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Effect of extrusion technology in nutritional quality of food: A review

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Abstract

Extrusion technology is becoming more and more popular in agro-food processing industry. For creation of a novel food product, global agro-food industries use mixing, forming, texturization and cooking. Extrusion cooking is a high temperature, short time process (HTST) and two of its major benefits are inactivation of enzymes and reduction of microbial contamination. Extrusion cooking outperform the conventional cooking most of the time as it's productivity and nutrient retention in foods is higher. Extrusion is emerging as crucial processing technique in food industry because of numerous advantages over other processing techniques. This technique is one of the most economically sound method as it provides platform for processing of different products from different food groups either by changing minor or significant ingredient and conditions processing. Extrusion technique is used in the food processing sector to produce a wide range of snacks, pasta, morning cereals, pet foods, supplemental foods, and other textured foods. It is an affordable technique that allows by-products and residue from food processing to be added back into the food supply. Extrusion technology's adaptability makes it simple to combine several affordable basic materials to create goods that are both nutritionally fortified and value-added. Less moisture is present in extruded items, which also have a longer shelf life and are safe for microorganisms. The benefits of this technology include product variability, excellent quality, production of novel foods, and quick processing times.

Keywords: Antioxidant, bioactive, concentration, digestibility, extrusion, nutritional, phenolic, physiochemical

Introduction

In the current situation, the term "extrusion" refers to a process in which dry or semi-moist components are forced through a die aperture with the correct cross section while altering the barrel temperature screw speed and configuration. Mixing, kneading, coating, venting, shear heating, shaping, particle drying or puffing are various unit activities that are involved in extrusion; its primarily a thermo mechanical processing (Maurya and Said, 2014) [30]. Modern consumers are experimenting with new food consumption standards as a result of the substantial rise in lifestyle disorders. Creation of new food market with high quality and creative meal options is noticed which is due to the consumers concern about food quality and safety. The current generation of customers like food that is affordable, safe, sanitary, high in nutrients, flavourful, and aesthetically pleasing. The food products are being constantly improved and modified by researchers and food industries by creating value-added foods from plant-derived by-products and wastes (Zambrano Zaragoza *et al*., 2019) [50]. By using fruit pomace and vegetable peels as a source, it's feasible in creating products high in bioactive ingredients such micronutrients (vitamins and minerals), phytochemicals, polyphenols, antioxidants and antimicrobial action. It is reviewed by (Patil and Kaur 2018; Zambrano-Zaragoza *et al*., 2019; Leonard *et al*., 2020) [36, 50] that products made by utilizing underused legumes such as pseudo-cereals, millets and whole grains and used flour are gluten-free, have high dietary fibre and low glycaemic index. Extrusion technology is maximizing energy efficient techniques to produce foods which have lower processing cost, superior quality of product, continuous production and high throughput (Grasso, 2020) [17].

The term "extrusion" is derived from Latin word "extrude" that is to force out or push out. Procedure of extrusion is to squeeze the material (either plastic, metal or mixture of food components) under high pressure and temperature through a die or orifice that has specific cross section area (Riaz, 2019) [40].

Food extrusion is a technique in which a material is pushed to flow at a predefined rate through a die (shaped hole) under varied circumstances as a mix of heat and mechanical treatment to generate a variety of products (Alam *et al*., 2016) [1]. Plasticizing and cooking of protein and/or starch rich components with heat and mechanical treatment given in a cylinder to achieve a predefined form is extrusion cooking (Harper, 2019; Riaz, 2019) [18, 40]. Since food extrusion is (HTST) high temperature, short time process that reflects on the resulting product as the texture, fluid flow, and size reduction. It also affects the final product through mixing, shearing, kneading, shaping, moulding, cooking, plasticizing, caramelizing, heat and mass transfer.

Currently, extrusion technique is widely applied in food processing industries, including separation, encapsulation, shearing, shaping, mixing, cooling or heating, sterilizing, flavor production, venting moisture and volatiles and conveying (Menis-Henrique *et al*., 2020) [32]. Numerous upgrade and improvements are conducted on equipment's used in extrusion to generate products with functional features that are efficient and sustainable. Some of them include solid dispersion stability and bioavailability of food increased by hot melt extrusion (Maniruzzaman *et al*., 2012; Ottoboni *et al*., 2017) [27, 35] and nutrient retention using supercritical carbon dioxide extrusion (Lohani and Muthukumarappan 2017; Paraman *et al*., 2015) [26]. In hot melt extrusion (HME) heat is provided to material in order to regulate viscosity and allow the food to flow smoothly down the die. New technology like 3-D printing is being introduced in extrusion which allows development of personalized and customized food products which has complicated structures, designs and geometries via extrusion, fast prototyping and layer by layer deposition (Nachal *et al*., 2019) [34]. Extrusion technology is not only popularizing in food industries by also gaining recognition in packaging industries by developing eco-friendly packaging material employing biopolymer.

The present evaluation focuses on the most recent advancements in food extrusion technology. This review paper emphasises the use of extrusion technology in the development of innovative food items with excellent nutritional, physicochemical, and sensory properties.

Process

The process of extrusion involves forcing raw materials to flow under precise control down the length of the extruder barrel and through a predetermined throughput via a formed hole (referred to as the die assembly). In the beginning, raw materials are frequently ground to the desired particle size. They frequently travel via a preconditioner where more components may be added, along with the possibility of steam injection. Three different energy sources work together to cook and mix the product during extrusion: mechanical energy (shear from the screw parts), thermal energy from the heating system, and self-heating from the barrel's melt viscosity (T.H *et al*., 2017). It is crucial to regulate temperatures and process periods to maximize the quality of the completed product since the rheological behaviour of the dough in the barrel has a significant impact on that quality.

There are three major categories into which variables that affect the extrusion process may be divided:

- The composition and formulation of the raw material (viscosity, moisture content, chemical composition)
- Thermo mechanical cooking factors, such as ma chine design (screw profile, length/diameter of the machine) and Operational circumstances (screw speed, temperature profile, water content, dry mix rate, residence time)
- Die texturization factors (die design, insert shape, opening section).

Extrusion techniques may be divided into four basic categories: cold extrusion, hot extrusion, steam induced, and co-extrusion. Without using direct heat or cooking within the extruder, cold extrusion is used to gently combine and form dough. It is mostly employed to make dough and pasta. Raw materials are thermo mechanical transformed by hot extrusion under pressure at high temperatures for a brief period of time. For the wide range of uses, this extruder makers must provide incredibly adaptable machinery. The qualities of the end product, for instance, might be significantly influenced by the material used to make the extrusion die. When compared to stainless steel dies, bronze dies are known to make pasta with a rougher surface and superior quality (McHugh, 2017) [31].

Types of extrusion processes: Cold extrusion is more focused on mixing and shaping foods without cooking them like biscuits, pasta, dough etc. Hot extrusion or extrusion cooking which is used in production of several food items including chips, sugar confectionary, soya-base weaning foods etc.

- **Cold extrusion:** Using cold extrusion, food is mixed and shaped at a constant temperature, including pasta and meat products. Also utilized is a temperature of less than 100o C, for extrusion under low pressure. Cold extruded items are preserved by freezing, baking, or drying processes. Extrusion cooking, on the other hand, gets rid of potentially harmful microorganisms and keeps dry food goods fresher for longer. Dry goods that are packaged during storage do not oxidize or absorb moisture. Cold extruders are suitable for both small-scale manufacturing and domestic use (Moscicki *et al*., 2011) [33].
- **Hot extrusion:** Extrusion cooking, commonly referred to as hot extrusion, is the process of heating food to a temperature more than 100 °C. For fast temperature rise, frictional heating and other heating techniques are applied. Food is transferred to barrel sections with small flights that serve to generate shear and pressure once it has been heated. After final shaping, food is swiftly chilled to remove moisture in the form of steam before being released from the die under pressure (Zuilichem *et al*., 2011) [33]. Products can be shaped into a wide variety of shapes, including doughnuts, shells or squirls, strips, rods, tubes, and spheres. Extrusion cooking creates a variety of food products, such as puffed cereals (RTE), expanded snack items, etc.
- **Operating conditions & Process of extrusion:** The significant working conditions are the temperature and tension in the barrel as well as its width and rate at which items are sheared. The shear rate is influenced by screw speed, geometry (size, number, pitch and breadth of flights) and the internal barrel design. Additional heating of barrel maybe due to steam jacketed barrel, a steam heated screw or an electric heating material around it. (Maskan, M. and Altan, A *et al*., 2011) [29]. 'High-shear' extruders have high screw rates and shallow trips to make the high tensions and temperatures expected to make extended items; 'medium-shear' extruders are utilized to

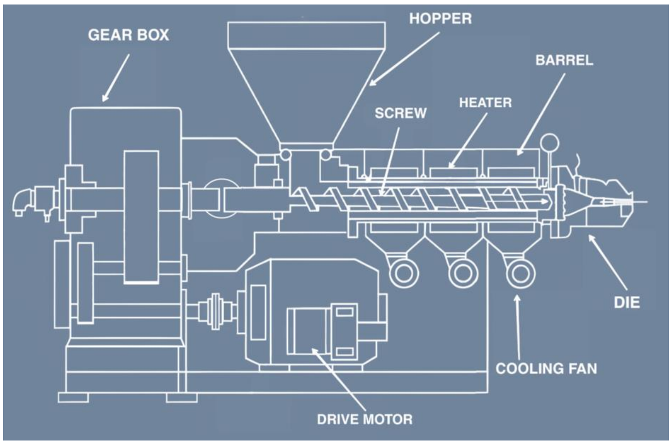
make texturized proteins and semi-clammy food sources; and 'low shear' extruders have a profound flighted screw that works at low paces in a smooth barrel to make low tensions for framing meat items or gums. The choice of the right kind of extruder for a specific application ought to assess the kinds of fixings and the properties expected in the item (for example its mass thickness, surface, variety furthermore, other tangible properties) and the expected creation rate. Die holes can be of many forms, such as round holes for producing rods, square holes for producing bars, or slots for producing sheets, or they can make more complicated shapes. The food's temperature, moisture content, and degree of barrel shearing all affect how much the product expands and, consequently, how it feels. While some products feature chilled dies to decrease expansion, others need for heating the dies to provide the necessary degree of expansion. Because there are so many different possible equipment design feature combinations, small-scale processors should consult extruder manufacturers before making a purchase. (Moscicki *et al.*, 2011) [33]

Application of different types of extruders

Food products in the snack industry utilize one of three types of extruders. These include screw, piston, and roller- type extruders (Alam *et al.*, 2016) [1]. Screw type extruders are probably still in use today. The single screw-extruder and twin-screw extruders are the two types of extruders that are most often utilized based on screw design. (Moscicki and Zuilichem *et al.* 2011) [33] analyzed the single-screw extruder which was first time used in 1935. Thermoplastic materials were plasticized using single-screw extruder, whereas, for producing the food goods, twin-screw extruders were used in mid 1930s. Following, in pasta industry, single-screw extruders are used for producing staples like spaghetti and macaroni.

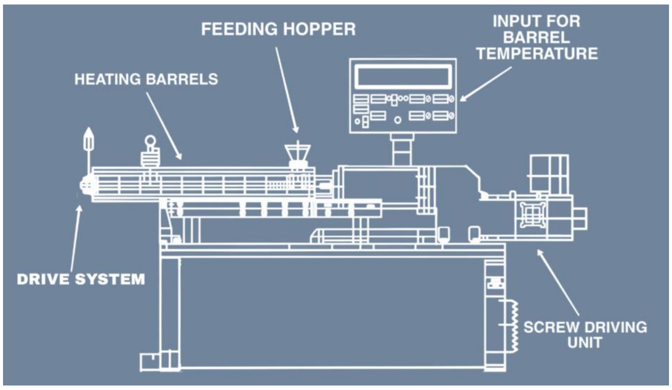
Single screw extruder

The single screw extruder is easy to operate and has low capital and operational costs. But it has several operational issues, such inadequate mixing capacity. Therefore, prior to the extrusion process, feeding conditioning and ingredient premixing are required (Martha *et al.*, 2017) [28]. The apparatus consists of a feeder, a barrel with a single- screw extruder, a pressure and temperature control unit, a gear unit and a motor. The feed, the compression, the plasticizing zone, and the region where the die is inserted at the end of the barrel are the three components of the screw-barrel unit of this type of extruder. In the barrel, the materials are forwarded, the gap between the screw flights is filled, and are pressed. As a result, frictional and shear forces are increased. Screw flights induce an increase in mobility resistance. In the third zone, starch molecules degrade and melt/plasticize. Furthermore, the plasticized food item is pushed through a small aperture, or die. The melted material rapidly expands and the emergence from the die head causes the completed products, which have a puffed, porous shape. The immediate decrease in vaporization of moisture (about 40-60%) and pressure causes this expansion (Kanojia and Singh, 2016; Patil *et al.*, 2005) [21].



Twin screw extruder

High mechanical complexity is a disadvantage of twin-screw extruder, this increases the operational coasts and the capital (Martha *et al.*, 2017) [28] but also limits its capacity to mix well and pump efficiently. Inside a barrel, a pair of parallel screws revolve. Depending on the way the screws rotate, it is separated into two categories: First are the screws that rotates in the same direction known as co-rotating screws, and the second are the screws rotate in the opposite directions known as counter- rotating screws. In the food industry, the co-rotating twin screw extruder is often employed due to its efficiency, self-cleansing system, and reliable handling. It makes it simple to regulate the characteristics of both products and processes. (Tonya Schoenfuss *et al.*, 2013) [45] developed enlarged puffed goods using modified corn-starch-based non-fat dry milk powder and a twin-screw extruder. (Brncic *et al.*, 2006) [7] looked at the impact of processing settings on the textural quality of snacks made from wheat starch and extruded in a twin-screw extruder. (Bing *et al.*, 2009) [6] researched characteristics of starch film processing by twin screw extruder. A twin-screw extruder was used and slit die to test the processing capacity of maize starch with various amylose/amylopectin ratios.



The recent development in food extrusion technology

Hot melt extrusion (HME)

Hot melt extrusion initially worked in plastic industries but then expanded into food industries for cereal food product manufacture. HME is an effective method that produces solid dispersions, by modifying their physio-chemical, thermal and mechanical properties to improve food stability and bioavailability. HME has ability to improve solubility, gelatinize starch and denature protein, so it has become quite popular in food processing. It basically increases the digestibility while also inactivating enzymes, bacterial and other anti-nutritional factors (Alam *et al*., 2019) [2]. Wide and dep application of HME occurs in pharmaceutical industries where medicines consisting molecular dispessions of bioactive compounds, plymers or liquids can be developed for controlled modified and targeted drug delivery (Maniruzzaman *et al*., 2012) [27]. Basic HME has some essential components which are,

- Platform that serves as a foundation for driving system
- An extrusion barrels
- A rotating screw mount on screw shaft
- An extrusion die is used to determine the products shape.

The standard HME extruder consist one or two crews moving in a fixed barrel either simultaneously or alternatively. The barrel is constructed in portion so that molten material has to stay in barrel must shorten. The barrels end is connected to an endplate die that provides the shape (like rod, pellets, tablets etc.) to material depending on application. HME typically uses twin screw extruders with a feed zone, compression zone and metering zone (Fang *et al*., 2003) [116]. The feed zone's responsibilities include constant feeding from the hopper and mixing. The compression zone aims to create additional mixing by utilising special screw components like interrupted flights and kneading blocks. The compression zone is where the extrudate is principally homogenised, sheared, and melted, making it a suitable form to reach the metering zone. The food particle melts and is blended at a steady temperature in this last zone to produce food with a uniform composition. The potential of the HME to disguise medicine taste by microencapsulation, its capacity to improve the solubility of hydrophobic chemicals, and its use in the creation of nanoparticles are some of its well-known applications (Maniruzzaman *et al*., 2012) [27]. The anti-Atherosclerotic pathogenic potential of the substances was revealed in a newly developed dietary health supplement high in flavonoids (epicatechin, produced from cocoa) (Ramirez *et al*., 2020) [39]. In terms of target delivery, repeatability, and taste masking capabilities, hot-melt extrusion has been shown to be a superior alternative to currently used technologies like spray drying, co-crystallization, freeze-drying, etc. Because the hot melt products have better thermodynamic stability, they have a very low tendency to recrystallize (Huang *et al*., 2019) [19]. The native crystallites melt and the water is redistributed through the granules during the hotmelt extrusion process. (Alam *et al*., 2019) [2] have investigated the functional properties of these pellets as a potential source of protein in food, despite the fact that hot melt extruded insect-based pellets are routinely utilised in the pharmaceutical business. The pellets were made using either insect flour alone or insect flour combined with maize flour in this way.

A co-rotating twin-screw extruder with a screw speed of 100 rpm, a water flow of 0.03 kg/h, and a die zone temperature of 70 °C was used to extrude the pellet. The granules' solubility, durability, and dispersion properties were improved by hot-melt extrusion. However, taking into account how the insects were fed, the application of extruded insect grains is still in the future. When five mixes comprising H. illucens (HI) larvae or pupae and wheat flour were extruded at a single barrel temperature of 60 °C and a single screw speed of 60 rpm, (Ottoboni *et al*., 2017) [35] examined how this influenced the digestibility of the mixes. The production of snacks derived from insect flour utilising HME may be a practical solution to meet the high protein requirements of the world population. According to (Ramirez *et al*., 2020) [39], HME is also used in feeds, cheese spreads, medications, and flesh replacements. Nutraceutical foods have been produced with incorporated bioactive ingredients using hot-melt extrusion technique. The simple interaction of bioactive elements (flavours, vitamins, colours, and essential oils) and wall components (maltodextrin, maize starch, mannose, and b-cyclodextrins) is achieved during the plasticization of wall materials. In order to protect the heat-sensitive bioactive compounds, the glass transition temperature is decreased utilising cheap carrier agents and plasticizers (Zuidam and Heinrich *et al*., 2010) [52]. Excellent productivity is guaranteed with less oxygen contact in the extrusion channel using the solvent-free technique. Therefore, these results have given researchers the chance to look more closely at how HME can be used to create goods with smaller particles, greater solubility, and stronger antioxidant properties. However, more investigation into the toxicity and bio accessibility of HME compounds is required in the food industry.

Extrusion based 3-D printing

With extrusion printing, food samples are created by pushing the food over approximate constant pressure. This method is comparable to traditional fused deposition modelling (FDM). However, in extrusion printing, the feedstock can be both solid and (soft) low viscosity paste, but in FDM the starting material is the yarn. The material is entered from the extruder (barrel) before being extruded through the mold by the pressure of the piston in the structure food shapes layer by layer. Pasta with meat and cheese are two examples of processed foods with this approach. (Lipton *et al*., 2010) [24] examined several sugar cookie recipes. Results showed that regulating the concentration of ingredients affected food production models, including the ratio of butter, egg yolk and sugar. To make modeling easier Added transglutaminase and bacon fat. Furthermore (Yang C *et al*., 2018) [49] used room temperature extrusion printing Lemon juice gel with Extruder Screw Feeder. After, which (L. Wang *et al*., 2018) [47] performed an experiment to print fish surimi gels with approach by (Fanli Yang *et al*., 2018) [49] The results show that in addition to the nozzle height, nozzle diameter, nozzle feed and extrusion speed are affected 3D printing for food. (M. Lanaro *et al*., 2017) [22] studied melt extrusion prints complex chocolate patterns based on machine design, including mechanism design, to create strong material. The results suggest that there are two main areas of design:

- Engineering the extruder assembly to be as stiff as feasible, eliminating flexing and permitting more precise chocolate deposition, and
- Enhancing the design of active cooling systems to quench the chocolate at lower temperatures.

Novel functional food using extrusion cooking

Extrusion cooking is a prospective method to create meals that are both ready to eat and ready to cook while keeping the bioavailability of nutrients by altering their structure using hydrothermal treatments. Extrusion-produced goods are becoming more and more well-liked. Popularity in the food industry stemming from a variety of ingredients, especially from plant-based byproducts, can be effectively leveraged to create distinctive value-added products. The section that follows highlights some recent findings and advancements in this field. Through extrusion, new functional foods can be created (Chen Y *et al*., 2014) [10].

Meat analogue: It has the potential to improve the nutritional content and utility of such a meat substitute. The most challenging aspect of making plant-based protein into a fibrous texture is high moisture extrusion, which is a promising method that is widely employed worldwide. Twin screw extruders can be used to mix, heat, cut, and manufacture vegetable protein sources with a moisture content of up to 75% in order to create a ribbed and fibrous sheet (Wild, F. *et al*., 2016) [38]. Although scientists succeeded in giving plant-based meat substitutes a fibrous texture, the product's lack of flavour and odour prevented it from capturing a larger market. Bovine bones with the Maillard process impart crucial sensory properties to their look, texture, taste, and flavour, according to research by (Chiang *et al*., 2020) [12]. He also investigated the physicochemical properties of soy protein and wheat gluten, two vegetable proteins, and an extrudate Maillard transformed beef bone hydrolysate. Applied to cured meats. The study demonstrated that additional effort is needed to create a plant protein sausage with improved texture and sensory attributes.

Fortification: Through repurposing food processing sector waste to make commodities with value additions, food can be improved. Extrusion is one of them; it is an HTST (high temperature, short time) technique. there are many different technologies that may be applied to create high nutritional snack meals that also have sensory appeal while preserving product safety. It is possible to add fibre, vitamins, and minerals from fruits and vegetables (pomace and skins) to mixtures of local flours with a high content of carbs and proteins. These new foods, which have higher physicochemical and nutritional qualities, are produced via extrusion cooking. There have been numerous studies on the impact of extrusion parameters (extrusion temperature, moisture content of the extrusion mix, time, setup, screw speed, die pressure, etc.) and raw material composition (moisture content in raw materials, particle size and the proportion of each) in preserving the quality of the extrudate in terms of nutrition, functional properties, and the like for an extended life. Extrusion increased the overall fibre content while also enhancing the digestibility of both proteins and carbohydrates (Wang *et al*., 2017).

Starch modification: IECT (Improved Extrusion Cooking Technology) is a ground-breaking method of gelatinization that was developed from a standard screw extruder to enhance the qualities of the extrudate, particularly starch modification. In order to increase and improve the structural qualities of the extrudate, a classic extrusion process, which comprises high temperature, high pressure, and shear forces, was pioneered by (Liu *et al*., 2011). They used broken rice and bran as basis materials. IECT, on the other hand, can modify its physical chemistry properties to provide desired structural attributes. Long screw (1950 cm), long residence time (40–68 s), high mould pressure (13.3–19.1 MPa), low temperature (69.8–120 °C), and high screw speed (20th–32.6 rpm) are all characteristics of the extruder (Zhang *et al*., 2014) [10]. In numerous research, the IECT has been utilized to improve the nutritional value, retrogradation rate, and starch digestibility of high amylose starches, as well as the effects of these factors on gelatinization properties. After cooking, the amylose and amylopectin in starchy foods rapidly deteriorate, making them hard and losing their flavour, acceptability, and usability. Due to the low temperature and high pressure, the combination of proteins, fats, and carbohydrates during IECT is rarely augmented. The enhances textural characteristics and aids in the encapsulation of nutrients (Liu *et al*., 2019).

Effect of extrusion process on cereal-based products and its nutritional aspects

The starch gelatinization, protein denaturation, component interactions, and browning reactions that occur during thermal processing processes for cereals such baking, roasting, and extrusion result in a variety of physical and chemical changes. According to Ragaee *et al*. (2014) [37], these alterations enhance the organoleptic qualities, promote food accessibility, and inactivate enzymes and heat-labile harmful chemical inhibitors. Extruded foods are mostly made of grains, legumes, and/or vegetable proteins. Structure, texture, mouthfeel, and a number of other properties sought for particular completed goods are the main functions of these components. The appealing characteristics of extruded meals is significantly influenced by factors such as water absorption, water solubility, oil absorption rates, expansion rate, bulk density, and dough viscosity (Alam *et al*., 2016) [1]. By combining feedstock moisture content, press temperature, and screw speed, which oversee the physical and chemical transformations in the end product and consequently affect the product quality, several changes in the food matrix have been reported through the extrusion process (Leyva-Corral *et al*., 2016) [23].

During the extrusion cooking process, a number of chemical changes occur, including gelatinization of starch or proteins, denaturation of proteins, modification of lipids, and inactivation of enzymes and microorganisms. Grain protein denaturation during extrusion cooking results in tannin protein synthesis complexes and the maintenance of antioxidant activity by opening slack tannin-protein connections. In the digestive tract of humans, these complexes are broken down to release bound tannins and perform as free radical scavengers. Another significant chemical effect of extrusion is browning, or the production of Maillard reaction product (MRP), which enhances the antioxidant qualities of the finished product (Zilic *et al*., 2014). Nevertheless, numerous studies have discovered that it is bioactive when extrusion occurs because substances with antioxidant effects (like phenols, tocopherols, carotenoids, anthocyanins, flavonoids, tannins, and other bioactive compounds) are lost. According to (Dlamini *et al*., 2007) [15], thermal complexing with the Maillard reaction can result in the breakdown of phenolic compounds reaction by-products and high moisture content, which promotes the polymerization of phenolic compounds and has an impact on extractability and antioxidant activity. On the other hand, earlier research on grains has shown that thermal processing can help to liberate bound phenolic acids through the breakdown of cell components and cell walls. For instance, it has been demonstrated that phenolic compounds can be transformed into more readily extractable forms in single screw extruders operating at high temperatures, high shear, and low moisture (15/100g). The structural changes in the materials subjected to extrusion are related to all these chemical changes, which promote the release of bioactive compounds in the cell wall array and make these components less difficult to remove. Strong cutting forces, high temperatures, and pressure all contribute to these physical changes by easily destroying the tough cell walls of matrix foods (Chiu *et al*., 2012) [13].

Macronutrients (lipids, proteins, and carbs) and micronutrients (vitamins and minerals) are two key categories of nutrients that influence the nutritional qualities of cereals. Extrusion techniques affect the nutrient content of food and feed combinations in both favourable and unfavourable ways, according to a number of studies. According to Singh S. *et al*. (2007) [42], these results are affected by the extruder's settings (temperature, feed moisture, screw speed, and screw configuration) and the characteristics of the raw material (composition, particle size). To provide the optimal food offer, extrusion cooking, as previously explained, has been thoroughly explored. As a multi-stage, multi-functional thermal/mechanical process, extrusion can have positive or negative effects on the bioavailability and nutritional value of grain products (Ragaee *et al*., 2014) [37]. On the one hand, extrusion causes the starch to gelatinize and enhances its digestibility, encourages the destruction of anti-nutritional components (unwanted enzymes, trypsin, and haemagglutinins), raises the concentration of soluble fibre, improves protein digestibility, and lowers lipid peroxidation. On the other side, extrusion may cause some minerals' bioavailability to decrease. As a result of the Maillard reaction that takes place throughout the procedure, heat-labile vitamins and some amino acids are lost, which may reduce the nutritional value of the proteins. This section will examine the effects of extrusion cooking on the nutritive qualities of grains (Brennan *et al*., 2013) [5].

Macronutrients

Lipids: Oxidation in extruded foods can be delayed by a number of factors, such as: Denaturation of oxidising enzymes like lipase and other enzymes; Formation of lipid-amylose complexes, which decreases the availability of both strength and lipids and lengthens the shelf life of extruded products; Release of endogenous antioxidants in granules during extrusion that can provide protection against oxidation (Sproston *et al*., 2016) [41]. The polyunsaturated fatty acids (PUFA)-3 and -6 are essential for human health, and because they have more installations, they are more vulnerable to oxidation. As a result, people prefer alternatives to traditional food processing, which results in less loss and less oxidation of these nutrients. The effects of extrusion on corn-based snack meals were examined by (Ramos Diaz *et al*., 2017) [38] using varied ratios of quinoa and amaranth. The number of fatty acids (palmitic, oleic, linoleic, and linolenic acid) and tocopherols was found to be lower after extrusion when compared to flour combinations. The authors claim that the considerable drop in fat concentration acids and tocopherols during extrusion is caused by the creation of amylose-lipid complexes. Additionally, it's critical to keep in mind that the various components used in the aforementioned studies varied, which had an impact on the amount of amylose available for lipid binding and complex formation (Jouppila *et al*., 2017) [38].

Amino acids and proteins: Beans, peas, chickpeas, lentils, and other edible dried seeds are traditionally the principal sources of vegetable protein in the diet, along with cereals (corn, sorghum, rice, and barley). The concentration of important amino acids in the protein, as well as its digestion and utilisation, all affect its nutritional value. Grain structure and disulphide bond composition, surface functional groups, protein hydrophobicity and conformation, and surface functional groups are just a few of the factors that can affect how easily grain proteins are digested. Additionally, processing factors like pressure, temperature, fermentation, freeze/thaw cycles, and scissors may change how digestible a protein is. Extrusion has been investigated in various research to improve protein digestibility by exposing enzyme-sensitive areas of proteins and denaturing proteins. This phenomenon is linked to how proteins' structure and conformation are affected by strong shear. Production of highly digestible proteins occurs during extrusion. According to (Vaz and Arêas *et al*., 2010) [44], the breakdown and denaturation of proteins throughout the process essentially causes the rise in protein solubility seen in extruded meat-based foods. Similar to this, unless heat and shear are employed, enzymes and enzyme inhibitors lose their effectiveness during extrusion. Protease inhibitor levels may be reduced to enhance plant protein assimilation. Extrusion was also suggested as a potential method for modifying the allergenic qualities of dietary protein. The protein's structure may affect how antigenic the substance is. After thermal processing, there is a depletion of, eventually resulting in a decrease in post-meal IgE and IgG binding capacity (Sun-Waterhouse *et al*. 2014) [43].

Carbohydrates, starch, and fibre: One of the most thoroughly studied extrusion components in products with nutritional value is how extrusion technology affects the digestion of carbohydrates. The majority of extruded foods, including granola, snack foods, and weaning foods-the most crucial food component-contain starch. Raw starch is difficult for humans to digest. However, the extrusion process can increase the digestibility of starch because of the gelatinization and fragmentation caused by shearing and heating. Starch is more easily accessed by digestive enzymes thanks to depolymerization. In addition to this, the physical breakdown of starch molecules that occurs during extrusion creates smaller, easier-to-digest pieces. Extrusion can enhance the amount of carbohydrates that are readily available by up to three times when compared to raw (non-extruded) grain.

Many cases in the literature show that extrusion improves starch digestibility (Gilbert *et al*., 2017). After extrusion, wheat, corn, and barley all have higher (2–3%) levels of enzyme-resistant starch, according to numerous studies. The extrusion process settings were modified by (Jing *et al*., 2013) to achieve the highest levels of soluble dietary fibre in soybean residues (temperature 115 °C, feed moisture 31%, and screw speed 180 rpm). This caused the residue's soluble dietary fibre content to increase by 10.6%, and it also gave it the ability to retain more water, oil, and swelling than unextruded residues did. Under optimum circumstances (170 °C and 150 rpm for the extrusion screw), blown extrusion of soybean residue produced equivalent results (Chen *et al*., 2014) [10]. Researchers discovered that the concentration of soluble fibre, as well as water solubility, water holding capacity, and swelling capacity, rose more than 10-fold in soybean residues as compared to the untreated. Additionally, they investigated the physiological effects of their high-fibre product and found that it can significantly lower *in vivo* levels of triglycerides, low-density lipoprotein cholesterol, and total cholesterol (Liu, Y *et al*., 2017) [25].

Micronutrients

Vitamins: In general, the chemical structure and composition of vitamins vary widely. The stability of the during the heating process also varies. The degree of deterioration is affected. By a variety of factors during food preparation and storage, including humidity, temperature, light, oxygen, time, and pH. This significantly affects the stability of water-soluble vitamins cooking by extrusion. For example, higher drum temperatures and low input humidity cause decomposition of ascorbic acid during extrusion (Brennan *et al*., 2011) [4]. In contrast, a long barrel extruder (20%) results in a lower retention rate of the vitamin B group (44-62%) than a short barrel (90mm) extruder. Vitamin absorption varies by grain variety and is mostly independent of the original amount consumed. In comparison to the oat and corn/pea components, pyridoxine (vitamin B6) in corn was more stable during extrusion heating. Another study of enhanced maize extrudates shed light on the impact temperature fluctuations during the extrusion process on the content of thiamine (B1) and riboflavin (B2). The lowest temperature resistance of the vitamin E isomers is found in -tocopherol and -tocotrienol (Boyaci *et al*., 2012) [9].

Minerals: The minerals are believed to be stable after heat treatment. On the other hand, larger changes in smaller molecules during the extrusion process may have an impact on other food-related compounds. Mineral stability when heated by grain kernel extrusion has been demonstrated in numerous research. Surprisingly, extrusion cooking can boost mineral absorption by lowering other factors that inhibit it. In the digestive tract, phytates can combine with minerals to produce insoluble molecules, which lowers the bioavailability of certain elements. Extruded foods can also improve mineral absorption, which may be because extrusion cooking breaks down polyphenols. Mineral absorption may also be impacted by fibre (which includes cellulose, lignin, and hemicelluloses). The high temperature during extrusion, on the other hand, can restructure the components of the fibre and alter their chelation capacities (Gamlath S, *et al*., 2007) [42].

Effect of extrusion technology on bioactive compounds of cereals

Phenolic compounds (phenolic acids and anthocyanins): In addition to their nutritional worth, cereals contain bioactive compounds that might possibly be beneficial for your health. These biologically active phytochemicals have been shown to be natural antioxidants and can help lower the risk of developing a number of ailments. Bioactive substances that are present in nature but are destroyed or altered during food preparation could impair a food's antioxidant capacity. Consequently, the According to study, food processing can both positively and negatively impact antioxidant activity.

Wheat grain phenolic content may be positively or negatively impacted by extrusion cooking. (Mongolian BA *et al*., 2014) One-way extrusion affects the concentration of extractable phenols is by causing the breakdown of thermolabile phenolic compounds and the polymerization of other compounds. On the other hand, extrusion in the increases phenolic accessibility by upsetting cell wall matrices and rupturing covalent connections in high molecular weight polyphenol complexes. Which of these events takes place most frequently determines the overall impact of extrusion on the total phenolic content. Additionally, the antioxidant activity of foods is correlated with the presence of bioactive substances like phenols, carotenoids, flavonoids, and anthocyanins. Numerous studies have recently been published on the impact of extrusion and extrusion configuration on the phytochemical content and antioxidant activity of cereals. Concerns about large losses or gains in bioactive compounds during extrusion were addressed along with thermal stress and chemical alterations. For instance, moisture content, time, and temperature have a significant impact on how quickly phenols compounds are released (Wang *et al*., 2014) [46].

Other bioactive compounds: The acetyl derivatives of genistein and daidzein as well as the malonyl analogues were demonstrated to be reduced by increasing the temperature and moisture content of a corn/soybean mixture in the extrusion barrel providing evidence for this heat decarboxylation. Compared to raw corn, research using eight genotypes of Mexican Creole corn (yellow and red) that were processed into extruded flours and tortillas revealed that the overall carotenoid content was retained between 69 and 79%. The concentration of the major carotenoid components (lutein, zeaxanthin, cryptoxanthin, and -carotene) advanced similarly to the extrusion process (He F *et al*., 2014). Surprisingly, when compared to raw maize, lutein, the most significant carotenoid in maize, retained an average of 60–71%. The heating process, which causes carotenoid degradation and processes like isomerization and oxidation, could be the main cause of the considerable decrease in carotenoid levels and profiles, as well as lipophilic antioxidant activity, throughout the tortilla-making process. The information above implies that the influence of extrusion depends on both the type of cereal and its bioactive ingredients as well as the right processing parameters (Corrales-Bauelos *et al*., 2016) [14].

Advantages and disadvantages of extrusion technology

The benefits of extrusion technology are:

1. Lower manufacturing costs and exceptional productivity
2. A variety of applications, products with a high production and quality
3. Easy to digest and absorb, with less nutritional loss
4. Good taste and easy to eat

Some of the drawbacks are:

1. The barrel and screw edge exhibit serious abrasion.
2. Screw and barrel processing is rather expensive.
3. Because the material inside the barrel produces heat, the heater outside the barrel must provide much of the heat.

Conclusion

Extrusion technology has been widely used in the food industry, especially to produce cereals, snacks, and pet foods. It involves the use of heat, pressure, and mechanical shear to process raw materials into a finished product with desirable physical, chemical, and nutritional properties. In recent years, extrusion technology has gained attention in the field of nutrition due to its potential to improve the nutritional quality of foods. This review paper discusses the effect of extrusion technology on the nutritional quality of food. The nutritional quality of food is determined by various factors, including the content of macronutrients (carbohydrates, proteins, and fats), micronutrients (vitamins and minerals), and bioactive compounds (antioxidants, phytochemicals, and prebiotics). Extrusion technology has been shown to influence the content and bioavailability of these nutrients in different ways. Extrusion technology also has a positive impact on the carbohydrate content of food.

Reference

1. Alam MS, Kaur J, Khaira H, Gupta K. Extrusion and extruded products: changes in quality attributes as affected by extrusion process parameters: A Review, Critical Reviews in Food Science and Nutrition. 2016;56(3):445-475.
2. Alam MR, Scampicchio M, Angeli S, Ferrentino G. Effect of hot melt extrusion on physical and functional properties of insect based extruded products. J. Food Eng. 2019;259:44-51.
3. Anukiruthika T, Moses JA, Anandharamakrishnan C. 3-D printing of egg yolk and white with rice flour blends. J. Food Eng. 2020;265:1–39.
4. Brennan C, Brennan M, Derbyshire E, Tiwari BK. Effects of extrusion on the polyphenols, vitamins and antioxidant activity of foods. Trends in Food Science & Technology. 2011;22(10):570-575.
5. Brennan MA, Derbyshire E, Tiwari BK, Brennan CS. Ready-to-eat snack products: The role of extrusion technology in developing consumer acceptable and nutritious snacks. International Journal of Food Science & Technology. 2013;48(5):893-902.
6. Bing Su, Fengwei Xie, Ming Li, Penny A Corrigan, Long Yu, Xiaoxi Li, *et al*., Extrusion Processing of Starch Film, International Journal of Food Engineering, Article. 2009;75(1):1-12
7. Brncic M, Tripalo B, Jezek D, Semenski D, Drvar N, Ukrainczyk M. Effect of twin-screw extrusion parameters on mechanical hardness of direct expanded extrudates, Article in Sadhana. 2006;31(5):527–536.
8. Butterworth PJ, Warren FJ, Ellis PR. Human α-amylase and starch digestion: An interesting marriage. Starch-Stärke. 2011;63(7):395-405.
9. Boyaci BB, Han J-Y, Masatcioglu MT, Yalcin E, Celik S, Ryu G-H. Effects of cold extrusion process on thiamine and riboflavin contents of fortified corn extrudates. Food Chemistry. 2012;132(4):2165-2170.
10. Chen Y, Ye R, Yin L, Zhang N. Novel blasting extrusion processing improved the physicochemical properties of soluble dietary fiber from soybean residue and *in vivo* evaluation. Journal of Food Engineering. 2014;120:1-8.
11. Chiang JH, Hardacre AK, Parker ME. Extruded meat alternatives made from Maillard reacted beef bone hydrolysate and plant proteins. Part II–application in sausages. Int. J. Food Sci. Technol. 2020b;55(3):1207–1217.
12. Chiang JH, Hardacre AK, Parker ME. Effects of Maillard reacted beef bone hydrolysate on the physico-chemical properties of extruded meat alternatives. J. Food Sci. 2020a;85:567–575.
13. Chiu HW, Peng JC, Tsai SJ, Lui W-B. Effect of extrusion processing on antioxidant activities of corn extrudates fortified with various Chinese yams (Dioscorea sp.). Food and Bioprocess Technology. 2012;5(6):2462-2473.
14. Corrales-Bañuelos AB, Cuevas-Rodríguez EO, Gutiérrez-Uribe JA, Milán-Noris EM, Reyes-Moreno C, Milán-Carrillo J, *et al*., Carotenoid composition and antioxidant activity of tortillas elaborated from pigmented maize landrace by traditional nixtamalization or lime cooking extrusion process. Journal of Cereal Science. 2016;69:64-70.
15. Dlamini NR, Taylor JR, Rooney LW. The effect of sorghum type and processing on the antioxidant properties of African sorghum-based foods. Food Chemistry. 2007;105(4):1412-1419.
16. Fang Q, Hanna M, Lan Y. Extrusion system components. Encycl. Agric., Food, Biol. Eng. 2003. p. 301–305.
17. Grasso S. Extruded snacks from industrial by-products: a review. Trends Food Sci. Technol. 2020;99:284–294.
18. Harper JM. Extrusion of Foods, 1. CRC press. 2019.
19. Huang D, Xie Z, Rao Q, Liamas E, Pan P, Guan S, *et al*., Hot melt extrusion of heat-sensitive and high melting point drug: inhibit the recrystallization of the prepared amorphous drug during extrusion to improve the bioavailability. Int. J. Pharm. 2019;565:316–324.
20. Jing Y, Chi Y-J. Effects of twin-screw extrusion on soluble dietary fibre and physicochemical properties of soybean residue. Food Chemistry. 2013;138(2):884-889.
21. Kanojia V, Singh M. Extruded Product Quality Assessment Indices: A Review, Review article. International Journal of Agriculture Sciences. 2016;8(54):2928-2934.
22. Lanaro M, Forrestal DP, Scheurer S, Slinger DJ, Liao S, Powell SK, *et al*., 3-D printing complex chocolate objects: platform design, optimization and evaluation. J. Food Eng. 2017;215:13–22.
23. Leyva-Corral J, Quintero-Ramos A, Camacho-Dávila A, de Jesús Zazueta-Morales J, Aguilar-Palazuelos E, Ruiz-Gutiérrez MG, *et al*., Polyphenolic compound stability and antioxidant capacity of apple pomace in an extruded cereal. LWT-Food Science and Technology. 2016;65:228-236.
24. Lipton J, Arnold D, Nigl F, Lopez N, Cohen DL, Norén N, *et al*., Multi-material food printing with complex internal structure suitable for conventional post-processing. In: Solid free form Fabrication symposium, 2010;43:809–815.
25. Liu Y, Chen J, Luo S, Li C, Ye J, *et al*., Physico-chemical and structural properties of pregelatinized starch prepared by improved extrusion cooking technology. Carbohydr. Polym. 2017b;175:265–272.
26. Lohani UC, Muthukumarappan K. Process optimization for antioxidant enriched sorghum flour and apple pomace based extrudates using liquid CO2 assisted extrusion. LWT. 2017;86:544–554.
27. Maniruzzaman M, Boateng JS, Snowden MJ, Douroumis D. A review of hot-melt extrusion: process technology to pharmaceutical products. ISRN Pharm, 2012. p. 3-4.
28. Martha G Ruiz-Gutiérrez, Miguel Á Sánchez-Madrigal, Armando Quintero-Ramos. Chapter 5- The Extrusion Cooking Process for the Development of Functional Foods, Extrusion of Metals, Polymers, and Food Products, Sayyad Zahid Qamar, Intech Open, 2017. p. 58-70.

29. Maskan M, Altan A. Contemporary Food Engineering Series, CRC Press. 2011. p. 145-156.
30. Maurya AK, Said PP. Extrusion Processing on Physical and Chemical Properties of Protein Rich Products. Journal of Bioresources Engineering and Technology. 2014;2:61-67.
31. McHugh TH. How extrusion shapes food processing. Food Technology. 2017;71(7):67-69.
32. Menis-Henrique MEC, Janzantti NS, Monteiro M, Conti-Silva AC. Physical and sensory characteristics of cheese-flavored expanded snacks obtained using butyric acid and cysteine as aroma precursors: effects of extrusion temperature and sunflower oil content. LWT. 2020;122(1–24):109001.
33. Moscicki L, Zuilichem DJV. Chapter- 1, Extrusion-Cooking Techniques, Applications, Theory and Sustainability, Edited by Leszek Moscicki, Wiley VCH Verleg GmbH & Co. KGaA, c2011. p. 12-25.
34. Nachal N, Moses JA, Karthik P, Anandharamakrishnan C. Applications of 3-D printing in food processing. Food Eng. Rev. 2019;11(3):123–141.
35. Ottoboni M, Spranghers T, Pinotti L, Baldi A, DeJaeghered W, Eeckhoute M. Inclusion of HermetiaIllucens larvae or prepupae in an experimental extruded feed: process optimization and impact on *in vitro* digestibility. Ital. J. Anim. Sci. 2017;17:1-10.
36. Patil SS. Current trends in extrusion: development of functional foods and novel ingredients. Food Sci. Technol. Res. 2018;24(1):23–34.
37. Ragaee S, Seetharaman K, Abdel-Aal E-SM. The impact of milling and thermal processing on phenolic compounds in cereal grains. Critical Reviews in Food Science and Nutrition. 2014;54(7):837-849.
38. Ramos Diaz JM, Sundarrajan L, Kariluoto S, Lampi A-M, Tenitz S, Jouppila K. Effect of extrusion cooking on physical properties and chemical composition of corn-based snacks containing amaranth and quinoa: Application of partial least squares regression. Journal of Food Process Engineering. 2017;40(1):1-15.
39. Ramirez OAE, Uribe LR, Escobar MDPN, Durango KM, Ramírez CMÁ, Rivas JCM, *et al*. U.S. Patent No. 10,555,986, 2020.
40. Riaz MN. Chapter 19- Food Extruders. Handbook of Farm, Dairy and Food Machinery Engineering, 3rd Edition. Elsiver, 2019. p. 483–497.
41. Sproston MJ, Akoh CC. Antioxidative Effects of a glucose-cysteine maillard reaction product on the oxidative stability of a structured lipid in a complex food emulsion. Journal of Food Science. 2016;81(12):2923-2931.
42. Singh S, Gamlath S, Wakeling L. Nutritional aspects of food extrusion: A review. International Journal of Food Science & Technology. 2007;42(8):916-929.
43. Sun-Waterhouse D, Zhao M, Waterhouse GI. Protein modification during ingredient preparation and food processing: Approaches to improve food processability and nutrition. Food and Bioprocess Technology. 2014;7(7):1853-1893.
44. Vaz L, Arêas JAG. Recovery and upgrading bovine rumen protein by extrusion: Effect of lipid content on protein disulphide cross-linking, solubility and molecular weight. Meat Science. 2010;84(1):39-45.
45. Tonya Schoenfuss. Twin-screw extrusion puffing of non-fat dry milk powder. Agriculture Utilization Research Institute, 2013. p. 1-30.
46. Wang T, He F, Chen G. Improving bio accessibility and bioavailability of phenolic compounds in cereal grains through processing technologies: A concise review. Journal of Functional Foods. 2014;7:101-111.
47. Wang L, Zhang M, Bhandari B, Yang C. Investigation on fish surimi gel as promising food material for 3-D printing. J. Food Eng. 2018;220:101–108.
48. Wild F. Manufacture of meat analogues through high moisture extrusion, 2016.
49. Yang F, Zhang M, Prakash S, Liu Y. Physical properties of 3D printed baking dough as affected by different compositions. Innovat. Food Sci. Emerg. Technol. 2018b;49:202–210.
50. Zambrano-Zaragoza ML, Quintanar-Guerrero D. Novel techniques for extrusion, agglomeration, encapsulation, gelation, and coating of foods; Food Eng. 2019;264:109668.
51. Žilić S, Mogol BA, Akıllıoğlu G, Serpen A, Delić N, Gökmen V. Effects of extrusion, infrared and microwave processing on Maillard reaction products and phenolic compounds in soybean. Journal of the Science of Food and Agriculture. 2014;94(1):45-51.
52. Zuidam NJ, Heinrich E. Encapsulation of aroma. In: Zuidam, N.J., Nedovic, V.(Eds.), Encapsulation Technologies For Active Food Ingredients and Food Processing, 2010. p. 127–60.