lubricant during the process by reducing friction between particles in the mix and the screw and barrel surface. Most of the lipids will melt at 40ºC and mix with other ingredients and dispersed as oil droplets. Lipids may also form complexes with starch in the formation of amylose –lipid complex as reported by Steel *et al*., (2012). Extrusion-inactivation of lipase and lipoxidase helps protect against oxidation during storage. Higher temperatures reduce the lipase activity and moisture level, thereby decreasing rancidity.

Additives

Additives are also important in the makeup of the final product. Their reactions during the extrusion process can greatly affect the flavor or colour of the product. Flavoring or coloring agents are mixed into the product and confer a different appearance to the product during the extrusion process. Additives like sodium bicarbonate and calcium carbonate can be used to increase expansion and cell wall formation and swelling (Guy, 2001). Sugar and other ingredients may be added.

Extrusion Cooking Variables

According to Raiz, (2000) extrusion cooking variables can be classified into raw material variables, extruder design variables and process variables as shown in table 1. The raw materials are usually mixed and preconditioned before introducing in the extruder. Guy (2001) and Riaz (2000) reported that the selection of raw materials for extrusion is dependent on the required product quality in relation to strength (ability of the extrudate to withstand mechanical stress), resistance and flexibility (ability of the extrudate to bend without breaking). The choice of extruder design and operating variables will directly affect the product quality, energy efficiency and process stability (Guy, 2001). Table 2 present basic functions of extruder design and operating variables as reported by Guy, (2001), Okorie, (2021) and Raiz, (2000)

Table 1: Extrusion cooking variables

Raw material variables	Extruder design variables	Operating variables
Moisture content (10-30%)	Screw speed	Barrel temperature (90-200^oC)
Particle size	Screw configuration	Feed rate
Starch content	Barrel length to diameter ratio	Pressure (20Mpa)
Protein content	Die shape and diameter	Residence time
Fat content	Type of extruder (single-screw or twin- screw)	Mechanical energy
Fiber content		
Additives		

Source: Raiz, (2000).

Table 2: Basic functions of extruder design and operating variables

Extruder design variables	Functions	Operating variables	Functions
Screw speed	Controls material flow, shear and mechanical energy	Barrel temperature	Shape, cook and texturize food material
Screw configuration	Conveys material through the barrel	Feed rate	Controls residence time
Barrel length to diameter ratio	Controls residence time	Pressure	Controls cooking, texture and expansion
Die shape and diameter	Determines product shape	Residence time	Ensures adequate cooking, controls expansion and texture
Type of extruder (single-screw or twin screw)	Transport, mix, cook and shape food material	Mechanical energy	Converted to heat and shear forces and controls cooking, texture, expansion and quality

Source: Guy, (2001), Okorie, (2021) and Raiz, (2000)

Application of extrusion technology

Breakfast and whole cereal products

Breakfast cereals are produced from grains for human consumption. Breakfast cereals are convenient to use. Changes in lifestyle and the need to eat healthy food have necessitated the demand for breakfast cereals especially in form of extruded food. Breakfast cereals are made from cereals, legumes or cereal-legume mix to improve nutrients. In production of expanded extrusion –cooked breakfast cereals, flour with additional ingredient are processed at low moisture content (20%). Cereals undergo cooking, modification such as flaking, toasting, puffing, shredding and expansion to make them suitable for human consumption. These processes convert raw and dense grains into friable, crunchy and chewable products. According to Steel *et al*., (2012) two different processes can either be used for production of breakfast cereals. Pallet/ shred production for manufacturing cereals like cornflakes/shredded cereals and direct expanded cereals production where the blend is forced through a heated barrel to cook the dough and then the product pass through a cooling section to prevent expansion. The process of obtaining shredded cereals is same with that of flaked cereals except for shredding without additional drying and tempering.

Confectionary and snacks products

Extrusion cooking can be used to produce confectionary and snacks products. The production of snacks has progressed into three different generations (Sule *et al*., 2024). Generally the production of extruded snacks involves the following unit operations: mixing (cereal, legume, cereal-legume mix, sugar etc), heating, gelatinizing the starch and vaporizing excess water which thereafter is vented from the extruder (Riaz, 2000).

Meat analogue and extenders

Meat analogue is also known as meat substitute, alternatives, fake, mock or imitation meat. Meat analogue looks like meat in structure and texture. Presently the demand for plant protein based meat is increasing in recent time and there is a shift from conventional meat consumption to alternative meat. The factors that lead to the shift are health concerns, the need for vegetarian diet , zero cholesterol, high biological digestion potency of about 93 -97% in the body and reduction in green house gas emission from animal rearing (Ismail *et al*., 2020 and Zhang *et al.*,2019). Meat extenders are made from low moisture content (20-40%) that are rehydrated and use as meat while meat analogue are created at high moisture content (40-80%) with a longer cooling die that allows for fibrous structure formulation at moderately low temperature lower than 75ºC. Traditionally low moisture extrusion has been reported to be used to texturize protein into meat analogue and later high moisture extrusion became popular in producing fibrous texture and dense structure with strong springiness (GI-Hyung, 2020). As extrusion progresses the effect of temperature, shear force and pressure confirm changes and molecular interactions among protein, carbohydrate, lipid and other components that influences the quality of texteruized vegetable protein (meat analogue).

Dairy products

Extrusion cooking can cause extensive changes in the molecular structures of the dairy proteins. Such changes can further impart distinctive functional properties to dairy proteins, ensuing new protein-based food ingredients through texturization that uses mechanical shear, heat and pressure to bring about structurally changes to the food components. Such novel texturized proteins can be used to produce puffed extruded high-protein dairy snacks with negligible damage to the nutritive components and functionality of the texturized dairy proteins (Onwulata *et al.,* 2011).

Animal and fish food

Extrusion technology can be used to produce semi-moist and dry expanded feed for animal and fish consumption. This application enhances the use of cereal grains, plant sources and animal protein in the formulation of special feed for animals. Single or double screw extruder can be used in producing animal feed. The ingredients will be mixed properly, pre conditioned, compressed and force through the die of the extruder. The extrudates can then be cut into pellets dried and package as reported by Abinaya *et al.,* (2022) for animal and fish feeding.

Food waste

Food waste from various sources can be utilized to produce diverse products rich in vitamins, minerals, anti oxidants and photochemicals. Extrusion cooking was reported to improve the functional, sensory and nutritional properties of food waste products (Sule *et al*., 2024).

Effect of extrusion cooking on nutritional quality of food

Preserving and improving the nutritional value of food is important during extrusion cooking. Although starch gelatinization, destruction of anti-nutritional factors, increased soluble dietary fiber and reduction in lipid oxidation has been reported during extrusion cooking (Guy, 2001). However to achieve a nutritionally balanced extruded product, careful control of process parameters is imperative. Mild extrusion cooking with high moisture content, low residence time and temperature was found to improve the nutritional quality of extrudated products while high extrusion temperatures greater than 200°C, low moisture contents (less than 15%) and presence of high reactive sugars can affect nutritional quality negatively (Singh *et al*., 2007). Some vitamins can be destroyed at high temperatures processing although the extent of destruction is minimal in HTST extrusion. According to Sule *et al.,* (2024) Thiamine can be damaged during extrusion depending on the processing conditions, temperature rise, and screw speed. Riboflavin losses are much reduced with 94% retention after extrusion and decreases with increasing water content in the mixture. Vitamins D and K are more stable in extrusion while vitamins A and E are unstable in the presence of heat. Vitamin C is also heat sensitive and is destroyed during extrusion cooking. The amount of vitamin retention decreases with increasing temperature, screw speed, specific energy input, decreasing moisture content, feed rate and die diameter (Singh *et al*., 2007) Mineral components are stable during extrusion and their absorption enhanced through destruction of anti-nutritional factors in food. Extrusion eliminates trypsin, haemagglutinins, tannins, protease inhibitors, phytates, oxalates, saponins and also inhibits the activities of spoilage microorganisms (Singh *et al*., 2007). Extrusion cooking increases digestibility in protein rich food due to denaturation at lower temperatures resulting in the rearrangement of the protein structure although at elevated temperatures in the presence of sugar will result in maillard reaction and reduction in protein quality (Adeleye *et al*., 2020).

Effect of extrusion cooking on sensory properties of food

Sensory characteristics are important in extrusion cooking hence processing conditions affects product quality. Excessive high temperature, reaction of protein with reducing sugar may affect the sensory properties of food leading to fading of colour. High protein content at constant feed moisture content results an increase in brittleness, hardness, and crispness and also decrease in color intensity. Heat sensitive flavours are destroyed during extrusion cooking according to Onwulata *et al.*,(2011).

CONCLUSION

Among different processing techniques extrusion cooking is becoming popular over other regular processing techniques. It enables the production of underutilized accepted food products that are ideal for human consumption. It has capacity to increase digestibility of starch and protein by gelatinizing and denaturing, solubilizing dietary fiber, reduces anti nutritional factors (trypsin inhibitors, hemagglutinins and gossypol etc), undesirable enzymes (lipoxigenases, peroxidases, lipoxidases, and lipases), microorganisms, contaminants and toxins. However to achieve a nutritionally balanced extruded product, careful control of extrusion cooking variables are imperative. Extrusion cooking has the ability to produce a wide range of products to include breakfast and whole cereals products, confectionary and snack products, meat analogue and extenders, dairy products and conversion of food waste to value added products.

Key Authors' contribution to knowledge: Conceptualization: Anosike, F.C. **Writing**: Anosike, F.C., Benneth, I.C. and Uwandu, A.C. **Literature search**: Anosike, F.C. and Uwandu, A.C. **Proof read**: Anosike, F.C., Benneth, I.C., Uwandu, A.C. and Nkwocha G.A. **Editing**: Anosike, F.C. and Prudent, O. I. **Approval**: Anosike, F.C., Uwandu, A.C., Benneth, I.C., Nkwocha, G.A. and Prudent, .O. I.

Conflict of interest: None

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