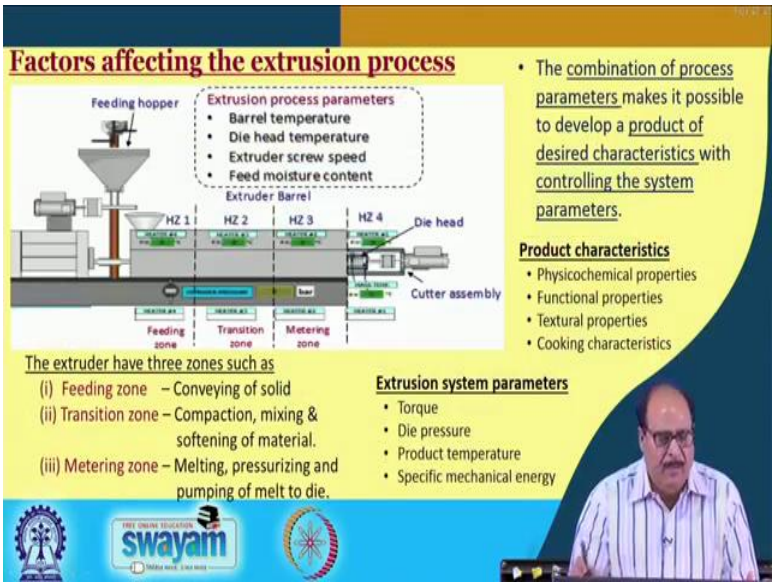
Novel Technologies for Food Processing and Shelf Life Extension

Prof. Hari Niwas Mishra
Department of Agricultural and Food Engineering
Indian Institute of Technology, Kharagpur

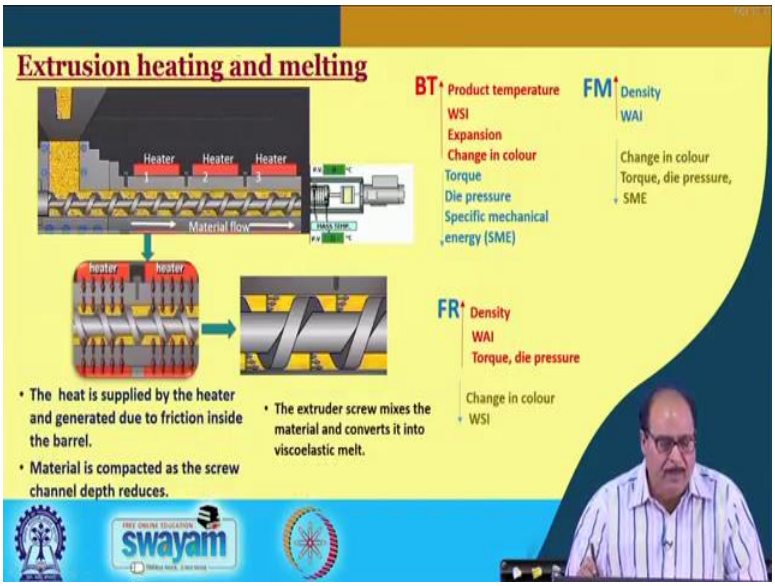
Lecture - 24
Extrusion Technology (Part 2)

In this 2nd part of the extrusion technology lecture, the effects of various extrusion process parameters and the material characteristics as well as product characteristics will be studied. A few case studies will also be introduced where some of the products have been developed using extrusion technology.

Extrusion is a thermo mechanical process in which heat transfer, mass transfer, pressure changes and shear are combined to produce effects such as cooking, sterilization, drying, melting, texturization, puffing, mixing, kneading, forming, etc. So, many different types of effects can be obtained in the product by having proper combinations of the characteristics of the material, extruder process variables and system variables etc. Specifically designed die is used to shape the product such as pasta, noodles, rice analogues or variety of other products in a variety of shapes and sizes are produced using this technology.



By having appropriate combination of the system and process parameters, one can produce products of desired characteristics. So, the important extrusion process parameters include barrel temperature, die head temperature, extruder screw speed and feed moisture content. The product characteristics include physicochemical properties, functional properties, textural characteristics and cooking characteristics. The extrusion system parameters are torque, die pressure, product temperature, specific mechanical energies, etc. The extruder have three zones (see Fig.); feeding zone, transition zone and metering zone. The feeding zone is used for conveying the solid; in the transition zone, compaction, mixing and softening of the material takes place whereas, in the metering zone, there is melting, pressurizing and pumping of the melt to the die.

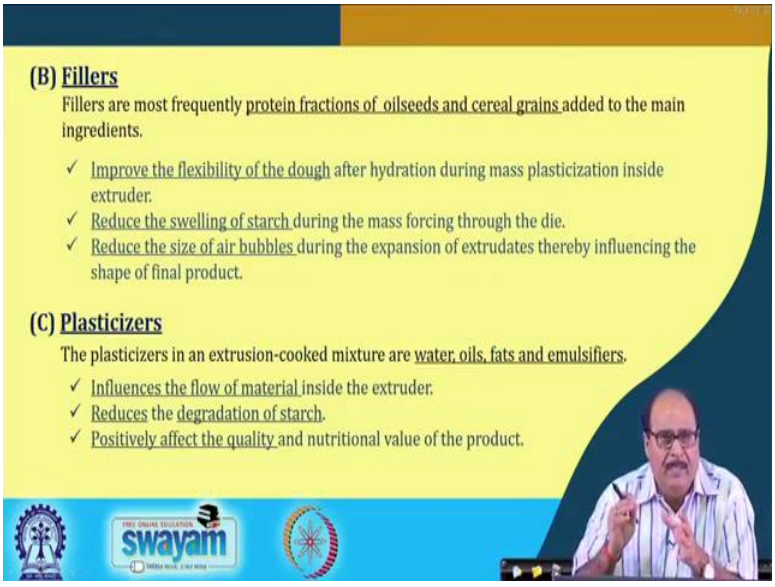


Some extruders (in Fig.) have 3 or 4 heating sections like heater 1, heater 2 and heater 3. The heat is applied using these heaters and also the heat is generated due to friction within the screw barrel. The material is compacted as the screw channel depth reduces. So, the extruder screw actually mixes the material and converts it into a visco elastic melt particularly towards the end of the die and then, when it passes through the die because of its flexible nature and other conditions of pressure and temperature inside, it takes the shape of the die. So, because of the pressure or temperature gradient, the material either expands or compacts.

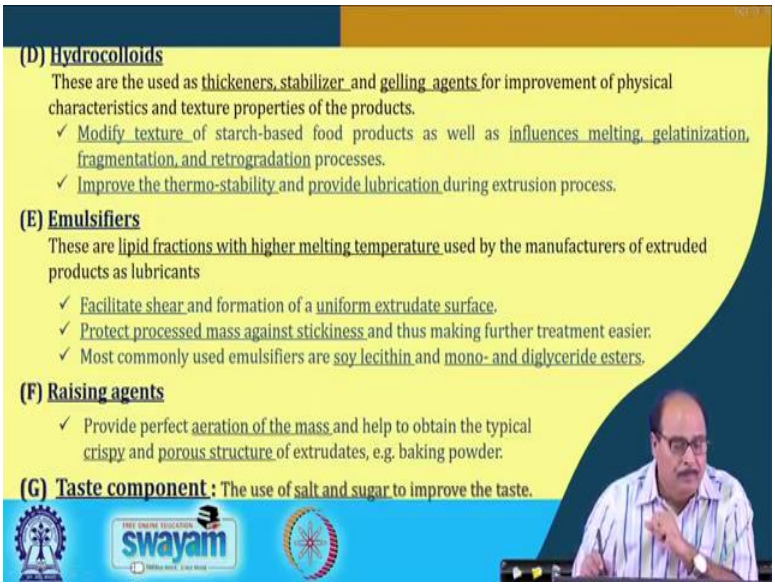
If the barrel temperature increases, the product temperature, water absorption index, expansion and colour change, all are likely to increase whereas, the torque, die pressure, and specific mechanical energy are likely to decrease. As far as the feed moisture is concerned, if it is high, the density and water absorption index will be more, whereas the change in colour, torque, die pressure and specific mechanical energy will be less. The density, water absorption index, torque and die pressure increase while change in the colour and water absorption index decrease with the increase in the feed rate. So, accordingly one should appropriately maintain the barrel temperature, the feed moisture and the feed rate to get the desired system parameter and ultimately desired product characteristics.

There are different types of raw materials used in the extrusion process and they have different functions to play inside the extruder in final shaping the product characteristics. For example, there are certain ingredients which are used as structure forming material like for example maize, wheat, rice, potato, oats, etc.

So, they are used to provide the final desired structure of the material depending upon the size, type and amount present in the food system. For example, maize which has medium size granules, average protein content and definite flavour and yellow colour imparts a good flavour and good colour to the extruded product; also because of its arrangements of the components and granular size etc., it expands well. Similarly wheat flour also expands well because of its starch and protein characteristics. Rice flour has small tightly packed starch granules, it slowly hydrates and starch gets gelatinized during the processing, it has average protein levels and it gives bland flavour and white colour. Potato on the other hand has large granules, high starch level, has definite flavour, gold to light brown colour and the starch characteristics of potato also result in well or good expansion, but the material becomes sticky. So, potato can be an excellent binder. Oats contain large fibre and higher content of lysine as compared to other cereals etc.

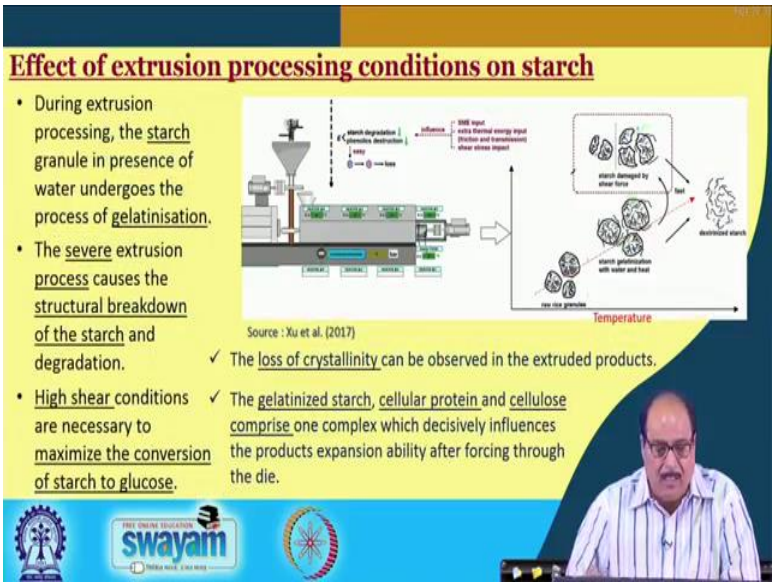


The other type of material can be used as fillers; fillers are most frequently protein fractions of oilseeds and the cereal grains which are added to the main ingredients. They improve the flexibility of the dough after hydration during mass plasticization inside the extruder. They reduce the swelling of starch during the mass forcing through the die and also, they reduce the size of air bubbles during the expansion of the extruder there by influencing the shape of the final products. So, these are the functions of the different fillers. The plasticizers in an extrusion cooked mixture are normally water, oil, fats and emulsifiers. They influence the flow of the material inside the extruder, reduce the degradation of starch and positively affect the quality and nutritional value of the product.



The other type of the material ingredients can be used as hydrocolloids like they are used for providing thickness, thickening effect, stabilization and gelling effects for the improvement of the physical characteristics and textural properties of the end product. These hydrocolloids modify texture of the starch based food products as well as they influence the melting characteristics, gelatinization, fragmentation and retrograding processes. Hydrocolloids improve the thermal stability and provide lubrication during the extrusion process. The emulsifiers are the lipid fractions with higher melting temperature used as lubricants in the extruded product. They facilitate shear and formation of uniform surface structure, they protect processed mass against stickiness and thus making further treatment easier. The most commonly used emulsifiers in the products or in the extrusion technology are the soy lecithin and mono and diglyceride esters.

Apart from this, sometime depending upon the requirement of the product, some raising agents can also be used such as to provide aeration of the mass and help to obtain the typical crispy and porous structure of the extrudates e.g. the baking powder. Components like salt, sugar, sometimes some spices etc. are added to improve the taste in the extruder product.



Effect of extrusion processing conditions on the material characteristics: Starch is one major component in the structure forming action which influences the product texture and other characteristics. So, during the extrusion processing the starch granules in presence of water undergo the process of gelatinization if the extrusion conditions are severe. In the rice granules (Fig.) how the starch looks like when gets gelatinized on coming in contact with the water and heat which is there inside the screw barrel is shown in figure.

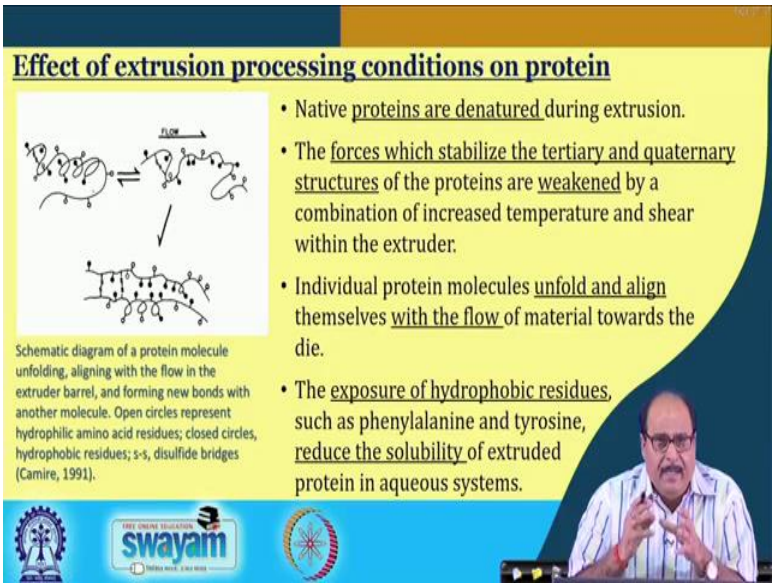
Depending upon the conditions of temperature and pressure present inside the barrel, the starch granules get damaged by the shear forces etc. and finally, dry hydrolysis may take place. It may undergo dextrinization and in fact this dextrinized starch sometime gives the sweeter taste because these dextrins are intermediate between glucose and the starch molecule. They have the intermediate characteristics i.e. less sweeter than glucose, more sweeter than the starch.

So, these high shear conditions are necessary in order to maximize the conversion of starch into glucose, so that the material gets the better sensory characteristics and other components. Even the glucose might contribute to the browning of the extruded product which is sometimes desirable.

So, the loss of crystallinity can also be observed in the extruded product which is basically because of the gelatinization effect. The gelatinized starch, denatured protein

and the cellulosic materials etc. which might be there in the raw material decisively influence the product expansion ability after forcing them through the die.

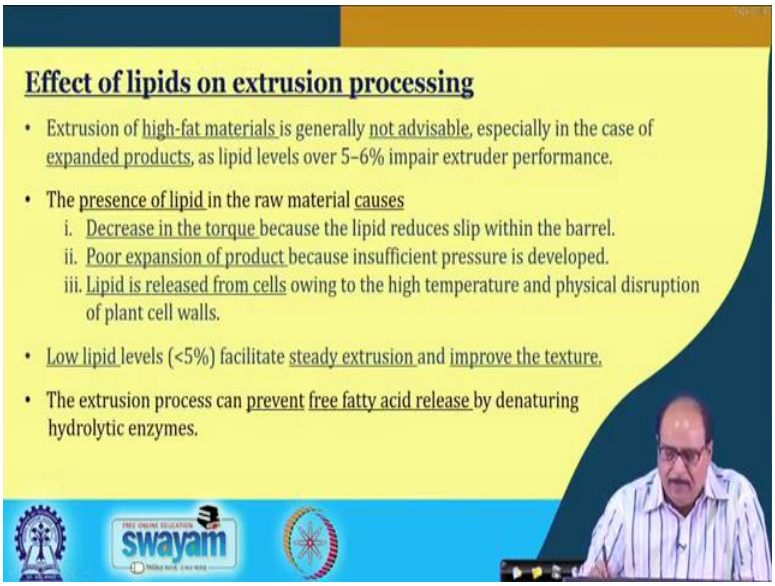
So, the starch is an important ingredient as far as the extruder products and their characteristics are concerned. They are used for density control and to provide strength in the material. Actually certain modified starches can increase the strength and reduce breakage in the expanded products. They might result in the shelf life improvement, moisture uptake, improve the flavour, water holding capacity, fat binding capacity, and other functionalities.



The extrusion process conditions have an important influence on the protein characteristics like denaturation during extrusion process.

The forces which stabilise the tertiary structure and quaternary structure of the proteins are weakened by a combination of increased temperature and shear within the extruder barrel. All these forces in fact are responsible to keep the structure in its native form bounded by covalent linkages, sulphide linkages, etc. So, the individual protein molecule unfold and align themselves with the flow of the material towards the die. The exposure of hydrophobic residues such as phenylalanine and tyrosine, they reduce the solubility of the extruded protein in aqueous systems.

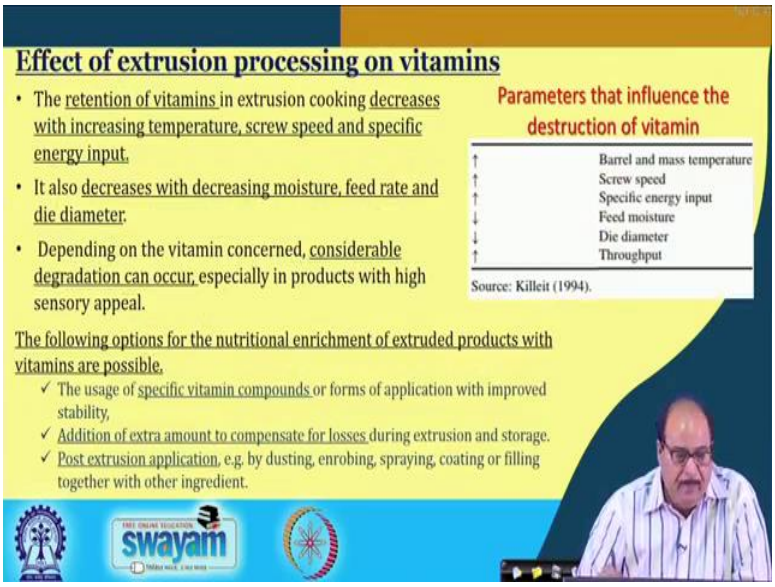
In the schematic diagram shown, native structure is seen to be disturbed. If there is a hydrophobic R-group extended towards the surface on the native structure, then protein has good solubility. They may get disturbed and these hydrophilic R group may go towards the interior of the molecule as a result of this denaturation. So, the protein solubility may get disturbed accordingly, the extruded product may have been less soluble because of these changes in the protein characteristics.



As far as the effect of lipids on extrusion processing is concerned, extrusion of high fat materials is generally not advisable especially in the case of expanded product. If expansion of material is needed after extrusion, the fat content should be kept low as low as possible. For example if the lipid level is more than 5 to 6 %, it impairs extruder performance and the presence of lipid in the raw material causes decrease in the torque as the lipid reduces slip within the barrel. There is poor expansion of the product because insufficient pressure is developed. Lipid is released from the cells owing to the high temperature and physical disruption of the plants cell walls. So, high fat content may

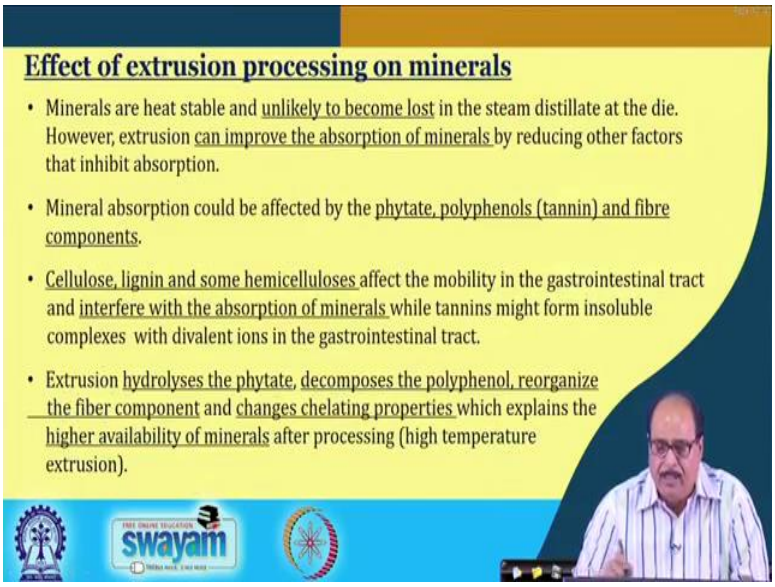
have some difficulties or may influence the product characteristics. Low lipid level rises less than 5 % in the material facilitate a steady extrusion and improve the texture.

The extrusion processes can prevent free fatty acid release by denaturing the hydrolytic enzyme. So, the hydrolytic rancidity in the extruder product can be prevented or can be reduced in compared to the normal products because the pressure and heat generated inside the extruder barrel can cause the hydrolytic enzymes denatured.

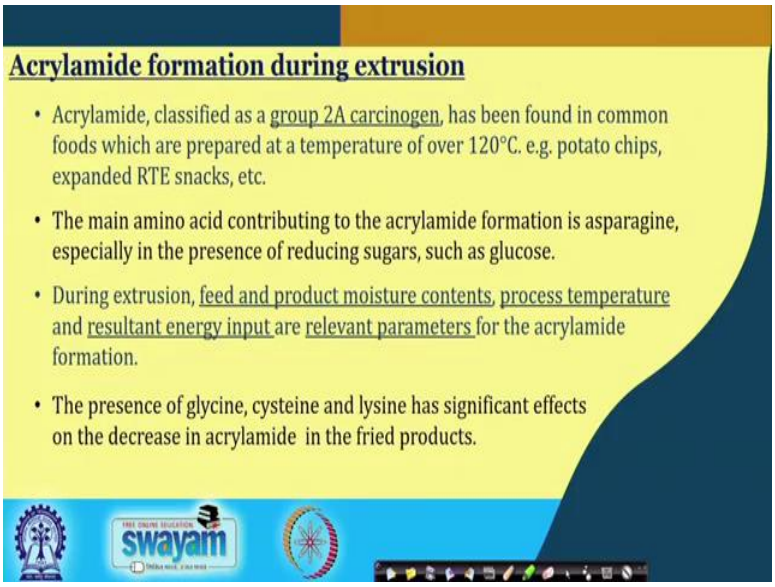


Effect of extrusion processing on vitamins: The retention of vitamins in extrusion cooking decreases with increasing temperature, screw speed and specific energy input. It also decreases with decreasing moisture, feed rate and die diameter; if the die diameter decreases, the vitamin retention will decrease. Then depending on the vitamin concerned, considerable degradation can occur especially in the product with high sensory appeal. So, care should be taken to have minimum change or minimum destruction of the vitamins.

The usage of specific vitamin compounds or forms of application with improved stability, i.e. those vitamins which have better stability can be used. And some time addition of extra amounts of vitamins may be in the form of vitamin mineral premix can be added in the product to make up the losses. This addition can be done during extrusion or storage stage or even post extrusion either by dusting, enrobing, spraying, coating or filling together with other ingredients that can be applied. So, by this desired quantity of vitamins can be maintained.



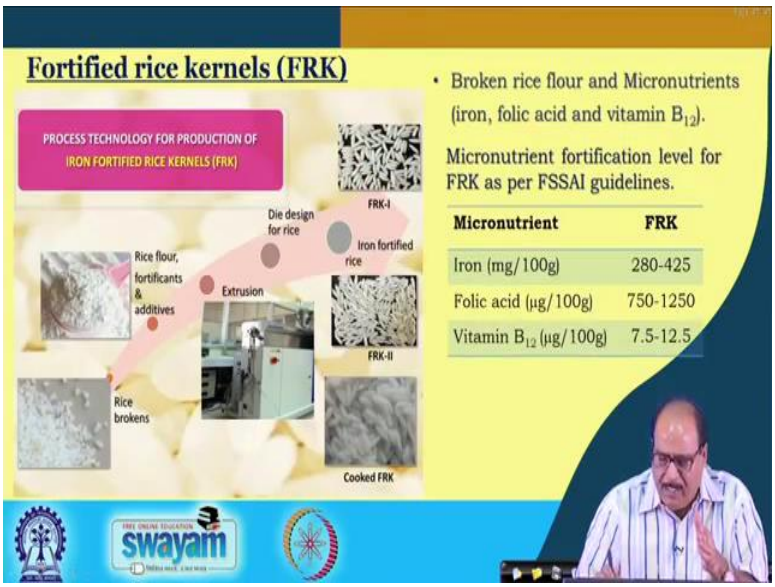
Effects of extrusion process on minerals: Minerals are more heat stable and are not likely to become lost in the steam distillate at the die, however extrusion can improve the absorption of minerals by reducing other factors that inhibit absorption. Mineral absorption could be affected by the phytate, polyphenols like tannins etc. and fibre components. So, cellulose, lignin and some hemicelluloses affect the mobility of these minerals in the gastrointestinal tract and interfere with their absorption while tannins might be insoluble complex might form in soluble complexes with divalent ions in the gastrointestinal tract. So, the extrusion hydrolyses the phytates, decomposes the polyphenols, reorganizes the fiber components and changes chelating properties and this explains the higher availability of the mineral after extrusion processing particularly after high temperature extrusion. So, the availability of the mineral might be more in the extruder product as extrusion process improves the absorption characteristics of the minerals.



Acrylamides normally classified as a group 2A carcinogen and it is found common in foods which are prepared at temperature of more than 120 °C e.g. potato chips, expanded RTE snacks, etc. Here the causative agents are mainly amino acid which contribute to the acrylamide formation is asparagine and especially in the presence of reducing sugars like glucose etc. This asparagine reacts with the glucose and the sugar-amine acrylamides are formed. So, during extrusion, the feed and product moisture content, process temperature and resultant energy inputs are relevant parameters for the acrylamide formation and this accordingly they can be properly controlled. For example, if the temperature inside the extruder barrel etcetera is maintained less than 120 °C, the formation of acrylamide can be either eliminated or can be avoided. Also the presence of glycine, cysteine and lysine has the significant effects on the decrease in acrylamide content in the fried products.

Using extrusion technology, fortified rice kernels, essential amino acid balanced nutri dal, ready to eat snacks (may be from the millets etc.), sweet potato extrudates, chlorella fortified pasta, fortified rice noodles, and such other innovative products have been developed at Food Chemistry and Technology Laboratory, IIT Kharagpur.

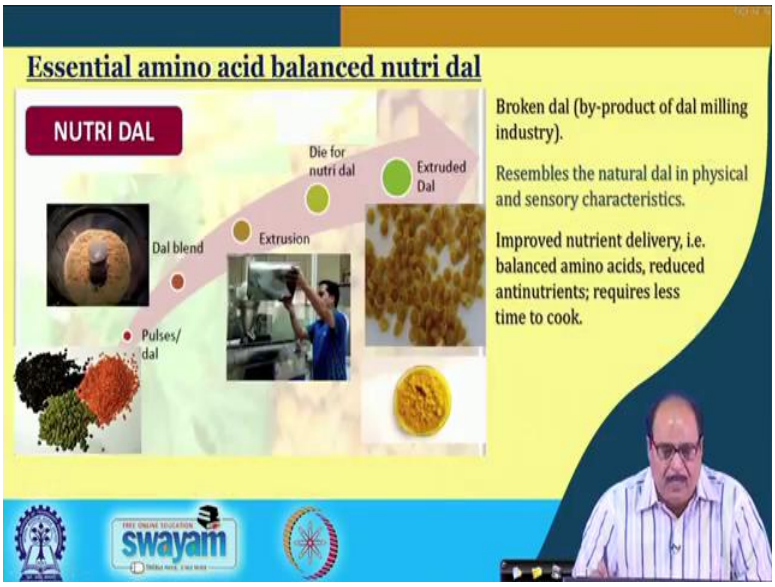
These have been done by appropriate selection of the process parameters. Most of these products are in ready to eat form; frying and other things might not be required. Some of these products and their manufacturing technologies will be taken up in further slides.



Fortified rice kernels (FRK): These are made by using the broken rice. Broken rice from the rice mill is taken and converted into flour. The conditioned rice flour is added with the fortificants like iron, folic acid and vitamin B_{12} in appropriate quantity as per the

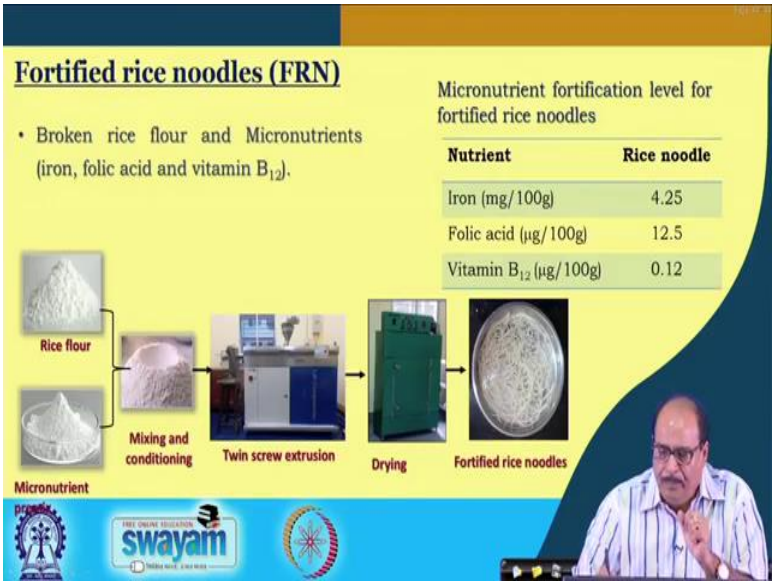
guidelines set by Food Safety and Standards Authority of India. The extruder is designed and developed indigenously for this purpose and the rice die has been designed. The mix is forced through the extruder and the fortified rice kernels are made using this extrusion technology.

Inside the extrusion barrel just at the die head, the condition of temperature and pressure are manipulated in such a way that when material comes out, there is a sufficient degree of compression in the products. It then expands and these rice get the desired characteristics. They resemble to normal rice in their cooking, eating and other sensory characteristics. After cooking (see Fig.), it does not disintegrate and retains its shape.

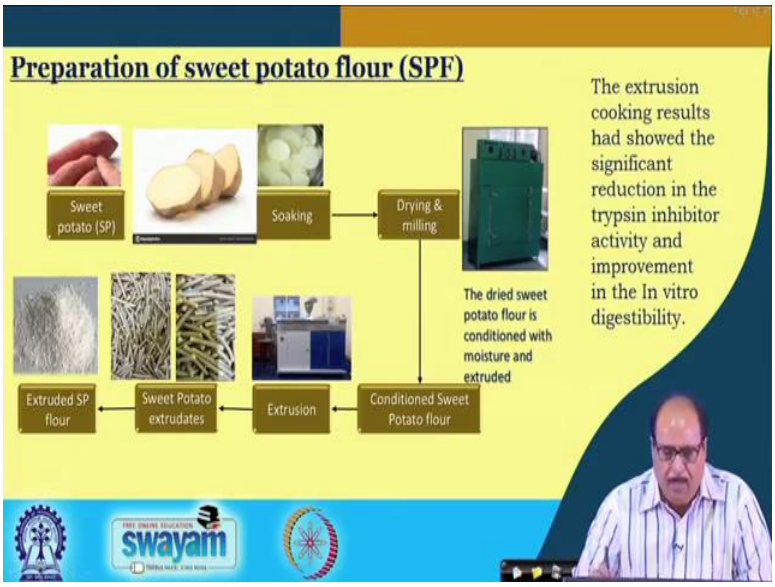


Similarly another product is the essential amino acid balanced nutri dal. Dal forms a major source for the protein. Split pulses are taken from different dal mills and appropriately mixed. The formulation was done using linear programming. This is forced through the extruder and maintaining desired pressure and temperature conditions, the dal can be obtained. So, this can be actually called ‘nutri dal’ because in a single product, all essential amino acids are contained. 100 g of this dal is comparable to 100 g of egg as far as the essential amino acid composition is concerned.

The other product is the gluten free pasta. Here also chickpea flour and rice flour are mixed together, a batter is formed that is mixed and conditioned and fed to twin screw extruder. And finally, it is dried and gluten free pasta is obtained. The ingredients all are gluten free but of course the extrusion process conditions or particularly mixing and conditioning are optimized in such a way that the produced pasta retains its shape, and it swells double when it is cooked. So, desired characteristics of the pasta are there in this product.

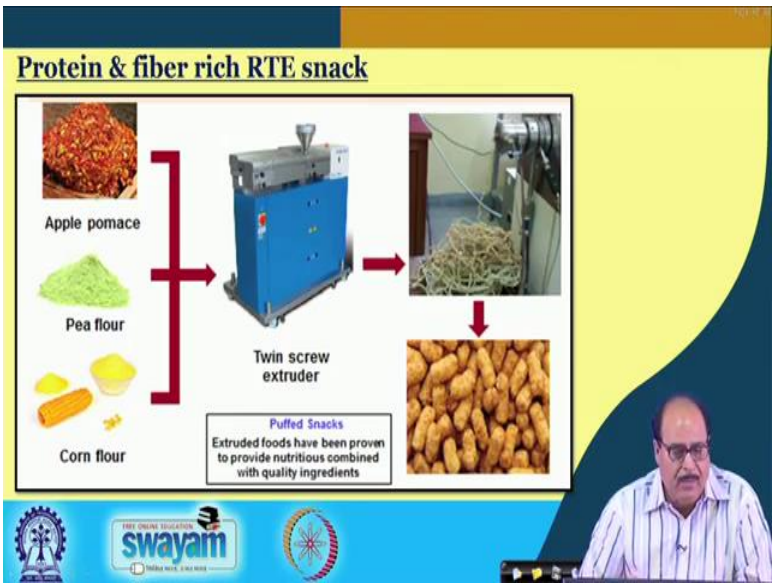


Similarly, the fortified rice noodle is formed that is found to resemble the commercial products in its sensory and other characteristics. So, it is a health noodle as it has been fortified by micronutrients like iron, vitamin B_{12} and folic acid.



Another process is the preparation of sweet potato flour using extrusion technology. Sweet potato is taken, washed, made into slices and then, soaked. After soaking, it is dried, conditioned and fed into the extruder. It results in the significant reduction of the trypsin inhibitor and improvement in the in-vitro digestibility.

Finally the sweet potato extrudates are further ground into flour, and this becomes a very good ingredient for use in the food production. So, this sweet potato flour was used in the preparation of high energy ready to eat food for malnourished children.



The other product is protein and fiber rich ready to eat snack foods. The pea protein is added with corn flour in appropriate amount and some apple pomace. So, here it is a protein and fiber rich material, comparatively less starchy. So, these are mixed in

appropriate amount and then finally, fed to the extruder under desired conditions and finally ready to eat expanded snacks of desired characteristics are obtained.