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# **Review Article**

# **Definition of Extrusion Cooking Technology, the Food Industry in Focus: A Review**

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## **ABSTRACT**

The aim of this paper was to review the different definitions of extrusion cooking of food available in literature. Extrusion cooking of food entails different unit operations in a single process whereby different food ingredients are uniformly mixed and forcefully passed through a die. It has been used in producing various shapes and sizes of food products. Extrusion technology is mostly applied in the manufacture of snacks, breakfast cereals and ready-to-eat food products and the more modern 3D breakfast cereals and snacks. Extrusion cooking involves a high temperature short time process and is very useful in producing low-fat snacks. Extrusion cooking of food entails different unit operations in a single process. An extruder has five major components, preconditioner, barrel, screw, die (usually with cutter) and the feeding system. It originated in the metallurgical industry. Food extruder may be classified thermally, geometrically or conveying mechanism based on applications, design and configurations. Extruders have the same operating principles, basically, a screw extruder is made up of a rotating screw in a fixed barrel and a die at the exit. Different types of extruders have advantages and limitations. Different researchers have used a variety of raw material for extrusion cooking ranging from flours of cassava, maize, wheat, corn, millet and soybean. Pasta and breakfast cereals are the commonest extruded cereal-based food products.

Key words: Cereals, extruder, high temperature, mixing, shear, short-time, snacks

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Data Availability: All relevant data are within the paper and its supporting information files.

#### **INTRODUCTION**

The five major components of an extruder include: Preconditioner, barrel, screw, die (usually with cutter) and the feeding system [1]. The very important operating parameters of an extruder include barrel temperature and pressure, die aperture diameter and rate of the shear. The rate of the shear is determined by barrel internal design, length:diameter ratio of the barrel, screw speed and screw geometry. There are different types of extruders, however classification of extruders can be based on number of screws, shear, heat generation and direction of rotation. Factors to consider when selecting an extruder for extrusion process include nature of ingredients, type of product, bulk density required in the product, the sensory properties of the product, feed rate. Feed rate is determined by some factors such as element and speed of the screw, moisture content, feeding element type. Also, feed rate determines some factors such as residence time, temperature of dough, pressure of the barrel, torque requirement<sup>1</sup>. High pressure and temperature are a requirement to produce expanded snack foods. These high pressure and temperature results in high shear in the extruders, usually characterized by shallow flights and screw speed which is high. The die design and swelling of the melt at the exit of the die determines the final shape of the extruded product. Different authors have concluded that extrusion cooking solubilizes fibre, increases protein and starch digestibility, inactivates antinutrients, toxins and harmful enzymes such as peroxidases. Hence the need to review these definitions.

### **Extrusion technology**

**Definition:** The extruder originated in the metallurgical industry in 1797. It was in mid-1800 that extrusion was applied to food (casings were being stuffed with chopped meat). A single-screw extruder was first used in the pasta industry in 1930<sup>2</sup>.

From the definitions given by different authors (Table 1), it may be summarized that extrusion cooking of food entails different unit operations in a single process whereby different food ingredients are uniformly mixed and forcefully passed through a die. It has been used in producing various shapes and sizes of food products. Extrusion technology is mostly applied in the manufacture of snacks, breakfast cereals and ready-to-eat food products and the more modern 3D breakfast cereals and snacks. Extrusion cooking involves a high temperature short time process and is very useful in producing low-fat snacks. Extrusion cooking solubilizes fibre, increases protein and starch digestibility, inactivates antinutrients, toxins and harmful enzymes such as peroxidases3. During extrusion cooking, the structure and texture after processing of the food products (extrudates) are changed.

**Types of extrusion technology:** Navale *et al.*<sup>1</sup> reported that different types of extruders differing in configurations and performances are in existence and are classified based on certain factors (applications, design, configurations). Muthukumarappan and Swamy<sup>3</sup> made an attempt to classify extruders (Fig. 1). Food extruders are classified thermally as forming (cold) or cooking (hot) and geometrically as single or

Table 1: Definition of extrusion

Definition	References	
Food extrusion involves the process of forcing food materials to flow under a variety of operations,	Offiah <i>et al.</i> <sup>4</sup>	
including kneading, melting and/or shear, through an orifice (die) which is specifically designed to		
shape and/or expand the material. Food extruders may be designed to perform several unit operations		
concurrently, including mixing or homogenization, shearing, starch gelatinization, protein denaturation,		
texturization, enzyme inactivation, thermal cooking, pasteurization, dehydration, shaping and size reduction		
Extrusion cooking is a process that combines the unit operations of mixing, cooking, shaping and forming	Fellows <sup>5</sup>	
to produce foods such as breakfast cereals, snack foods, soya meat analogues and confectionery. It is a		
high-temperature short-time process that inactivates microorganisms and enzymes and reduces the water		
activity of products but largely retains their nutritional value and improves organoleptic properties,		
especially texture		
The extrusion process is an efficient continuous process, which uniquely combines several unit operations,	Tiwari and Jha <sup>6</sup>	
viz: mixing, shearing, heating, pumping, forming and sizing		
Extrusion cooking technology, a high temperature short time (HTST) processing being used increasingly	Navale <i>et al.</i> <sup>1</sup>	
in the food industries for the development of new products such as cereal based snacks, including		
dietary fiber, baby foods, breakfast cereals and modified starch from cereals. As it is a HTST process,		
which reduces microbial contamination and inactivates enzymes, the main method of preservation		
of both hot and cold extruded foods is by the low water activity of product (0.1-0.4)		
The extrusion process is defined as a high temperature short time treatment where feed material is	Bdour <i>et al.</i> <sup>7</sup>	
exposed to friction and shearing forces		

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Table 1: Continue	
Definition	References
Extrusion process is a contemporary food processing technology to produce wide variety of foods and	Shankar <i>et al</i> . <sup>8</sup>
products that are microbial safe because it is a high temperature and shot time process and extrusion	
process is best suited for large scale production and leaves no effluents	
Food extrusion is a process where a food material or a mixture of ingredients (called feed) is forced to flow (under	Rhee <i>et al.</i> <sup>9</sup>
various conditions of mixing, heating and shear) through a die which is designed to form and/or puff-dry the extrudate.	
Extrusion cooking has become a common processing method in the cereal, snack and vegetable protein industries for	
converting starchy and proteinaceous raw materials into fabricated products	
Cooking-extrusion is a multi-step, multi-functional thermal/mechanical process used in a large number of food applications	Boukid <i>et al.</i> <sup>10</sup>
	Smith and Hardacre <sup>11</sup>
Extrusion cooking is a short time, high temperature and high shear process. Typically, dry granulated	Smith and Hardacre.
starchy food material are fed into the extruder barrel where they are forced by rotating spiral screws	
from a small orifice. As the product leaves the die, typically at about 120C residual water in the starchy	
melt expands into steam forming a low density, crisp foam	
Extrusion cooking is food processing technology that combines several unit operations including	Oliveira <i>et al.</i> <sup>12</sup>
mixing, cooking, kneading, shearing, shaping and forming	
Extrusion cooking is a hydrothermal treatment of high temperature and short duration, during which flours or starches	Ruiz-Ruiz <i>et al.</i> <sup>13</sup>
are subjected to high temperatures and mechanical shearing at relatively low levels of moisture content	
Extrusion cooking is such a common processing effort for converting starchy and proteinaceous material	Choudhury <i>et al.</i> <sup>14</sup>
into fabricated products at high temperature short time duration to produce expanded snacks	endanary et an
Extrusion cooking is a high-temperature, short-time process in which moistened, expansive, starchy	Ogunmuyiwa <i>et al.</i> <sup>15</sup>
	Ogumnuyiwa <i>et ai</i> .
and/or proteinaceous food materials are plasticized and cooked in a tube by a combination of moisture,	
pressure, temperature and mechanical shear, resulting in molecular transformation and chemical reactions	
In the extrusion process, the raw material is made to flour and moistened, then subjected to high	Arivalagan <i>et al</i> .¹6
${\sf temperature}$ treatment for short time cooking, wherein the desired level of ${\sf temperature}$ is achieved	
through shearing and friction forces created in the extruder	
Extrusion cooking is an industrial cooking process that combines high pressure, heat and mechanical	Chávez <i>et al.</i> <sup>17</sup>
force in a short period of time, causing physical and chemical changes	
Extrusion cooking is a high-temperature short-time (HTST) process, since cooking temperature can be	Sujka <i>et al.</i> <sup>18</sup>
as high as 180-190 °C during extrusion but retention time is usually only 20-40 s. Extrusion uses a	,
combination of a few parameters: pressure, shear, moisture and heat	
Extrusion is a mechanical process exposing material to high temperature, shear and pressure over a short period of time	Obiang-Obounou and Ryu <sup>19</sup>
Extrusion cooking of snack foods is a high temperature and shear process that is characterised by	
	Dehghan-Shoar <i>et al.</i> <sup>20</sup>
forming a melt from the starchy ingredient, at high temperature (140-180°C) and low moisture	
content (~12%). Processing is rapid with a typical mean residence time of 15-30 s	
Extrusion cooking, particularly in the snack food industry, is a complex process that differs from conventional	Athar <i>et al.</i> <sup>21</sup>
processing by using high shear rates and high temperatures (4150 1C) for very short periods (seconds)	
Extrusion is a continuous food processing technique classified as a high temperature short time operation	Rodríguez-Miranda <i>et al</i> . <sup>22</sup>
in which raw food materials are thermo-mechanically cooked in a screw-barrel assembly by a combination	
of moisture, pressure and temperature in order to be mechanically sheared and shaped	
Extrusion cooking is a high temperature short time (HTST) cooking technique which provides thermal	Yu <i>et al.</i> <sup>23</sup>
and shear energy to a food material to induce desirable physical and chemical changes	
Extrusion cooking technology is a high temperature, short time, versatile and modern food operation	Jiddere <i>et al.</i> <sup>24</sup>
that converts agricultural commodities from usually granular or powdered form into fully cooked shelf	siddere et al.
stable product with enhanced textural and flavour attributes	
	Dawing at a125
Extrusion cooking technology is a high-temperature, short-time, versatile and modern food operation	Berrios <i>et al.</i> <sup>25</sup>
that converts agricultural commodities, usually in a granular or powdered form, into fully cooked,	
shelf-stable food products with enhanced textural attributes and flavor	
Extrusion transforms starch- and protein-based solid materials into a viscoelastic fluid under high pressure	Diaz <i>et al.</i> <sup>26</sup>
and temperature conditions. A drop of pres- sure at the die point vaporizes the water embedded in	
the fluid, leading to the formation of pores and an increase of sectional expansion. The content and type	
of fibre present in the flours may determine physical (sectional expansion, porosity, wall thickness	
etc.) and sensory (crispiness, crunchiness, hardness etc.) characteristics of extruded snacks	
Extrusion cooking is the technology having the possibility of changing the functional properties	Pardhi <i>et al.</i> <sup>27</sup>
of food ingredients. During extrusion cooking, the raw materials undergo many chemical and	
structural transformations, such as starch gelatinization, protein denaturation, complex formation	
between amylose and lipids and degradation reactions of vitamins and pigments	
Extrusion is a method of physical texturing of a raw material for the purpose of its refinement and for imparting	Timonen-Soivio <i>et al.</i> <sup>28</sup>
to it the features of a semi-product or product. In the food industry that technology is used for the production of	Timonen Joivio et al.
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a broad array of products such as breakfast flakes, diet supplements, functional foods, pastries and confectionery,	
snacks and feeds from e.g. waste materials from the agricultural and food industry	D. J
Extrusion technology is increasingly used in the food industry for producing different types of food	Radovanovic <i>et al.</i> <sup>29</sup>
products such as breakfast cereals and ready-to-eat snacks. It is a high temperature, high pressure,	
short time and continuous processing technique that enable manufacturers to produce highly	
nutritious food products with incorporation of different types of ingredients, flours and starches	

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Definition  Extrusion cooking provides the conditions for gelatinizing starch, polymerizing proteins and crosslinking molecules to form oppinable mixtues. The addition of proteins to starches increases sites for cross-linking and affects textual quality proteins and provided provided in the provided provided in the provided p	Table 1: Continue	
Entrousine a process which combines several unit operations including mining, coloning, heading, shaping and forming, Usually the food to compressed and worked to form a semi-solid mass.  This is then forced through a restricted opening the die) at the discharge end of the screw. The main purpose of extrusion is to increase variety of book in the diet by producing a range of products with different shapes, between, colonis and flowurs from basic in gredients  Extrusion is a processing method that combines the effects of mechanical shear and temperature to discuss the colonism of the discussion of the content of soluble dietary filters of the processing method that combines the effects of mechanical shear and temperature to discuss the colonism of the content of soluble dietary filters, probably due to disruption of covalent and noncovalent bonds, which would lead to smaller and more soluble molecular fragments. This abo loads to increase per douction of short-chain futty acids from the fecal microflora, which could have health benefits for humans. Furthermore, extrusion also reduces antifurnational factors and enhances the ability to lower choicesterol.  Extrusion cooking is a versalite, low cost and efficient food processing technique. It cooks more applity than other techniques because it combines motinisation, protein denaturation, complies formation between amyloce and lipids and degradation of vitamins or pigments, in the case of station geletinates to the process of vitamins or pigments, in the case of station geletinates to the food material, the more energy is required to invalid the processing and under the process of footing a pumpatile material to fine station of the food material, the more energy is required to invalid the processing entroped and applications of vitamins or pigments, in the case of station geletinates to the process of footing and string of the station processing entroped and publication of the process of footing and entry and entroped to the processing and under a merital to from a	Definition	References
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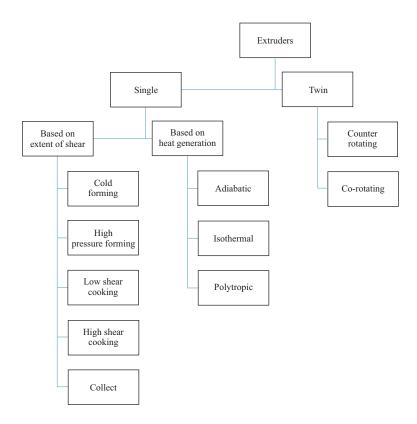


Fig. 1: Classification of extruders based on number of screws, shear, heat generation and direction of rotation Source: Muthukumarappan and Swamy<sup>3</sup>

Table 2: Advantages and limitations of different types of extruders

Type of extruder	Advantages	Limitations
Single-screw	Lower capital, operating and maintenance costs	Does not self-clean. There may be problems emptying the
	(capital cost about half of a twin-screw machine).	extruder barrel if it is allowed to cool and the product
	Wet single-screw extruders have higher capacity, higher	solidifies
	capital costs but lower operating costs than dry extruders	
	Less skill required to operate and maintain	Not able to process materials that contain >12-17% fat or
		>30% moisture due to product slippage in the barrel
	Less complicated assembly of screw configurations	More limited ingredient particle size range (very fine
		powders and coarse ingredients are not suitable)
	Wet single-screw extruders have greater processing control	Dry extruders require higher motor power and undergo
	that produce superior-shaped products compared to dry extruders	greater wear than other types of extruder. The high exi
		pressures make it difficult to shape products <2 mm or
		process highly viscous materials
Twin-screw	Can produce intricate shapes and small sizes (<1.0 mm)	More complex than single-screw extruders
	Greater flexibility and control than single-screw extruders	More expensive (twice the price of single-screw machines)
		and have higher maintenance costs
	Can handle very viscous, oily (18-27% fat), wet (up to 65% water) or sticky	
	materials (up to 40% sugar compared to 10% in single-screw machines)	
	Self-wiping screws are easier to clean without dismantling, giving more	
	rapid product changeover	
	Can handle very fine ingredients or coarse ingredients directly	
	without pretreatments	
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Source: Fellows<sup>5</sup>

twin screws<sup>6</sup>. Extruders may also be classified based on conveying mechanism: Piston, roller or screw<sup>4</sup>. Irrespective of extruder design or type, extruders have the same operating

principles, basically, a screw extruder is made up of a rotating screw in a fixed barrel and a die at the exit<sup>4</sup>. The two types of extruders have advantages and limitations (Table 2).

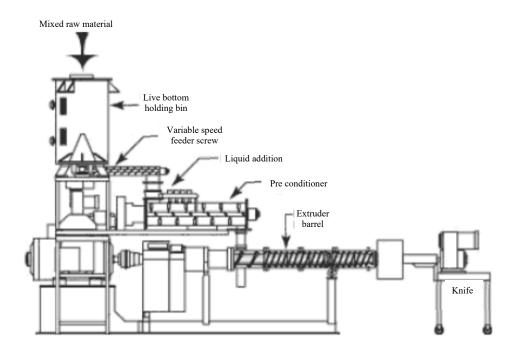


Fig. 2: Layout of a typical snack food line for direct expanded products

Source: Tiwari and Jha<sup>6</sup>

Extrusion equipment: The five major components of an extruder include: pre-conditioner, barrel, screw, die (usually with cutter) and the feeding system<sup>1</sup>. The very important operating parameters of an extruder include barrel temperature and pressure, die aperture diameter and rate of the shear (Fig. 2). The rate of the shear is determined by barrel internal design, length:diameter ratio of the barrel, screw speed and screw geometry. Factors to consider when selecting an extruder for extrusion process include nature of ingredients, type of product, bulk density required in the product, the sensory properties of the product, feed rate<sup>5</sup>. Feed rate is determined by some factors such as element and speed of the screw, moisture content, feeding element type. Also, feed rate determines some factors such as residence time, temperature of dough, pressure of the barrel, torque requirement<sup>1</sup>.

High pressure and temperature are a requirement to produce expanded snack foods. These high pressure and temperature results in high shear in the extruders, usually characterized by shallow flights and screw speed which is high<sup>5</sup>. The die design and swelling of the melt at the exit of the die determines the final shape of the extruded product<sup>46</sup>.

# Extrusion technology and microstructure of extruded foods:

The microstructure of food is affected by food processing. The

food components such as proteins, vitamins and starch are usually involved in irreversible changes during processing. The proteins are denatured most times while the water soluble vitamins are lost. Extrusion cooking of food entails different unit operations in a single process whereby different food ingredients are uniformly mixed and forcefully passed through a die. It has been used in producing various shapes and sizes of food products. Extrusion technology is mostly applied in the manufacture of snacks, breakfast cereals and ready-to-eat food products and the more modern 3D breakfast cereals and snacks. Extrusion cooking involves a high temperature short time process and is very useful in producing low-fat snacks. Extrusion cooking solubilizes fibre, increases protein and starch digestibility, inactivates antinutrients, toxins and harmful enzymes such as peroxidases<sup>3</sup>. During extrusion cooking, the structure and texture after processing of the food products (extrudates) are changed but most researchers have not paid attention to these changes. Nuclear magnetic resonance and scanning electron microscope techniques can be used to investigate these microstructural changes. There are various classifications of extruders. An extruder basically has a single screw, however, depending on the desired extrudate, adjustments could be made in its design such as number of screws and their direction of rotation. Different extrudates usually have their various differences in texture and structure. Muthukumarappan and Swamy<sup>3</sup> reported that most researchers have not investigated into the microstructure of extrudates. It has been confirmed that there are numerous tiny air cells, extrudate brittleness is decreased while its crunchiness is improved upon and the cell walls are pervious and rough at high extrusion temperatures. Using Fourier Transform Infrared Spectroscopy (FTIR), it was shown that extrudates from pea protein isolate, extruded at a low moisture level, resulted in expansion of the protein network. This was assumed to be kept in steady state by increased aggregation of protein which might have been formed by some sheets and helical structures. The SDS-PAGE (sodium dodecyl sulfate polyacrylamide gel electrophoresis) suggested that the protein's vicilin and convicilin were not altered except for the legumin. It was concluded that extrusion cooking decreases the solubility of protein in water<sup>47</sup>. Analysis of corn meal extrudates showed different pore sizes for samples with similar expansion index. Magnetic resonance imaging and X-ray microtomography of the samples gave values which were not significantly different from each other. However, X-ray microtomography gave a superior spatial resolution<sup>48</sup>. The porosity of rice grits and rice grit extrudates were compared in a study using mercury intrusion porosimetry, water vapour desorption and nitrogen adsorption. It was reported that extrusion cooking results in a more porous end product. Compared with rice grits, the extrudates had a smaller radius<sup>18</sup>. Scanning probe acoustic microscopy was carried out on starch material extrudate and acoustic images were correlated with X-ray diffraction data. The result showed that the acoustic image contrast had a straight line relationship with the amylose component of the extrudate<sup>49</sup>. Zhang et al.50 investigated the structure of cooked and  $extruded\ maize\ starch\ using\ NMR\ and\ reported\ that\ they\ were$ similar but differed in density.

The microstructure of foods changes on extrusion, depending on method of extrusion. Variation in the extrusion parameters can lead to extruded products with different and unique microstructure leading to differences in texture and, of course, varieties of products would result. A more detailed probe into the structure and texture of various food extrudates is now possible through modern techniques such as FTIR, NMR and microscopic techniques such as scanning electron microscope.

**Extruded snacks:** Direct expanded products are classified as second generation snack food because they are produced through extrusion cooking, in other words, it expands as soon

as it leaves the die of the extruder. Only minor treatments (such as drying or frying basically to reduce the moisture content) may be required before consumption. Extrusion technology is mostly applied in production of pasta products, baby foods, texturized foods, breakfast cereals and snacks<sup>51,52</sup>. Extrusion has also been widely used in the production of functional foods<sup>26,53</sup>. Robin and Palzer<sup>46</sup> reported that pasta and breakfast cereals are the commonest extruded cerealbased food products. Extrusion cooking changes the properties of starch and proteins significantly. Robin and Palzer<sup>[46]</sup> reported that extrusion cooking promotes cereal flour properties as seen in cold extrusion which favours production of protein network around starch granules which are not cooked, an example is pasta. In hot extrusion, the high temperature and pressure cooks the starch resulting in a ready-to-eat food product as seen in breakfast cereals and extruded snacks. Extrusion cooking creates room for different ingredients to be combined into a single product. Chemical and structural changes take place during extrusion cooking<sup>37</sup>. Extrusion cooking is now being preferred to conventional cooking due to some textural properties such as high expansion ratio and more crunchiness<sup>54</sup>. Most extruded product contain cereal. Robin and Palzer<sup>46</sup> reported that different factors (application, geography, consumer habits) affect the type of grain used in extruded foods. Altan et al.55 produced an expanded snack from barley grits and barley flour. Mäkilä et al.<sup>54</sup> produced antioxidant-rich extruded snack from blackcurrant juice press residues, cereals, starch from potato, sugar and salt.

Some researchers have produced extrudate with wheat as an ingredient. Some of them include: Peressini et al.56 for example, produced extrudate rich in fibre from wheat flour, defatted soy flour, corn starch, rice flour, corn grits, inulin, sugar and salt. Chakraborty et al.<sup>57</sup> from some ingredients including wheat, coriander leaves, rice and corn flours. Stojceska et al.58 from some ingredients including wheat flour and corn starch. Mezreb et al.59 from wheat flour and yellow corn. Dehghan- Dehghan-Shoar et al.<sup>20</sup> from wheat semolina, rice flour, corn grits and tomato paste or skin powder. Oliveira et al.<sup>12</sup> and Oliveira et al.<sup>60</sup> from wheat flour and corn. Robin et al.61 and Singkhornart et al.62 from wheat flour. Jafari et al.63 from wheat flour and sorghum. Pitts et al.64 from some ingredients including wheat and corn flour. Starch and protein materials are mostly used in extrusion process, sugarbased materials may also be used (Table 3). Navale et al.1 reported some raw materials used by different researchers for extrusion cooking (Table 4).

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Table 3: Examples of extruded foods

Starch-based products	Protein-based products	Sugar-based products
Breadings	Caseinates	Chewing gum
Breads, including flatbreads, breadsticks,	Fish pastes	Chocolate, caramel crispbreads and croutons
Expanded Snack foods	Processed cheeses	Fruit gums
Pasta products	Sausages, frankfurters and hot dogs	Fudge
Pastry doughs	Semi moist and expanded pet foods, animal	Hard boiled confectionery
	feeds, aquatic feeds	(e.g. toffees, caramels, peanut brittle
Pregelatinised and modified starches	Surimi	Liquorice
Ready-to-eat and puffed breakfast cereals	Texturised Vegetable Protein (TVP) or 'meat analogues'	Nougat
Weaning foods		Praline

Source: Fellows<sup>5</sup>

Table 4: Raw material used by different researchers for extrusion cooking

Sr. No.	Raw material
1	Cassava, maize and wheat flour
2	Wheat, mungbean and groundnut
3	Water yam starches
4	Rice-Sweet potato and rice-yam
5	Broken rice flour, pineapple waste pulp powder and red gram powder
6	African yam bean and cassava flour
7	Pearl millet
8	Tef, corn and soy protein isolated blends
9	Corn, millet and soybean
10	Carrot pomace, rice flour and pulse powder
11	Arrowroot starch
12	Barnyard millet and red gram
13	Defatted soy flour and rice
14	Corn grits
15	Lentil based snacks
16	Cassava starch
17	Rice and moong flour
18	Faba bean and rice
19	Soy and maize
20	Lentil starches
21	Defatted chick pea, corn and bovine lung flour
22	Full fat soy flour (FFSF) and cereal or pulse flour
23	Broken rice and corn grits
24	Mustered oil and rice grits
25	Faba beans
26	Yam flour
27	Potato and wheat flour
28	Rice flour and amaranth
29	Soy flour and maize
30	Garbanzo bean, lentil, whole peas and split peas
31	Soybean-sweet potato mixture
32	Rice and chick pea
33	By product from wheat mill with yellow corn, wheat starch and isolated soy protein
34	Wheat starch, whole wheat meal and oat flour
35	Maize grits
36	High moisture fish and soy protein
37	Wheat/ rice semolina and potato grits
38	Soyabean meal
39	Barley and rice flour, wheat flour
40	Soyabean and sorghum flour
41	Wheat flour, rosted Bengal gram, green gram, ground nut, jowar, skimmed milk powder and jaggery
42	Rice and soyabean residues
	Maize
43	
44	Full fat soy flour
45	Corn starch
46	Sorghum varieties

Source: Navale et al.1

Extruded snacks are expected to be crisp and crunchy. The ingredients and process determine the texture. The process variables referred to include temperature, pressure, feed rate among others<sup>65</sup>.

#### **CONCLUSION**

Many definitions by different authors abound in literature, however, basically, during extrusion cooking, the structure and texture after processing of the food products (extrudates) are changed. The microstructure of foods changes on extrusion, depending on method of extrusion. Variation in the extrusion parameters can lead to extruded products with different and unique microstructure leading to differences in texture and, of course, varieties of food products would result. Extrusion improves acceptability and retains nutrients which makes extruded food products more beneficial to man when consumed.

#### **REFERENCES**

- Navale, S., S.B. Swami and N. Thakor, 2015. Extrusion Cooking Technology for Foods: A Review. J. Ready to Eat Food, 2: 66-80.
- Brennan, J.G., 2005. Food processing handbook. 1st ed., Wiley, Weinheim, Germany, 9783527307197, 9783527607570, Pages:582.
- Muthukumarappan, K. and G.J. Swamy, 2018. Microstructure and its relationship with quality and storage stability of extruded products. In: Food Microstructure and Its Relationship with Quality and Stability, Devahastin, S., (Ed.). Woodhead Publishing, Sawston, Cambridge, pp: 161-191.
- Offiah, V., V. Kontogiorgos and K.O. Falade, 2018. Extrusion processing of raw food materials and by-products: A review. Crit. Rev. Food Sci. Nutr., 59: 2979-2998.
- 5. Fellows, P., 2017. Extrusion cooking. In: Food Processing Technology, Fellows, P, (Ed.). Elsevier, Amsterdam, Cambridge, MA, pp: 753-780.
- Tiwari, A. and S.K. Jha, 2017. Extrusion cooking technology: Principal mechanism and effect on direct expanded snacks

  – An overview. Int. J. Food Stud., 6: 113-128.
- 7. Bdour, M.A., G.J. Al-Rabadi, N.S. Al-Ameiri, A.Y. Mahadeen and M.H. Aaludatt, 2014. Microscopic analysis of extruded and pelleted barley and sorghum grains. Jordan J. Biol. Sci., 7: 227-231.
- 8. Shankar, A.S., C. Satyanarayana, S. Alavi, L. Edukondalu, M. Joseph and R. Lakshmipathy, 2018. Study on cereal-legume based complementary foods for infants. Int. J. Curr. Microbiol. Appl. Sci., 7: 3310-3317.
- Rhee, K., S. Cho and A. Pradahn, 1999. Expanded extrudates from corn starch–lamb blends: Process optimization using response surface methodology. Meat Sci., 52: 127-134.

- 10. Boukid, F., S. Folloni, R. Ranieri and E. Vittadini, 2018. A compendium of wheat germ: Separation, stabilization and food applications. Trends Food Sci. Technol., 78: 120-133.
- 11. Smith, J. and A. Hardacre, 2011. Development of an extruded snack product from the legume Vicia faba minor. Procedia Food Sci., 1: 1573-1580.
- Oliveira, L.C., M. Schmiele and C.J. Steel, 2017. Development of whole grain wheat flour extruded cereal and process impacts on color, expansion and dry and bowl-life texture. LWT, 75: 261-270.
- Ruiz-Ruiz, J., A. Martínez-Ayala, S. Drago, R. González, D. Betancur-Ancona and L. Chel-Guerrero, 2008. Extrusion of a hard-to-cook bean (*Phaseolus vulgaris* L.) and quality protein maize (*Zea mays* L.) flour blend. LWT - Food Sci. Technol., 41: 1799-1807.
- 14. Choudhury, M.H., R. Chakraborty and U.R. Chaudhuri, 2014. Thermal and microstructural property of extruded snack: An overview. Int. J. Eng. Res. Appl., 4: 9-18.
- Ogunmuyiwa, O., A. Adebowale, O. Sobukola, O. Onabanjo, A. Obadina and T. Keith *et al*, 2017. Production and quality evaluation of extruded snack from blends of bambara groundnut flour, cassava starch and corn bran flour. J. Food Process. Preserv., Vol. 41. 10.1111/jfpp.13183
- Arivalagan, M., M. Manikantan, A. Yasmeen, S. Sreejith,
   D. Balasubramanian and S.R. Kanade *et al*, 2018.
   Physiochemical and nutritional characterization of coconut (*Cocos nucifera* L.) haustorium based extrudates. LWT, 89: 171-178.
- 17. Chávez, D.W., J.L. Ascheri, C.W. Carvalho, R.L. Godoy and S. Pacheco, 2017. Sorghum and roasted coffee blends as a novel extruded product: Bioactive compounds and antioxidant capacity. J. Funct. Foods, 29: 93-103.
- Sujka, M., Z. Sokolowska, M. Hajnos and M. Wlodarczyk-Stasiak, 2016. Characterization of pore structure of rice grits extrudates using mercury intrusion porosimetry, nitrogen adsorption and water vapour desorption methods. J. Food Eng., 190: 147-153.
- 19. Obiang-Obounou, B.W. and G.H. Ryu, 2013. The effect of feed moisture and temperature on tannin content, antioxidant and antimicrobial activities of extruded chestnuts. Food Chem., 141: 4166-4170.
- 20. Dehghan-Shoar, Z., A.K. Hardacre and C.S. Brennan, 2010. The physico-chemical characteristics of extruded snacks enriched with tomato lycopene. Food Chem., 123: 1117-1122.
- 21. Athar, N., A. Hardacre, G. Taylor, S. Clark, R. Harding and J. McLaughlin, 2006. Vitamin retention in extruded food products. J. Food Compos. Anal., 19: 379-383.
- Rodríguez-Miranda, J., I. Ruiz-López, E. Herman-Lara, C. Martínez-Sánchez, E. Delgado-Licon and M. Vivar-Vera, 2011. Development of extruded snacks using taro (*Colocasia esculenta*) and nixtamalized maize (*Zea mays*) flour blends. LWT - Food Sci. Technol., 44: 673-680.

- 23. Yu, L., H.S. Ramaswamy and J. Boye, 2013. Protein rich extruded products prepared from soy protein isolate-corn flour blends. LWT- Food Sci. Technol., 50: 279-289.
- 24. Jiddere, G. and K.B. Filli, 2015. The effect of feed moisture and barrel temperature on the essential amino acids profile of sorghum malt and bambara groundnut based extrudates. J. Food Process. Technol., Vol. 6. 10.4172/2157-7110.1000448
- 25. Berrios, J.D.J., P. Morales, M. Cámara and M. Sánchez-Mata, 2010. Carbohydrate composition of raw and extruded pulse flours. Food Res. Int., 43: 531-536.
- Diaz, J.M.R., J.-P. Suuronen, K.C. Deegan, R. Serimaa, H. Tuorila and K. Jouppila, 2015. Physical and sensory characteristics of corn-based extruded snacks containing amaranth, quinoa and kañiwa flour. LWT - Food Sci. Technol., 64: 1047-1056.
- 27. Pardhi, S., B. Singh, G.A. Nayik and B. Dar, 2019. Evaluation of functional properties of extruded snacks developed from brown rice grits by using response surface methodology. J. Saudi Soc. Agric. Sci., 18: 7-16.
- Timonen-Soivio, L., A. Sourander, H. Malm, S. Hinkka-Yli-Salomäki, M. Gissler and R. Vanhala et al, 2015. The association between autism spectrum disorders and congenital anomalies by organ systems in a finnish national birth cohort. J. Autism Dev. Disord., 45: 3195-3203.
- Radovanovic, A., V. Stojceska, A. Plunkett, S. Jankovic, D. Milovanovic and S. Cupara, 2015. The use of dry Jerusalem artichoke as a functional nutrient in developing extruded food with low glycaemic index. Food Chem., 177: 81-88.
- 30. Kocherla, P., K. Aparna and D.N. Lakshmi, 2012. Development and evaluation of RTE (Ready To Eat) extruded snack using egg albumin powder and cheese powder. Agric. Eng. Int.: CIGR J., 14: 179-187.
- 31. Gbenyi, D.I., I. Nkama and M.H. Badau, 2016. Optimization of physical and functional properties of sorghum-bambara groundnut extrudates. J. Food Res., 5: 81-97.
- 32. Zhang, H., H. Wang, X. Cao and J. Wang, 2018. Preparation and modification of high dietary fiber flour: A review. Food Res. Int., 113: 24-35.
- 33. Kljak, K., E. Šárka, P. Dostálek, P. Smrčková and D. Grbeša, 2015. Influence of physicochemical properties of croatian maize hybrids on quality of extrusion cooking. LWT Food Sci. Technol., 60: 472-477.
- 34. Jacques-Fajardo, G.E., R. Prado-Ramírez, E. Arriola-Guevara, E.P. Carrillo, H. Espinosa-Andrews and G.M.G. Morales, 2017. Physical and hydration properties of expanded extrudates from a blue corn, yellow pea and oat bran blend. LWT, 84: 804-814.
- 35. Hagenimana, A., X. Ding and W.Y. Gu, 2007. Steady state flow behaviours of extruded blend of rice flour and soy protein concentrate. Food Chem., 101: 241-247.
- 36. Janve, M. and R.S. Singhal, 2018. Fortification of puffed rice extrudates and rice noodles with different calcium salts: Physicochemical properties and calcium bioaccessibility. LWT, 97: 67-75.

- Ananthanarayan, L., Y. Gat, V. Kumar, A. Panghal and N. Kaur, 2018. Extruded black gram flour: Partial substitute for improving quality characteristics of indian traditional snack. J. Ethnic Foods, 5: 54-59.
- 38. Lobato, L., D. Anibal, M. Lazaretti and M. Grossmann, 2011. Extruded puffed functional ingredient with oat bran and soy flour. LWT Food Sci. Technol., 44: 933-939.
- 39. Altan, A., K.L. McCarthy and M. Maskan, 2009. Effect of screw configuration and raw material on some properties of barley extrudates. J. Food Eng., 92: 377-382.
- 40. Nkama, I. and K.B. Filli, 2006. Development and characterization of extruded fura from mixtures of pearl millet and grain legumes flours. Int. J. Food Prop., 9: 157-165.
- 41. Luo, S. and F. Koksel, 2023. Application of physical blowing agents in extrusion cooking of protein enriched snacks: Effects on product expansion, microstructure and texture. Trends Food Sci. Technol., 133: 49-64.
- 42. Famuyide, O.Y., J. Lubaale, C. Ndiaye, K.G. Duodu and J.R. Taylor, 2024. Effect of extrusion cooking in combination with food-to-food fortification on the mineral bioaccessibility of African-type pearl millet-based porridge. NFS J., Vol. 34. 10.1016/j.nfs.2024.100165
- Ariz-Hernandez, I., I. Astiasaran and D. Ansorena, 2025. Plant-based burgers: Effects of protein source, type of extrusion and cooking technology on oxidation status and in vitro digestibility. Future Foods, Vol. 12. 10.1016/j.fufo.2025.100712
- 44. Téllez-Morales, J.A., J. Rodríguez-Miranda, F.S. Serrano-Villa and G. Calderón-Domínguez, 2025. Extrusion cooking analysis of corn starch and WPI mixture as a model system on the microstructure and thermodynamic parameters. LWT, Vol. 226. 10.1016/j.lwt.2025.117963
- 45. Tica, A., V.S. Pinnamaraju, E. Stirnemann and E.J. Windhab, 2025. Model predictive control of high moisture extrusion cooking. Control Eng. Pract., Vol. 162. 10.1016/i.conengprac.2025.106387
- Robin, F. and S. Palzer, 2015. Texture of breakfast cereals and extruded products. In: Modifying Food Texture, Chen, J. and A. Rosenthal, (Eds.). Woodhead Publishing, Cambridge, UK, pp: 203-235.
- Beck, S.M., K. Knoerzer and J. Arcot, 2017. Effect of low moisture extrusion on a pea protein isolate's expansion, solubility, molecular weight distribution and secondary structure as determined by fourier transform infrared spectroscopy (FTIR). J. Food Eng., 214: 166-174.
- 48. Horvat, M., G. Guthausen, P. Tepper, L. Falco and H.P. Schuchmann, 2014. Non-destructive, quantitative characterization of extruded starch-based products by magnetic resonance imaging and X-ray microtomography. J. Food Eng., 124: 122-127.

- 49. Liu, Z., B. Liu, M. Li, M. Wei, H. Li and T. Wan *et al*, 2013. Scanning probe acoustic microscopy of extruded starch materials: Direct visual evidence of starch crystal. Carbohydr. Polym., 98: 372-379.
- Zhang, B., S. Dhital, B.M. Flanagan, P. Luckman, P.J. Halley and M.J. Gidley, 2015. Extrusion induced low-order starch matrices: Enzymic hydrolysis and structure. Carbohydr. Polym., 134: 485-496.
- 51. Moscicki, L, 2016. Extrusion cooking: Principles and practice. In: Encyclopedia of Food and Health, Caballero, B., P.M. Finglas and F. Toldrá, (Eds.). Elsevier, pp. 576-580.
- 52. Bhattacharya, S, 2017. Extrusion technology and glass transition. In: Non-Equilibrium States and Glass Transitions in Foods, Bhandari, B. and Y.H. Roos, (Eds.). Woodhead Publishing, pp: 137-152.
- 53. Yao, Y. and G. Ren, 2014. Suppressive effect of extruded adzuki beans (*Vigna angularis*) on hyperglycemia after sucrose loading in rats. Ind. Crops Prod., 52: 228-232.
- 54. Mäkilä, L., O. Laaksonen, J.M.R. Diaz, M. Vahvaselkä, O. Myllymäki and H. Kallio *et al*, 2014. Exploiting blackcurrant juice press residue in extruded snacks. LWT Food Sci. Technol., 57: 618-627.
- 55. Altan, A., K.L. McCarthy and M. Maskan, 2008. Evaluation of snack foods from barley–tomato pomace blends by extrusion processing. J. Food Eng., 84: 231-242.
- 56. Peressini, D., M. Foschia, F. Tubaro and A. Sensidoni, 2015. Impact of soluble dietary fibre on the characteristics of extruded snacks. Food Hydrocolloids, 43: 73-81.
- 57. Chakraborty, P., A. Bhattacharya, D. Bhattacharyya, N.R.Bandyopadhyay and M. Ghosh, 2016. Studies of nutrient rich edible leaf blend and its incorporation in extruded food and pasta products. Mater. Today: Proc., 3: 3473-3483.

- 58. Stojceska, V., P. Ainsworth, A. Plunkett and S. İbanoğlu, 2009. The effect of extrusion cooking using different water feed rates on the quality of ready-to-eat snacks made from food by-products. Food Chem., 114: 226-232.
- 59. Mezreb, K., A. Goullieux, R. Ralainirina and M. Queneudec, 2003. Application of image analysis to measure screw speed influence on physical properties of corn and wheat extrudates. J. Food Eng., 57: 145-152.
- 60. Oliveira, L.C., N.M. Alencar and C.J. Steel, 2018. Improvement of sensorial and technological characteristics of extruded breakfast cereals enriched with whole grain wheat flour and jabuticaba (*Myrciaria cauliflora*) peel. LWT, 90: 207-214.
- 61. Robin, F., C. Dubois, N. Pineau, E. Labat, C. Théoduloz and D. Curti, 2012. Process, structure and texture of extruded whole wheat. J. Cereal Sci., 56: 358-366.
- 62. Singkhornart, S., S. Edou-ondo and G.-H. Ryu, 2014. Influence of germination and extrusion with CO<sub>2</sub> injection on physicochemical properties of wheat extrudates. Food Chem., 143: 122-131.
- 63. Jafari, M., A. Koocheki and E. Milani, 2017. Effect of extrusion cooking of sorghum flour on rheology, morphology and heating rate of sorghum–wheat composite dough. J. Cereal Sci., 77: 49-57.
- 64. Pitts, K.F., J. Favaro, P. Austin and L. Day, 2014. Co-effect of salt and sugar on extrusion processing, rheology, structure and fracture mechanical properties of wheat–corn blend. J. Food Eng., 127: 58-66.
- 65. Miskelly, D, 2017. Optimisation of end-product quality for the consumer. In: Cereal Grains, Wrigley, C., I. Batey and D. Miskelly, (Eds.). Woodhead Publishing, pp: 653-688.