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Extrusion Technology: A Novel Method of Food Processing

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Summary

Extrusion-technology is gaining increasing popularity in the global agro-food processing industry, particularly in the food and feed sectors. Extrusion cooking technologies are used for cereal and protein processing in food. Today their processing functions may include, conveying, mixing, shearing, separation, heating or cooling, shaping, co-extrusion, venting, volatiles and moisture, flavor generation, encapsulation and sterilization. They can be relatively low temperatures, as with pasta, spaghetti, noodles etc. keeping in this view, the present article describes in detail about the types of extruders, physic-chemical changes occurring during extrusion process and recent developments in food industry regarding extrusion process.

Introduction

Today's lifestyles are vastly different from those of the past, due to increasing in number of single person households and gender equality rights have lead to changes in food preparation and consumption habits. i.e., modernization and globalization made peoples very hurry and no time to cook their own food, especially during morning. A positive outcome of this has been made rapid advances in food technology not only these factors and also the increasing demand for non-meat, high-protein products made a highly profitable ventures in the food industry. Now a day's consumers do choice for nutritionally rich, therapeutic benefits and for attractiveness especially in case of baby foods. Thus to obtain above mentioned designer food, Food extrusion technology is used.

Definition

Food extrusion is defined as "A process in which material is pushed through an orifice or a die of given shape, the pushing force is applied using a piston or a screw, In food applications, screw extrusion is predominant". Karwe (1992).

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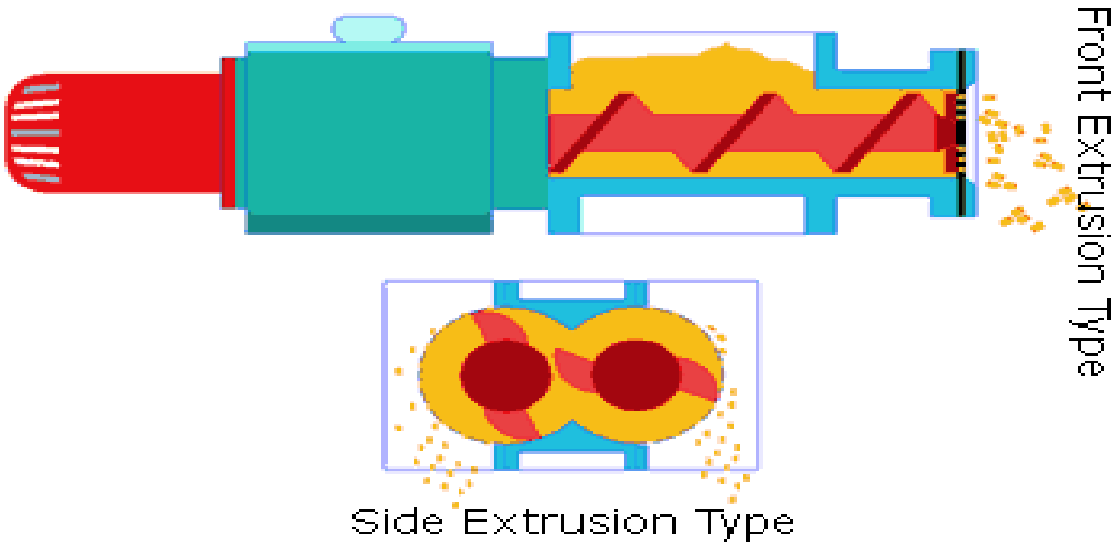

Fig. 1. Extruder from front and side view.

HISTORY:

Historically, one can trace the use of a screw as a conveying device to the greek philosopher Archimedes, who used a single screw in a cylindrical open channel to pump water uphill. Today's extruder consists of one or more screws encased in a metal barrel, attached to a drive motor. A hopper at one end is used to feed raw materials, while a die on the other gives shape to the product. Extruders were developed in the 1870s to manufacture sausage. Application of the single screw extruder evolved during the 1930s, when it was used to mix semolina flour and water to make pasta products. It was also used in the process of making ready-to-eat (RTE) cereals to shape hot, precooked dough. In both of these applications, the level of shear rate was low. During the late 1930s and 1940s, directly expanded corn curls were made using extruders, which were characterized by extremely high shear rates. The first patent on an application of twin screw extrusion technology was filed in mid-1950s. Since then, the application of extrusion technology has widened and grown dramatically.

Table 1. Showing history of the extruder

INVESTIGATOR	YEAR	FINDINGS
MC.Anelly	1964	First to describe a process for the production of spongy elastic particles from soy flour.
Atkinson	1970	Disclosure of a continous cooking extrusion process
EL-Dash	1981	First to process breakfast cereal products
Noguchi	1998	Extrusion cooking of high moisture protein foods.
Fast	2000	RTE cereals
saalia	2011	Degradation of afflatoxins by extrusion
Ryan	2011	Oat based breakfast cereal snack

Extruders:

Extruders come in several designs, dependent upon their application. Some extruders are designed simply to convey the raw materials, while others are designed to mix and knead them; most, however, are designed to impart mechanical and thermal energy to the raw materials to bring about desired physico-chemical changes.

Extruders can be broadly categorized on the basis of:

Method of operation:

- Cold Extruders and
- Hot Extruders (Extrusion Cooking)

Method of construction:

- Single-or twin- screw extruders.

The most commonly used extruders are single and twin-screw. Extruders with more than two screws have been used in the plastics industry but not in food processing.

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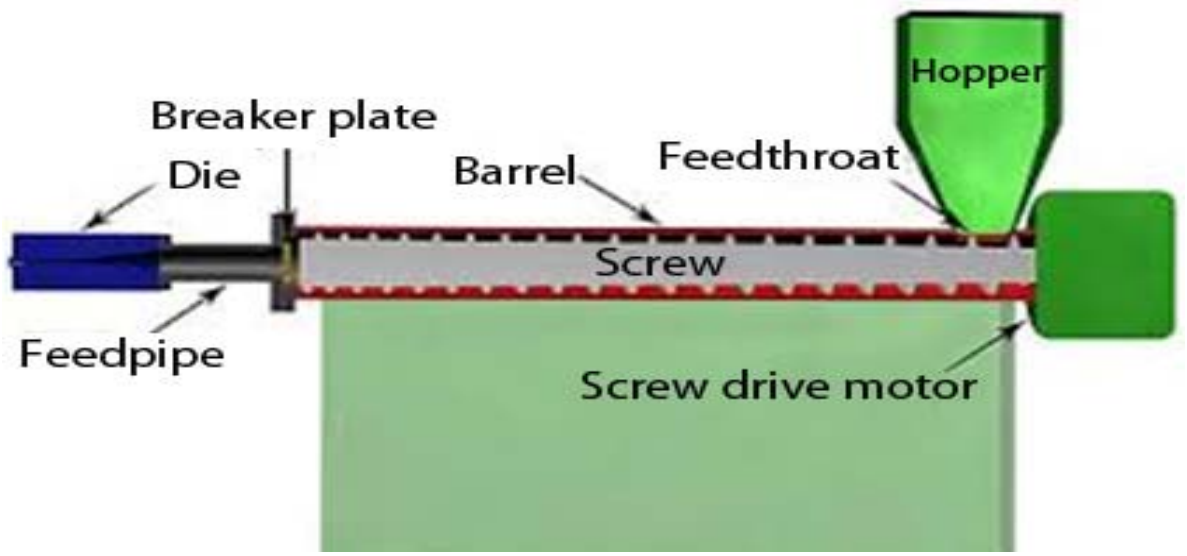

Fig. 2. Different parts of extruder.

Extruders are composed of five main parts:

(i) Pre-conditioning system;

(ii) Feeding system;

(iii) Screw or worm;

(iv) Barrel;

(v) Die and the cutting mechanism

Also, they can vary with respect to screw, barrel and die configuration. The selection of each of these items will depend on the raw material used and the final product desired (Riaz, 2000).

Pre-conditioning

Pre-conditioning with steam or water has always been an important part of the extrusion process. Pre-conditioning is not applied to all extrusion processes. In general, this step is applied when moisture contents around 20 to 30% and long residence times of the material are used. Pre-conditioning favours uniform particle hydration, reduces retention times within the extruder and increases throughput, increasing the life of the equipment, due to a reduction in the wearing of barrel and screw components, also reducing the costs of energy involved in the process.

Feeding system

It is necessary to guarantee a constant and non-interrupted feeding of the raw materials into the extruder for an efficient and uniform functioning of the extrusion process.

Screw

The screw of the extruder is certainly its most important component, not only to determine cooking degree, gelatinization and dextrinization of starch and protein denaturation, but also to ensure final product qualityScrews can be mono-piece (composed of a unique piece) or multi-piece (composed of various elements) Screw elements can vary in number and shapes, each segment is designed for a specific purpose. Some elements only convey raw or pre-conditioned material into the extruder barrel, while other segments compress and degas the feedstock. Others must promote kneading, backflow and shear.

Barrel or sleeves

The barrel is divided into feeding, kneading anThe sleeves surrounding the screw can be solid, but they are often jacketed to permit circulating of steam or superheated oil for heating or water or air for cooling, thus enabling the precise adjustment of the temperature in the various zones of the extruder.

Die

The die presents two main functions: give shape to the final product and promote resistance to material flow within the extruder permitting an increase in internal pressure. The die can present various designs and number of orifices.

Cutting mechanism

The cutting mechanism must permit obtaining final products with uniform size. Product

size is determined by the rotation speed of the cutting blades. This mechanism can be horizontal or vertical

Single screw extruder

Single screw extruders contain a single rotating screw in a metal barrel, and come in varying patterns. The most commonly used single scews have a constant pitch. The raw materials are fed in a granular form at the hopper located in the feed section. The rotating action of the screw conveys the material to the transition section. In the transition section, the screw channel becomes shallower and the material is compacted. A major portion of mechanical energy is dissipated in this section, which results in a rise in temperature of the material. Starch becomes gelatinized, and the material becomes more cohesive. It is transported further by the metering section and pushed through the die opening. The barrels of single-screw extruders usually have helical or axial grooves on inner surfaces. This helps to convey and mix the material more effectively. Caldwell (2000).

Twin screw extruder

Twin-screw extruders are composed of two axis that rotate inside a single barrel; usually the internal surface of the barrel of twin-screw extruders is smooth. However, this type of extruder is little used in the food industry, even though they present more efficient displacement

propertiesWhen the material enters the barrel, the ingredients are thoroughly mixed before further processing in the other zones of the extruder. In this initial step, the screw is designed with a large screw channel depth to provide enough space between the root of the screw and the barrel for sufficient mixing to take place, and often, the screws are reverse-threaded to permit intensive mixing and longer residence times before delivery. In the next zone, the diameter of the root increases rapidly while the channel depth becomes shallower in order to provide material cooking, thus increasing the pressure applied to the product, and the starchy content of food is gelatinized and the proteinaceous material denatured. Chang (2001).

Table 2. Difference between single and twin screw extruder.

PARAMETERS	SINGLE SCREW EXTRUDER	TWIN SCREW EXTRUDER
Transport mechanism	Friction between metal and food material	Positive displacement
Throughput capacity	Dependent on moisture, fat content and pressure.	Independent
Approx. power consumption per kg of product	900-1500 KJ	400-600 KJ
Heat distribution	Large temperature difference(20-180˚C)	Small temperature difference(110-180˚C)
Mechanical power dissipation	Large shear forces (550-6000kpa)	Small shear forces (2000-4000kpa)
De-gassing possibilities	Simple	Difficult
Rigidity	High	Bearing capacity is vulnerable
Capital cost	low	High (twice)
Minimum water content	10%	8%
Maximum water content	30%	95% Chessari (2001)

Physico-chemical changes during extrusion

The most used raw materials in the extrusion process are starch and protein based materials. The structure of the extruded products may be formed from starch or protein polymers. Most products, such as breakfast cereals, snacks and biscuits are formed from starch, while protein is used to produce products that have meat-like characteristics and that are used either as full or partial replacements for meat in ready meals, dried foods and many pet food products. Dehgonshoar *et al.*, (2010)

Major changes occurs during extrusion process are:

- Changes in starch
- Changes in proteins
- Changes in lipid and
- Changes in fibre.

Raw materials

In general, the chemical or physicochemical changes in biopolymers that can occur during extrusion cooking include: binding, cleavage, loss of native conformation, fragmention, recombination and thermal degradation. The structure of an extruded product is created by forming a fluid melt from a polymer and blowing bubbles of water vapour into the fluid to form a foam. The bubbles rapidly expand as the superheated water is released very quickly at atmospheric pressure.

Changes in starches

The major difference between extrusion processing and conventional food processing is that in the former starch gelatinization occurs at much lower moisture contents (12-22%). Once inside the extruder, and at relatively high temperatures, the starch granules melt and become soft, besides changing their structure that is compressed to a flattened form. The application of heat, the action of shear on the starch granule and water content destroy the organized molecular structure, also resulting in molecular hydrolysis of the material. The starch polymers are then dispersed and degraded to form a continuous fluid melt. The fluid polymer continuum retains water vapour bubbles and stretches during extrudate expansion until the rupture of cell structure. The starch polymer cell walls recoil and stiffen as they cool to stabilize the extrudate structure. Finally, the starch polymer becomes glassy as moisture is removed, forming a hard brittle texture.

Changes in protein

Proteins are biopolymers with a great number of chemical groups when compared to polysaccharides and are therefore more reactive and undergo many changes during the extrusion process, with the most important being denaturation. During extrusion, disulfide bonds are broken and may re-form. Electrostatic and hydrophobic interactions favour the formation of insoluble aggregates. The creation of new peptide bonds during extrusion is controversial. High

molecular weight proteins can dissociate into smaller subunits. Enzymes, also proteins, lose their activity after being submitted to the extrusion process due to high temperatures and shear.

Changes in lipids

Fats and oils can be described as lipids. Lipids have a powerful influence in extrusion cooking processes by acting as lubricants, because they reduce the friction between particles in the mix and between the screw and barrel surfaces and the fluid melt.

Changes in Fibres

Research has shown that cooking fibres by extrusion can produce changes in their structural characteristics and physicochemical properties, with the main effect being a redistribution of insoluble fibre to soluble fibre. This effect would be the result of the rupture of covalent and non-covalent bonds between carbohydrates and proteins associated to the fibre, resulting in smaller molecular fragments, that would be more soluble.

Influence of extrusion cooking on Moisture and Temperature

In the extrusion process of expanded products with low moisture, the expansion of the final product is inversely related to the moisture of the raw material and directly related to theincrease in extrusion temperature; however, the effect of moisture is more significant. In high moisture extrudates, expansion occurs when the product exits the die, but the structure collapses before the necessary cooling, resulting in a dense and hard product. Another important parameter for extrudate expansion is process temperature. Products do not expand if the temperature does not reach 100°C. Expansion increases with the increase in temperature when moisture content of the material is close to 20%, due to lower viscosity, permitting a more rapid expansion of the molten mass, or due to an increase in water vapour pressure. At low extrusion temperatures, expansion is reduced because starch is not completely molten. Radial expansion degree is proportional to temperature up to a certain value, decreasing at much higher temperatures. The reduction of expansion at very high temperatures is attributed to an increase in dextrinization, weakening starch structure.

Influence of extrusion cooking on various parameters

Three main factors of extruded product on consumer view are:

- Product quality.
- Nutritional quality.
- Microbiological quality.

Influence on product quality

Extrusion-cooking has an important influence on product quality, emphasizing features like expansion, texture, shelf-life, colour and flavour. Products obtained with high temperatures and short extrusion process times normally present a porous, open structure, what confers to them a “crunchy” texture. Colour in extruded products is influenced by temperature, raw material composition, residence time, pressure and shear force. Camire (2000).

Effect of extrusion on nutrition quality

The effects of extrusion cooking on nutritional quality are ambiguous. Benefits include destruction of antinutritional factors, gelatinization of starch, increased soluble dietary fibre and reduction of lipid oxidation. Starch digestibility is largely dependent on complete gelatinization. High starch digestibility is essential for specialized nutritional foods such as infant and weaning foods. Creation of resistant starch by extrusion may have value in reduced calorie products. The nutritional value of vegetable proteins is generally enhanced by mild extrusion cooking conditions due to the increase in digestibility, probably a result of protein denaturation and the inactivation of enzyme inhibitors present in raw materials, by the exposure of new active sites for enzyme attack.

Influence on microbiological quality

One of the most important consumer requirements is the microbiological safety of food products. Most conventional extruded products such as snack foods and breakfast cereals are safe to eat because the raw materials are subjected to high temperatures (higher than 130°C)

and the water activity temperatures (0.1-0.4) of the product is low because the product is dried to a moisture content of less than five per cent. Although it is well known that most vegetative organisms, yeast and moulds are destroyed under typical extrusion conditions (55-145°C). Fraiha *et al.,* (2010).

RECENT DEVELOPMENTS IN DAIRY, BREAKFAST CEREAL AND PET FOOD INDUSTRY.

Extruders permit the production of many foods of nutritional importance. The ability of extruders to blend diverse ingredients to make novel foods.

Some of the recent advances under

1. DAIRY
2. BREAKFAST CEREAL AND
3. PET FOODS are discussed further.

Extrusion in dairy industry

Milk protein posses health benefits and desirable functional properties. When protein is subjected for mechanical shear, considerable changes in the molecular structures of the protein is seen. This changes leads to a formation of new protein-based food product known as “TEXURIZATION”. Texturization stretches and shears the protein to form a new fibre-bundle like structure which withstands - hydration, cooking and other procedures.Doi (1992).

Table 3. Recent developments in dairy industry.

Authors	Year	Research
Banach *et al.,*	2013	Charecterization of extruded and toasted milk proteins and concentrates.
Iiankovan *et al.,*	2013	Pre-biotic fibre incorporated whey protein crisps processed by supercritical fluid extrusion.
Khanitha	2012	Functionalization of whey proteins by reactive super critical fluid extrusion.
Limon *et al.,*	2010	Physico-chemical evaluation and optimization of enriched expanded pellets with milk protein concentrate.

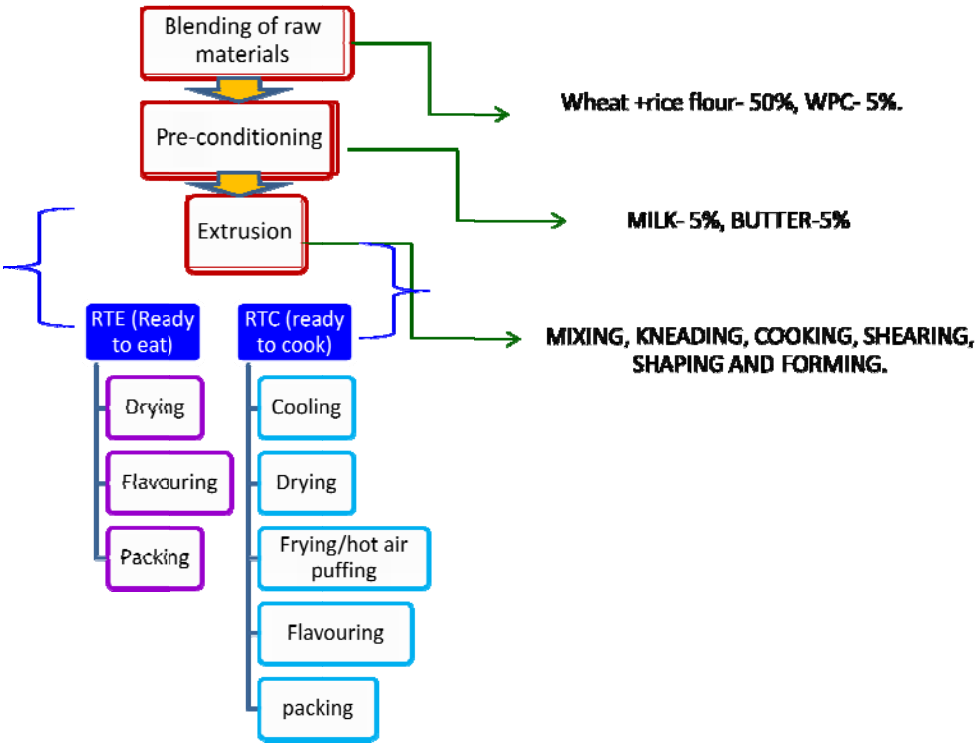

Fig. 3. Process of RTE and RTC extruded products**.**

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Extrusion for breakfast cereals

Basic processes of making breakfast cereals include flaking, oven, gun puffing, baking, shredding and direct expansion (extrusion cooking). Which convert raw and dense grains (7.7 kg/100 cm3) into friable, crunchy or chewable products with the density of 0.6 to 1.6 kg/100 cm3. But extrusion process combines all the above processes and presents advantages over the conventional processes. Paradiso *et al.*, (2008).

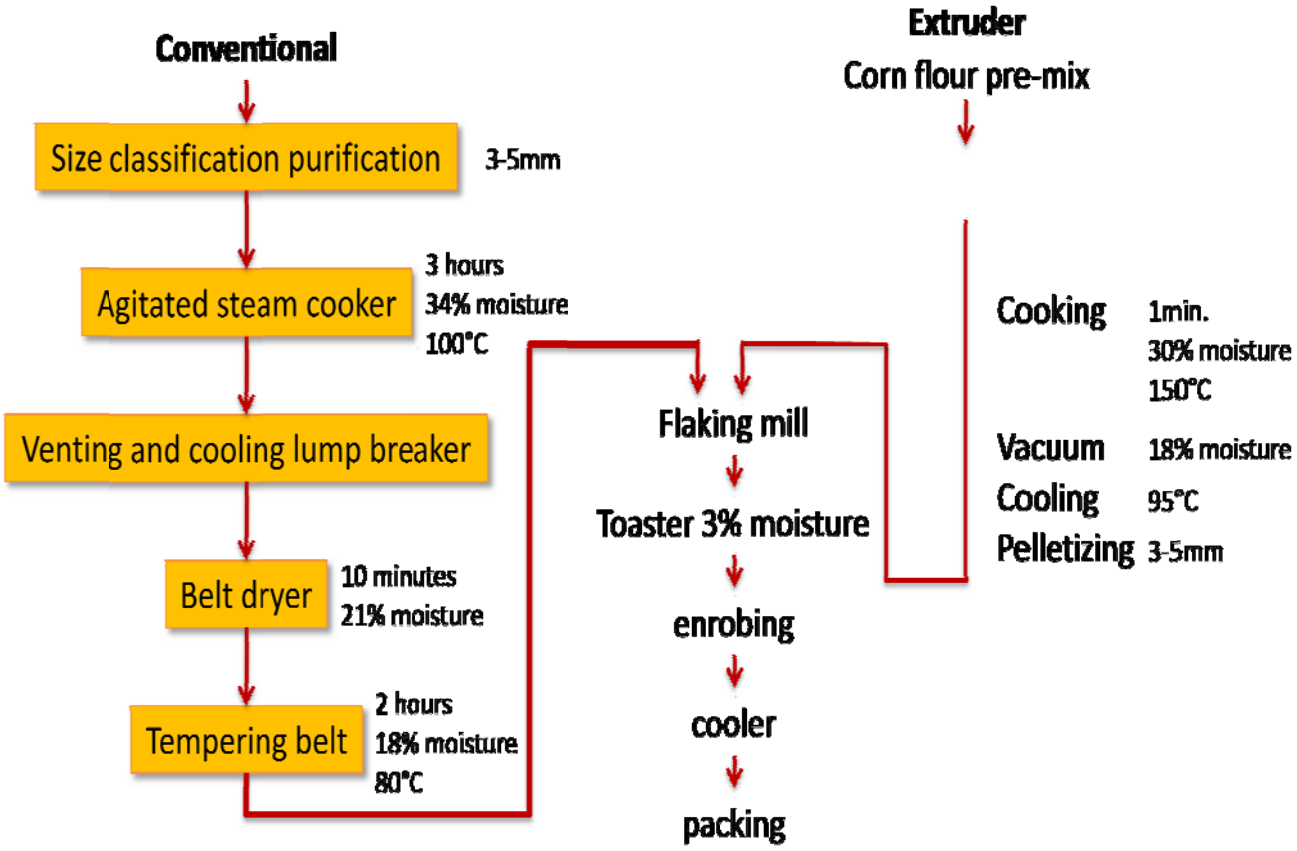

Fig. 4. Differences between conventional and extrusion process.

Meat analogues

Increase in vegetarians, lead to a preparation of protein incorporated meat extenders and meat analogues which can be obtained from extrusion process. Vegetable protein posses a charecteristic appearance and texture similar to fibrilar structure of meat (Strahm, 2006; Macdonald et al., 2009). Thus, Meat extenders are obtained from thermoplastic extrusion at low moisture contents (20-35%) and Meat analogues are obtained at high moisture contents (50-70%). The main vegetable proteins used to prepare meat analogues are legumes, soybeans, common beans and peas. The cereals which contain wheat proteins responsible for gluten network (Riaz, 2000; Strahm, 2006).

Pet foods and animal feeds

Extrusion is not only used to prepare food for humans but also used to prepare semi-moist and dry expanded pet foods, aquatic food, and foods for laboratory animals. Whereas, Dog and cat foods are directly extruded and dried. Feed for ornamental fish, high-grade complete feeds to maintaining the health, foods for exotic species in aquariums can also be made from extrusion process. This permits better utilization of available cereal grains, vegetable and animal proteins.

CONCLUSION

Extruders permit the production of many foods of nutritional importance. The ability of extruders to blend diverse ingredient in novel foods can be exploited in the development of functional foods. Traditional snacks or breakfast cereal can be enhanced by the addition of extra fibre or whole grain flour as ingredients. During extrusion, transformed into palatable cereal based products that also promote beneficial physiological effects.

Consumers are discriminating, Consumers want healthy nutrition, Consumers want fair prices. Rightly so! extrusion systems meet the current, constantly changing requirements – flexibly, efficiently and economically.

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