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Paper Title: The Principles of the Food Processing & Preservation

Module No. : 29

Module Title: Food Extrusion

29.0 Introduction

Food extrusion is a form of extrusion used in food processing. It is a process by which a set of mixed ingredients are forced through an opening in a perforated plate or die with a design specific to the food, and is then cut to a specified size by blades. The machine which forces the mix through the die is an extruder, and the mix is known as the extrudate. The extruder consists of a large, rotating screw tightly fitting within a stationary barrel, at the end of which is the die.

Extrusion enables mass production of food via a continuous, efficient system that ensures uniformity of the final product. Food products manufactured using extrusion usually have a high starch content. These include some pasta, breads (croutons, bread sticks, and flat breads), many breakfast cereals and ready-to-eat snacks, confectionery, pre-made cookie dough, some baby foods, full-fat soy, textured vegetable protein, some beverages, and dry and semi-moist pet foods.

29.1 Types of extrusion

There are two types of extrusion processes.

- Cold extrusion, which mixes and shapes foods such as biscuit dough and pasta without cooking them
- Hot extrusion (or extrusion cooking), which is used to produce a wide range of products, including crisp snack foods, sugar confectionery and soya-based weaning foods.

Both use equipment known as an ‘extruder’. This equipment has a screw inside a barrel that conveys materials along the barrel and kneads the food into a semi-solid, plasticized mass. In cold extruders the material is not heated but simply formed into shapes (including rods, tubes, strips or shells), when it is forced through openings in a ‘die’ at the discharge end of the barrel. In extruder-cookers the material is heated by friction and/or supplementary heaters in the barrel and it emerges from the dies under pressure. Some snack food products expand rapidly and have a light, crisp texture, caused by steam being flashed off due to the sudden pressure drop when they emerge from the die. Cold-extruded products are preserved by chilling, baking or drying, whereas extrusion cooking destroys contaminating micro-organisms and the dry products have a long shelf life. They are packaged to prevent them picking up moisture and to prevent oxidation during storage. Cold extruders are suitable for all scales of operation from household- to small-scale, but extruder-cookers are much more expensive and are likely to only be affordable by larger-scale producers.

29.1.1 Cold extrusion

The main application of cold extruders is in pasta production, although similar machines are used to form biscuit dough into different shapes. A pasta extruder is used to make many different types of pasta using dough made from durum wheat flour (or ‘semolina’) and eggs (optional). Coloured pasta can also be made by adding tomato purée or spinach paste etc.

Different sizes of equipment are available, from small manual machines that are used in micro-scale production and food service outlets, to larger electric machines. The equipment has a mixing chamber, extruder barrel and a die for the desired pasta shape. There is debate over the best material for dies, with some equipment manufacturers using stainless steel or plastic, and others preferring bronze dies, which they claim imparts a rough surface to the pasta that holds sauce better

than pasta made by other methods. Shapes are cut to the appropriate length as they emerge from the die, except rigatoni, which is extruded in long lengths and then cut to the correct size (straight for rigatoni or angled for penne rigati). Pasta is cooked immediately in food service outlets, or dried by processors for retail sale. It can also be frozen for up to six months.

29.1.2 Hot extrusion

Extruder-cookers may be single- or twin-screw machines. Twin-screw machines have approximately twice the capital and maintenance costs of single screw machines and are unlikely to be affordable by most small-scale processors as compared to single-screw extruders. The two factors that control the type and quality of foods that are produced by hot extrusion are the operating conditions in the extruder barrel and the mixture of ingredients that is used.

29.2 Operating conditions & Process of extrusion

The important operating conditions are the temperature and pressure in the barrel, the diameter of the die apertures and the product shear rate. The shear rate is influenced by the speed and geometry of the screw (size, number, pitch and diameter of the flights), and by the internal design of the barrel, including grooves in the barrel, or restrictions (known variously as óthrottle ringsô, ókneading discsô, or óshearlocksô). Additional heating may be provided by a steam-jacketed barrel, a steam-heated screw, or electric heating elements around the barrel.

óHigh-shearô extruders have high screw speeds and shallow flights to create the high pressures and temperatures needed to make expanded products; ómedium-shearô extruders are used to make texturised proteins and semi-moist foods; and ólow shearô extruders have a deep-flighted screw that operates at low speeds in a smooth barrel to create low pressures for forming meat products or gums. The selection of the correct type of extruder for a particular application should take account of the types of ingredients and the properties required in the product (e.g. its bulk density, texture, colour and other sensory properties) and the required production rate.

Dies have different shaped holes (e.g. round holes to produce rods, square holes for bars, or slots to produce sheets), or they may produce more complex shapes. The temperature and moisture content of the food and the extent of shearing in the barrel control the amount of expansion of the product and hence its texture. Some products require the dies to be heated to give the required degree of expansion, whereas others have cooled dies to reduce expansion. There are therefore a very large number of potential combinations of equipment design features and small-scale processors should seek advice from extruder manufacturers before purchasing a machine.

In the extrusion process, raw materials are first ground to the correct particle size, usually the consistency of coarse flour. The dry mix is passed through a pre-conditioner, in which other ingredients are added depending on the target product; these may be liquid sugar, fats,dyes, meats or water. Steam is injected to start the cooking process, and the preconditioned mix (extrudate) is then passed through an extruder. The extruder consists of a large, rotating screw tightly fitting within a stationary barrel, at the end of which is the die. The extruder's rotating screw forces the extrudate toward the die, through which it then passes. The amount of time the extrudate is in the extruder is the residence time.

The extruded product usually puffs and changes texture as it is extruded because of the reduction of forces and release of moisture and heat. The extent to which it does so is known as the expansion ratio. The extrudate is cut to the desired length by blades at the output of the extruder, which rotate about the die openings at a specific speed. The product is then cooled and dried, becoming rigid while maintaining porosity.

The cooking process takes place within the extruder where the product produces its own friction and heat due to the pressure generated (10ï 20 bar). The process can induce both protein denaturation and starch gelatinization, depending on inputs and parameters.

Many food extrusion processes involve a high temperature over a short time. Important factors of the extrusion process are the composition of the extrudate, screw length and rotating speed, barrel temperature and moisture, die shape, and rotating speed of the blades. These are controlled based on the desired product to ensure uniformity of the output.

Moisture is the most important of these factors, and affects the mix viscosity, acting to plasticize the extrudate. Increasing moisture will decrease viscosity, torque, and product temperature, and increase bulk density. This will also reduce the pressure at the die. Most extrusion processes for food processing maintain a moisture level below 40%, that is low to intermediate moisture. High-moisture extrusion is known as wet extrusion, but it was not used much before the introduction of twin screw extruders (TSE), which have a more efficient conveying capability. The most important rheological factor in the wet extrusion of high-starch extrudate is temperature.

The amount of salt in the extrudate may determine the colour and texture of some extruded products. The expansion ratio and airiness of the product depend on the salt concentration in the extrudate, possibly as a result of a chemical reaction between the salt and the starches in the extrudate. Colour changes as a result of salt concentration may be caused by "the ability of salt to change the water activity of the extrudate and thus change the rate of browning reactions". Salt is also used to distribute minor ingredients, such as food colours and flavours, after extrusion; these are more evenly distributed over the product's surface after being mixed with salt.

29.3 Ingredient mixture

Different mixtures of ingredients produce completely different products when the same operating conditions are used in the same extruder. This is because starch, proteins, moisture and other ingredients (e.g. oil or an emulsifier) have different effects on the structure and texture of the extruded food. For example, starch or proteins create a three-dimensional structure that contains the other ingredients. Starches from cereal or legume flours (e.g. maize, wheat, rice, barley, pea, bean), or from tuber flours (e.g. potato, cassava, tapioca) are used for extruded breakfast cereals, snack foods, pasta and biscuits. Proteins from soybeans, sunflower seeds, rapeseed, or gluten from wheat, are used to make meat-like products such as texturised vegetable protein.

When making extruded snack foods from cereal or potato starch, the process operates at high temperatures (130 - 180^{o}C) to produce a ófluid meltô that contains gelatinised starch and superheated water vapour. When this leaves the extruder it expands to form hard, porous, brittle snack food products. Flavourings and/or colourings are sprayed onto the food after it is extruded. Snack foods can also be made from extruded ópreformsô or óhalf-productsô. These are small, dense extruded pellets that are sold to other processors to make the final snack food by frying or toasting the pellets. When half-products are heated, they soften and the residual moisture in the pellets turns to steam, which rapidly expands the pellets to produce the snack food.

Extruded weaning foods are produced as flakes or pellets from a mixture of cereal and legume flours that have the correct protein and energy content for growing children. The extruded products may also be fortified with minerals and vitamins. In use, the products are ground to a powder and mixed with hot water to form a porridge that is fed to children. The high temperatures used in the extruder ensure that products are safe and have a shelf life in excess of 12 months when packed in moisture proof and airtight packaging. The process is used for both commercial weaning foods and foods used as emergency or supplementary foods by development agencies.

Extrusion cooking is also used to produce sugar confectionery products such as liquorice, toffee, fudge and boiled sweets from sugar, glucose and starch. Hard-boiled sweets are produced from sugar and corn syrup with added colours, acids and flavours. They are extruded as a órope ô and made into the required shapes using stamping or forming machines. Energy consumption using an extruder to produce confectionery is about half of that used in boiling pans.

29.4 Extruded products

Extrusion has enabled the production of new processed food products and "revolutionized many conventional snack manufacturing processes". The various types of food products manufactured by extrusion typically have a high starch content. *Directly expanded* types include breakfast cereals and corn curls, and are made in high temperature, low moisture conditions under high shear. *Unexpanded* products include pasta, which is produced at intermediate moisture (about 40%) and low temperature. *Texturized* products include meat analogues, which are made using plant proteins ("textured vegetable protein") and a long die to "impart a fibrous, meat-like structure to the extrudate", and fish paste. Confectionery made via extrusion includes chewing gum, liquorice, and toffee.

Some processed cheeses and cheese analogues are also made by extrusion. Processed cheeses extruded with low moisture and temperature "might be better suited for manufacturing using extrusion technology" than those at high moisture or temperature. Lower moisture cheeses are firmer and chewier, and cheddar cheese with low moisture and an extrusion temperature of 80°C was preferred by subjects in a study to other extruded cheddar cheese produced under different conditions. An extrudate mean residence time of about 100 seconds can produce "processed cheeses or cheese analogues of varying texture (spreadable to sliceable)".

Other food products often produced by extrusion include some breads (croutons, bread sticks, and flat breads), various ready-to-eat snacks, pre-made cookie dough, some baby foods, some beverages, and dry and semi-moist pet foods. Specific examples include macaroni, jelly beans, sevai, and some french fries. Extrusion is also used to modify starch and to pellet animal feed.

29.5 Effects of extrusion on nutritional quality

Extrusion enables mass production of food via a continuous, efficient system that ensures uniformity of the final product. This is achieved by controlling various aspects of the extrusion process. It has also enabled the production of new processed food products and "revolutionized many conventional snack manufacturing processes".

The extrusion process results in "chemical reactions that occur within the extruder barrel and at the die". Extrusion has the following effects:

- Destruction of certain naturally occurring toxins
- Reduction of microorganisms in the final product
- Slight increase of iron-bioavailability
- Creation of insulin-desensitizing starches (a potential risk-factor for developing diabetes)
- Loss of lysine, an essential amino acid necessary for developmental growth and nitrogen management
- Simplification of complex starches, increasing rates of tooth decay
- Increase of glycemic index of the processed food, as the "extrusion process significantly increased the availability of carbohydrates for digestion"
- Destruction of Vitamin A (beta-carotene)
- Denaturation of proteins.

The material of which an extrusion die is made can affect the final product. Compared to stainless steel dies, a pasta machine with bronze dies produces a rougher surface. This is considered to give an improved taste, as it better retains pasta sauces. "Bronze die" pasta is labelled as such on retail packages, to indicate a premium product.

The effects of "extrusion cooking on nutritional quality are ambiguous", as extrusion may change carbohydrates, dietary fibre, the protein and amino acid profile, vitamins, and mineral content of the extrudate in a manner that is beneficial or harmful. High-temperature extrusion for a short duration "minimizes losses in vitamins and amino acids". Extrusion enables mass production of some food, and will "denature antinutritional factors", such as destroying toxins or killing microorganisms. It may also improve "protein quality and digestibility", and affects the product's shape, texture, colour, and flavour. It may also cause the fragmentation of proteins, starches, and non-starch polysaccharides to create "reactive molecules that may form new linkages not found in nature". This includes Maillard reactions which reduce the nutritional value of the proteins. Vitamins with heat lability may be destroyed. Nutritional quality has been found to improve with moderate conditions (short duration, high moisture, low temperature), whereas a negative effect on nutritional quality of the extrudate occurs with a high temperature (at least 200°C), low moisture (less than 15%), or improper components in the mix.

Recent research publications indicate that use of non-traditional cereal flours, such as amaranth, buckwheat or millet, may be used to reduce the glycemic index of breakfast cereals produced by extrusion. The extrudate using these cereal flours exhibits a higher bulk and product density, had a similar expansion ratio, and had "a significant reduction in readily digestible carbohydrates and slowly digestible carbohydrates". Another research work states that replacing 5% to 15% of the wheat flour and white flour with dietary fibre in the extrudate breakfast cereal mix significantly reduces "the rate and extent of carbohydrate hydrolysis of the extruded products", which increased the level of slowly digested carbohydrates and reduced the level of quickly digested carbohydrates.