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Food Extrusion: A Highly Popular Technology to Process

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***Abstract:** The thermomechanical process of extrusion is described in the abstract. In the production of ready-to-eat pasta, cereals, snacks, pet meals, and textured vegetable protein (TVP), it has emerged as a crucial method of food processing. A snugly fitting screw revolving inside of a still barrel makes up an extruder. Ingredients that have already been pre ground and condition enter the screw where they are delivered, combined, and heated using various methods. The product exits the extruder through a die, where it typically puffs and transforms texture as a result of normal forces and the discharge of steam. Mathematical models for extruder flow and torque have been proven effective in understanding extrusion processes. These models have helped to determine the behaviour of raw material during extrusion. There are several food extruder designs available. The extruder is a high temperature, quick technique that minimises vitamin and amino acid losses in many of these applications. The extrusion process also affects the product's form, flavour, and colour. Extrusion is frequently used in the manufacture of wholesome meals. The increase of protein quality and digestibility, as well as the use of extrusion to denature antinutritional components, are highlighted.*

***Keywords:** Food Processing, Temperature, Product's, Pasta, Cereals, Snacks, Pet Meals, TVP*

I. INTRODUCTION

Extrusion is the technique of pushing soft, combined materials through a hole in a perforated plate or die that has been created to generate the desired form in the food processing industry. Following extrusion, blades chop the food to a predetermined size. An extruder is the device that pushes the mixture through the die, and the mixture is referred to as the extrudate. The die is normally located at the end of a stationary barrel that the extruder, which is typically a huge, revolving screw, is snugly fitted inside of. A cutting-edge method of food processing used to create a range of speciality dishes is extrusion cooking.

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Extrusion cookers are bioreactors that allow for high temperature, rapid cooking with extremely precise temperature and moisture control. Additionally, we may alter the pressure gradient inside the extruders by supplying various steam locks or adjusting the screw design. The majority of food extruders come with segmented screws and barrel sections, allowing for complete flexibility over the machine's setup and a wide range of process parameter combinations. As a result, an infinite variety of crops can be processed, either to enhance functional changes or to inactivate antinutritional elements already present in meals. Extrusion cooking technology also allows for the preferential treatment of protein, carbohydrates, and fats through processes like breaking oil globules to make oil free for simple expansion , texturizing protein, denaturing protein, and gelatinizing starch molecules Extrusion cooking is a high-pressure process that results in a quick expansion of the processed product as it exits the die hole and a porous and crunchy texture (see Fig. 4 for single screw extruders and Fig. 5 for twin screw extruders). About 40–60% of the moisture in the feed flashes out during the abrupt pressure drop that occurs as material departs the die, eliminating the necessity of a costly drying process after extrusion for the final product. Therefore, after toasting and chilling the extrudate, shelf-stable items may be made easily (Patil *et al.*, 2005[1]).

II. HISTORY

In the 1870s, the first extruder was created to produce sausages. Extrusion has been used to make dry pasta and breakfast cereals since the 1930s, and it has also been used to make pet food since the 1950s (the first extruded dog food was Purina Dog Chow in 1957, and the first extruded cat food was Purina Friskies in 1962). Extrusion is a process used in a few home kitchen equipment, including various types of pasta makers and meat grinders. Hand-squeezed pastry bags (piping bags) work through extrusion.

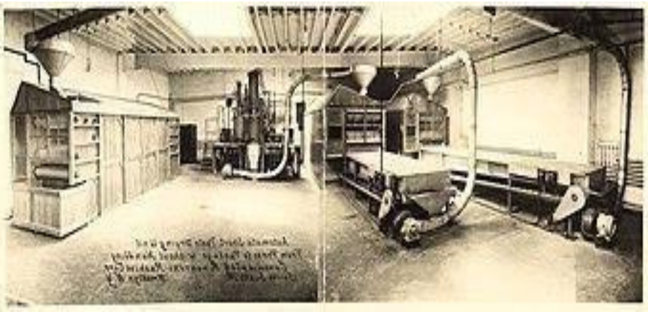

Fig. 1 A historical overview of an extrusion plant.

A. The Background and purpose of food extrusion

Extrusion technology has a long history that is strongly related to polymer science. The first seamless lead pipe was created via extrusion in the middle of the nineteenth century. Extrusion processing was required for the production of Bakelite in 1907 and Glyptal, a protective covering resin, in 1912. In the 1930s, formal extrusion applications to food production started, and they developed over the next 50 years as extrusion processing equipment's capabilities and complexity rose.

It has been observed that Indian cuisine has recently included a variety of extruded goods. It has become very popular among young people and older people alike. The role of various nutrient-dense and functional foods in young people's diets has been demonstrated.

B. Five components of Extrusion System

1) A container and delivery system for the process's main ingredients make up the primary feed system in the extrusion system's five parts.

2) Use a pump to transport all ingredients through the extrusion process phases.

3) Secondary feed system for adding additional materials or energy as necessary to obtain the required product qualities.

4) Reaction vessel where important operations such as mixing, kneading, shearing, heating, and cooling occur.

5) Exit assembly (sometimes referred to as the die) made to limit flow and aid in the shaping and moulding of the finished product.

C. Operational principles

Extrusion cooking is a high-temperature, short-time (HTST) method that inhibits enzyme activity and minimises microbial contamination.

All forms of extrusion operate on the same basic principles: raw ingredients are fed into the barrel of the extruder, and the screw or screws then move the food along it. Smaller flights further down the barrel limit the capacity and enhance the food's resistance to movement. It becomes squeezed as a result of filling the barrel and the intervals between the screw flights.

D. Processing properties for food extrusion.

a. Physical Characteristics

Viscosity: A key element in defining the extrusion process is the viscosity of the food item. High viscosity materials may demand greater temperatures and pressures, as well as more energy to extrude (Ainsworth *et al*.,2006[2]).

1. **Rheology:** The extrusion process is influenced by the rheological characteristics of the food item, such as elasticity and plasticity. High plasticity materials tend to adhere to the extruder die, whereas materials with high elasticity often have superior extrudability.
2. **Moisture content:** The food material's extrudability is influenced by its moisture content. High moisture content materials often extrude more readily, whereas dry materials may need extra water or other additives to increase their extrudability
3. **Temperature:** During extrusion, the temperature of the food material impacts its rheological and viscosity characteristics. Higher temperatures can make food more extrudable, but they can also alter the structure and texture of the meal unintentionally.
4. **Pressure:** The density and texture of the finished product are influenced by the pressure used during extrusion. Lower pressures can provide a more porous texture, whereas higher pressures can make the product denser.
5. **Die design:** The physical characteristics of the finished product can also be impacted by the extruder die design. Different die designs can result in extruded products with various forms, textures, and densities .

III. CHEMICAL FEATURES

The main chemical issue with food preservation is lipid oxidation. By lowering the content of important fatty acids like linolenic acid and linoleic acid, which are necessary fatty acids, this oxidation might lower the nutritional quality. These unsaturated fatty acids have a lengthy chain and are very prone to oxidation. Due to metal attrition on extruder components, high extrusion temperatures can increase the concentration of prooxidant transition metals, especially iron. It has been suggested that neutral, inorganic forms of minerals, such as iron, encourage oxidation.

Maillard reaction: The Maillard reaction, which is a chemical reaction between amino acids and reducing sugars, can be brought on by the high temperatures and pressures experienced during food extrusion. Desirable tastes, smells, and colours may arise as a result of this reaction in the finished product.

Starch gelatinization: During the extrusion of food, heat and pressure can also cause the starch molecules to gel, which can enhance the mouthfeel and texture of the finished product.

Protein denaturation: Due to the high temperatures and pressures used in the extrusion of food, protein molecules may get denaturized, changing both their structure and function. This may have an effect on the finished product's nutritional value and usability.

Lipid oxidation: During food extrusion, high temperatures and pressures can also result in lipid oxidation, which can give the finished product off smells and aromas. Antioxidants or lowering the extrusion temperature and pressure can help to reduce.

Additives: Food extrusion frequently uses additives including flavourings, stabilisers, and emulsifiers. These additives may have an impact on the end product's chemical characteristics, including its texture, taste, and shelf life.

A. Process control in extrusion

Extrusion process control is essential to assuring the process's effectiveness, uniformity, and quality. In order to obtain the required product qualities and reduce final product variability, it entails monitoring and managing a variety of process factors. During extrusion, a number of important process variables are often tracked and managed, including:

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Temperature: The extruder barrel and die's temperature play a key role in influencing the texture, colour, and flavour of the finished product. To produce the appropriate product properties, the temperature needs to be carefully regulated during the extrusion process.

Pressure: The extruded product's flow rate and viscosity are influenced by the pressure inside the extruder. To ensure constant product quality and avoid equipment damage, the pressure must be managed.

Screw speed: The speed of the extruder screw impacts the end product's texture and structure and controls how long the product stays in the extruder.

Moisture content: The extruded product's texture and shelf life are influenced by the moisture content of the raw ingredients used in its production. To avoid product spoiling, moisture content needs to be properly managed.

Extrusion equipment is outfitted with numerous sensors, controls, and automation systems to monitor and regulate key process parameters. In order to obtain the required product attributes, operators can utilise this equipment to alter the process parameters in real-time depending on data from the sensors. Extrusion process management is crucial for maintaining constant product quality and increasing production effectiveness.

B. Process variables for extrusion

An ingredient combination for food is pressed through a die during the extrusion process to produce a desired shape or form. The following factors can influence the end product's quality during the process.

Raw materials: The end product's quality and choice of ingredients throughout the extrusion process can have a big impact. The components should have the required rheological characteristics, particle size, and moisture content.

Moisture content: The quality and texture of the extrudate can be impacted by the quantity of water in the raw materials or added during processing. The amount of starch gelatinization, the expansion ratio, and the density of the extrudate are all influenced by moisture content.

Temperature: The amount of gelatinization and denaturation of the proteins and starches in the raw materials depends on the temperature of the extruder barrel and die. The extrudate's texture, colour, and ability to retain nutrients are all impacted by temperature.

Screw speed: The screw speed influences the amount of time raw materials spend in the extruder, which in turn influences how much the proteins and starches are gelatinized and denaturized.

Die design: The size and form of the extrudate are determined by the die design. The texture, surface, and porosity of the extrudate can be impacted by the geometry of the die.

Pressure: The density, expansion, and texture of the extrudate are all influenced by the pressure inside the extruder.

Residence time: The amount of gelatinization and denaturation of the proteins and starches depends on how long the raw materials remain in the extruder. The length of the extruder or the screw speed may be changed to alter the residence time.

Additives: To enhance the extrudate's quality, texture, and nutritional value, additives including tastes, colours, and functional components can be added to the basic materials. The extrudate's characteristics can be impacted by the kind and quantity of additives utilised.

C. Classification of Extruders

Extruders can be categorised according to how many screws they have into single, twin, and multi-screw extruders. Plasticizing system, heating and cooling system, gearbox system and electrical control system are the four components that make up a screw extruder (Santos *et al.*, 2022[3])

D. Extruders classified on the basis of operations.

Hot extruder Raw materials are thermomechanical transformed by hot extrusion under pressure in a brief, high-temperature process. The primary purpose of this form of extrusion is to heat raw ingredients to create textured food and feed products.

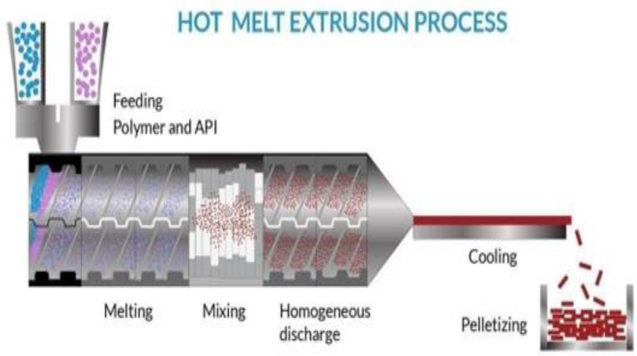

Fig. 2 Hot Extruder

IV. COLD EXTRUDERS

The process of cold extrusion is most frequently utilised downstream from the die to create particular forms of extrudate. Without the need of external heat energy, the extrudate is pushed through a die in this procedure (no heat energy from outside). Cold extrusion can refer to processes as basic as the procedures in the preparation of dough before baking. As an alternative, cold extrusion may also be employed to produce coextruded products in more complicated systems (Santos *et al.*, 2022[3]).

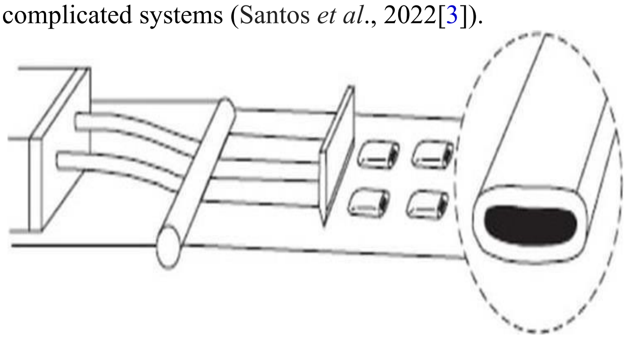

Fig. 3 Cold Extruder

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A. Extruders classified on the basis of Construction.

a. Single Screw Extruders:

Single screw forming extruders are used to make pasta, processed meats, and fillings, while single screw cooking extruders (SSCE) are used to make dry and semi-moist pet foods, expanded snacks, breakfast cereals, puddings, soup bases, and gelatinized starches and texturized vegetable proteins (Bhandari e*t al*., 2001[4]).

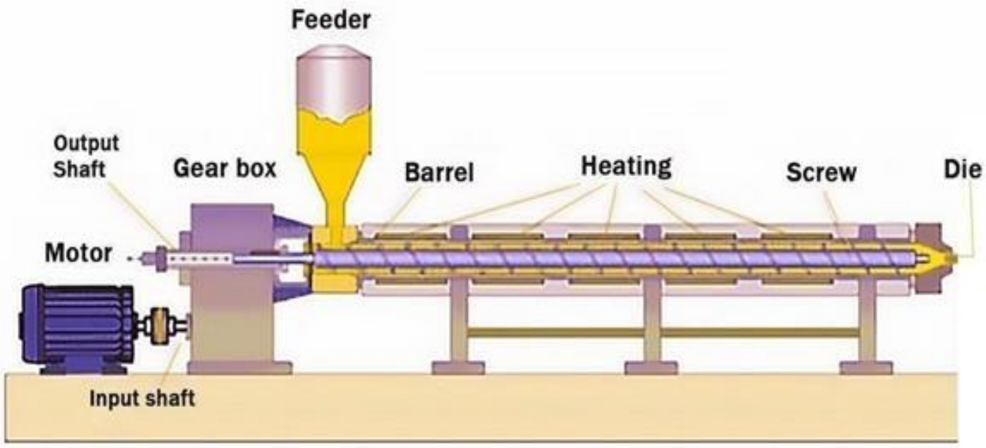

Fig. 4 Single Screw Extruder

B. Extruders with twin screws.

The majority of SSCE products as well as chocolate coatings, sweets, gums, enzyme modification processes, etc. are all uses for twin-screw extruders. A food extruder is a high temperature, brief time bioreactor that produces finished goods from a range of raw materials and ingredients. Processing for extrusion happens continuously (Bhandari e*t al*., 2001[4])

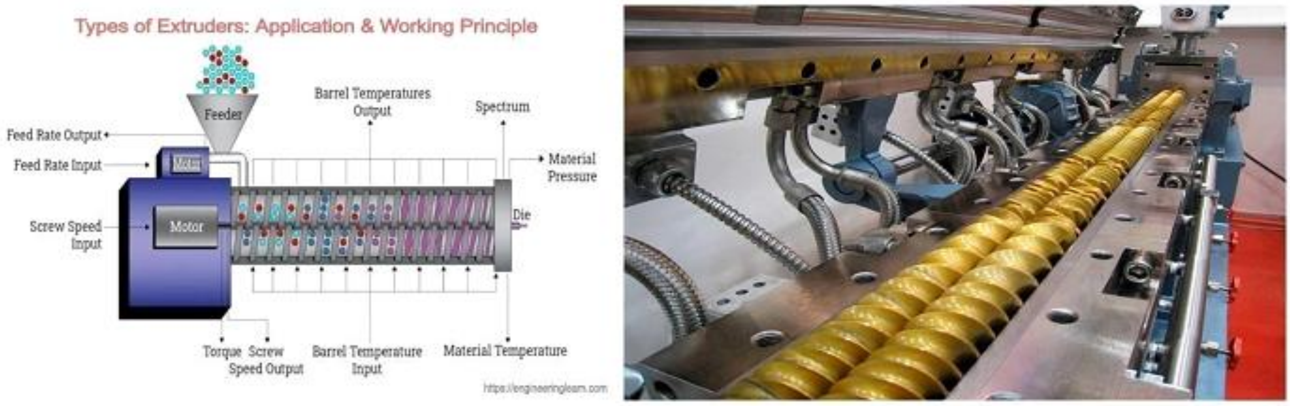

Fig. 5 Twin Screw Extruder

C. There are typically seven main parts in an extruder, including

1) The feed assembly
2) The extruder barrel.
3) Extruder drive
4) Extruder screw
5) Extrusion discharge or die system are all included.
6) Heating and cooling unit
7) Sufficient safety and control infrastructure

D. There are three portions or components in a single-screw extrusion system

Feed section: This is where the different components are fed and the first blending takes place. The components are moved to the transition or compression portion by the screw's revolving motion.

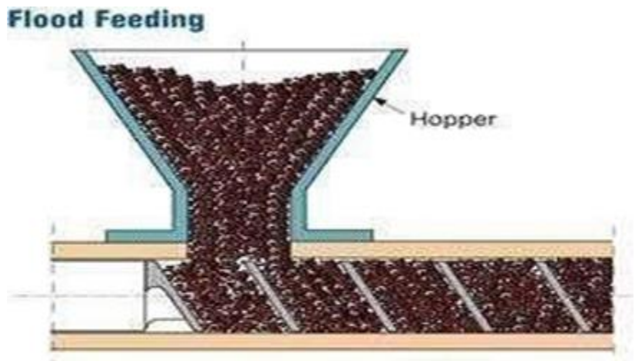

Fig. 6 Feed Section

Compression or transition section: This is the point at which the components start to change from the raw materials to the extrudate as pressure and temperature rise. The material is squeezed as the flow channel's dimensions are smaller, and as the temperature rises, mechanical energy is lost.

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The components' physical and chemical properties significantly alter during this part, which is sometimes referred to as the "kneading section" and during cooking zone (Yadav & Chandra., 2015a[5]).

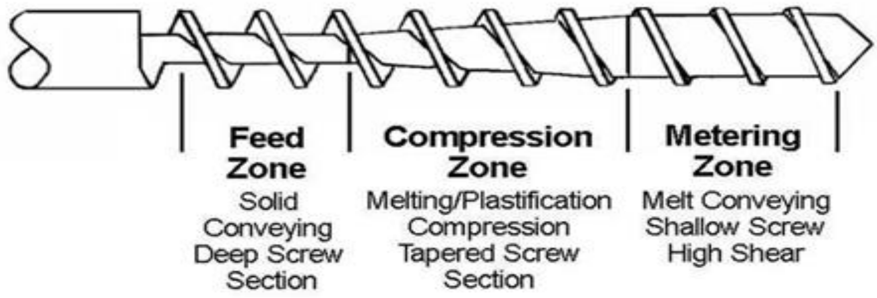

Fig.7 Compression or Transition Section

The metering (or cooking) portion: when the extrudate is more compressed due to further decreases in the flow channel's size and greater shearing action. Additionally, the barrel's overall dimensions are decreased in some designs

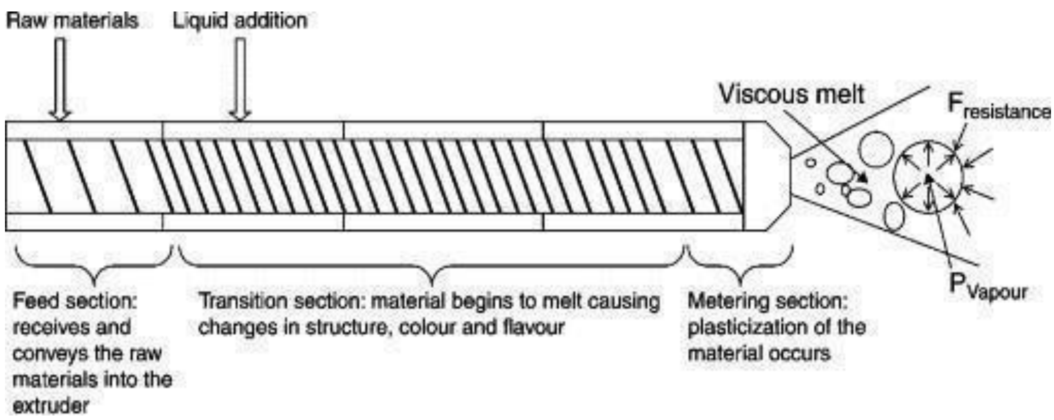

Fig. 8 Metering (or cooking) section

E. Extrusion Cooking

Extrusion cooking is the term used when heat energy is used into the extrusion process. The extrudate may get thermal energy throughout the operation from an external source or via friction at internal extruder surfaces in contact with the extrudate. Ingredients used to make the extrudate may transport thermal energy through the barrel's walls and surfaces. Additionally, the barrel's mechanical energy created by the rubbing of materials against one another is converted into heat energy in the extrudate (Bashir *et al.*, 2012[6])

F. Cereal-based products

Extroverted foods items made from cereal puffed morning cereals, RTE, and expanded snack foods basis for soups and beverages, instant beverages, foods for weaning, starches that have been pre-gelatinized and modified, dextrin's croutons and crispbread, pasta products, prepared composite flours (Rao *et al.*, 2018[7]).

G. Sweets-based Products

Gum chewing Fruit gums, toffee, caramel, brittle made of peanuts, and licoricey.

H. Protein based products

Sausage products, frankfurters, hot dogs, Surimi, caseinates and processed cheese all include textured vegetable protein (TVP), which is also used in semi-moist and expanded pet meals, animal feeds and protein supplements.

V. INNOVATIVE PRODUCTS:

A. Millets based extruded products.

a. Foxtail millet

Foxtail millet has the potential to be a significant source of protein. Good extrusion qualities of foxtail millet flour result in a smooth surface and crispy texture. Both varieties of foxtail millet are high in protein, fibre, and vitamins. For the purpose of product development, a total of five treatments with various foxtail millet ratio (100:0, 95:5, 90:10, 85:15, and 80:20) were provided. For all of the treatments, physico-chemical parameters including protein, fat, fibre, moisture, ash content, and sensory assessment were analysed (Yadav and Saini.,2018[8]).

B. Little millet (Panicum sumatrense)

Using extrusion cooking, small millet (Panicum sumatrense) and other flour are combined to create ready-to-eat snack items. Little millet (0–20%), corn (40–50%), and rice flour (40–50%) were combined to create the extruded product, which was subsequently produced using a twinscrew extruder (Saini and Yadav., 2018[9]).

C. Multi-millet based

Extrusion technology was used to create ready-to-eat snack items using composite millet-based formulations.

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Foxtail millet, finger millet, and sorghum fine semolina Various combinations of fine semolina, pear millet fine semolina, corn, Bengal gramme flour and rice flour were investigated. The flours underwent preconditioning to get them ready for extrusion cooking, and the moisture level was set at 21-23% for all the formulations. Defatted soyflour was used to develop extrudate (Bashir *et al.,* 2012[7]).

D. Green leafy vegetables

The purpose of the experiment was to create an extruded snack that was ready to eat and included a basis of maize and rice, spinach, and curry leaf powder. Effect of MC of feed (9 to 21%) and BR, or spinach powder, at various degrees of processing parameters: We investigated the effects of the ratio of curry leaf powder (25:5, 20:10, 15:15, 10:20, and 5:25), the proportion of rice and maize (35% each), and the extruder machine parameters barrel temperature (120–160°C), die head temperature (180–220°C), and screw speed (70–150 rpm) (Yadav and Chandra.,2015b[10]) (Imtiyaz & Yadav ., 2013[11]).

E. Moringa Leaf and Oat Flour

Using a lab-scale twin-screw extruder, expanded snacks made of Moringa (Moringa oleifera) leaf powder (MLP) and oat flour were created. Three levels of in-barrel moisture content (19, 22, and 26%, wet basis) and four levels of MLP (0, 15, 30, and 45%, dry blend basis) were examined. As MLP levels rose, the expansion of extrudates slowed. On the other hand, for all MLP treatments, in-barrel moisture had a favourable impact on expansion. The modification of the phase transition, water binding, and gas-holding capacity of the extrusion melt caused by MLP and in-barrel moisture was assessed and connected to the qualities of the final product (Liu *et al.*, 20119[12]).

F. Effects of Amaranth Leaf Flour on Yellow Maize/Soybean Chemical, Functional, and Sensory Properties

The extrudates made from flour mixes of yellow maize and soybean were examined to see how the addition of amaranth leaf flour affected their chemical, functional, and sensory qualities. Cleaning, drying, milling, and sifting through a 2 mm mesh screen were used to create flour samples from wheat, yellow maize, soybean, and amaranth leaf. Amaranth leaf flour was added to yellow maize and soybean (70:30) composite flour at replacement levels of 0, 5, 10, 15, and 20%, with wheat flour (100%) serving as the standard. The composite flour blends and wheat flour were mixed with baking ingredients to create extruded snack samples using a single screw extruder. The samples were then dried for 30 minutes in an oven at 60ºC for 30 min
(Nkesiga and Okafor., 2015[13])

G. Fruit-based products

Extrusion cooking research were performed in order to create two products: fruit licoricey and quick porridge utilising mango and pineapple as the primary components. For this study, the D-optimal combination design was chosen to examine how various functional components affect the sensory and nutritive properties of the finished product. The design resulted in 16 trial combinations, and for both goods, a third control formulation was created. In the four barrel zones, the temperature was adjusted to 120°C, 100°C, 80°C, and 60°C for licorice and 140°C, 120°C, 100°C, and 80°C for porridge, retaining the maximum temperature close to the die. The extrusion screw speed was set at 100 rpm. (Liu, G., 2019[14])

H. Pasta.

The study's objectives included using more nutrient-dense beetroot powder and raising the protein level of the pasta. For the control sample, pasta was made with 50% each of millet flour and refined flour. Beetroot powder was added by changing the ratio of millet flour from 50% to 10% and beetroot powder from 0 to 40% while preserving the amount of refined flour at 50%. Using a twin-screw extruder that was controlled by hand, pasta was produced. (Panditrao and Yadav, 2022[15]).

I. Barley-grape pomace mixtures

The barley flour-grape pomace mixtures were extruded in a 30 mm APV co-rotating twinscrew extruder. The impacts of independent factors such as die temperature (140–160 °C), screw speed (150–200 rpm), and pomace level (2-10%, db) on product responses (expansion, bulk density, texture, and colour) were assessed using response surface methods employing a central composite design. Selected extrudates underwent sensory examination for their appearance (colour, porosity), taste (bran flavour, bitterness, and sweetness), off-odor, texture (hardness, crispness, and brittleness), and general acceptability. To characterise the impacts of each variable on the answers from the products, multiple regression equations were generated. Changes in temperature, pomace level, and to a lesser degree, screw speed, had the most effects on the product reactions (Altan *et al.*, 2008a[16])

J. Tomato pomace mixtures processed by extrusion

A co-rotating twin-screw extruder was used to prepare mixtures of barley flour and tomato pomace. The effect of these variables on system parameters (SME, die melt temperature, and die pressure), as well as product responses (expansion, bulk density, water absorption and solubility indices, texture, and colour), was examined using response surface methodology on 20 different combinations produced by an experimental design with die temperature (140–160 °C), screw speed (150–200 rpm), and tomato pomace level (2–10%) as independent variables. Twenty samples of extrudate from five studies were chosen for sensory evaluation for colour, texture, taste, off-odor, and general acceptability. Each variable's impact on the system parameters and product responses was described using regression equations that were generated (Alten *et al.*, 2008b[17]).

K. Apple Pomace

Apple pomace, a by-product of apple juice processing, is a functional food component high in fibre and polyphenol. Extrusion of apple pomace (barrel moisture 15%, 20%, or 30%), followed by drying, enables its provision in a practical form. The cell wall structure of the apple pomace degraded as a result of extrusion. Extrusion considerably improved the water solubility while lowering the oil retaining capacity.

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Extrusion decreased the total extractable polyphenols evaluated as gallic acid equivalents (30% barrel moisture), but had no effect at lower barrel moisture contents (15% or 20%). However, extrusion boosted certain sub-groups of extractable flavanols, flavanols, phenolic acids, and dihydrochalcones (Daykar *et al.,* 2015[18]).

VI. CONCLUSION

Food goods of greater quality with excellent textures and lots of nutrients are in increased demand from consumers. Extrusion processing has shown to be a very efficient and cost-effective processing method for creating a variety of tasty food items. Extrusion has a lot of potential as a beneficial processing method for the food industry because of how simple and adaptable it is. Extrusion research will continue to advance the technology and broaden the range of items that may be produced as additional ways are discovered to use it efficiently and modify it.

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Ethical Approval and Consent to Participate	No, the article does not require ethical approval and consent to participate with evidence.
Availability of Data and Material/ Data Access Statement	Not relevant.
Authors Contributions	All authors have equal participation in this article.

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