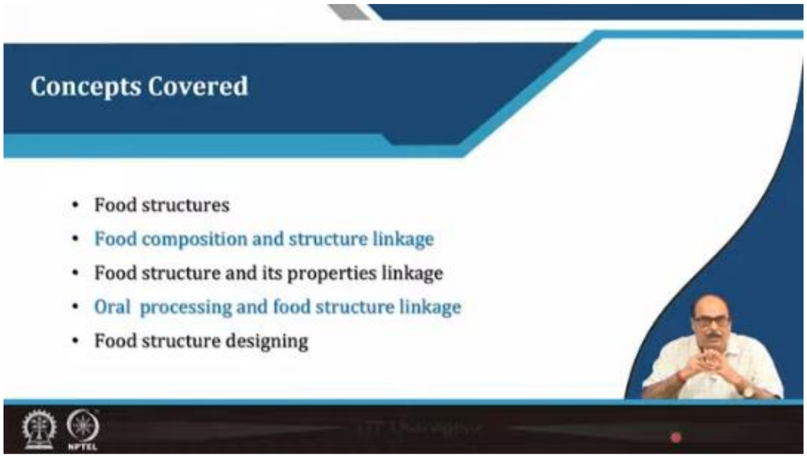
FOOD SCIENCE AND TECHNOLOGY

Lecture10

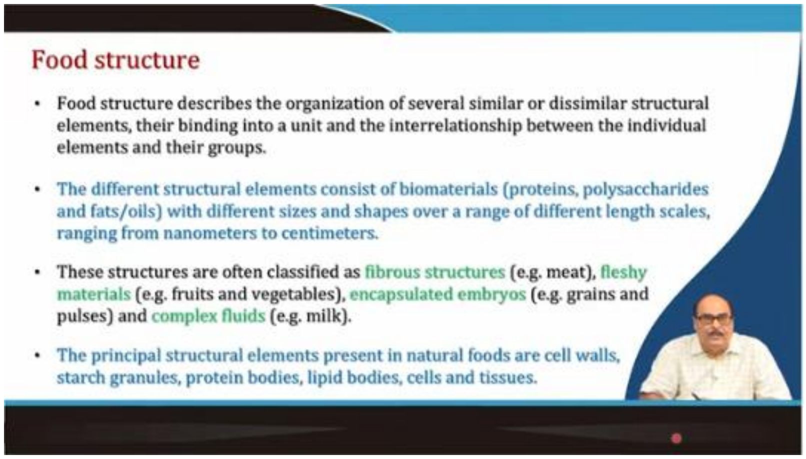
Lecture 10: Food Structure and Quality Relationships

Hello everyone, Namaste.

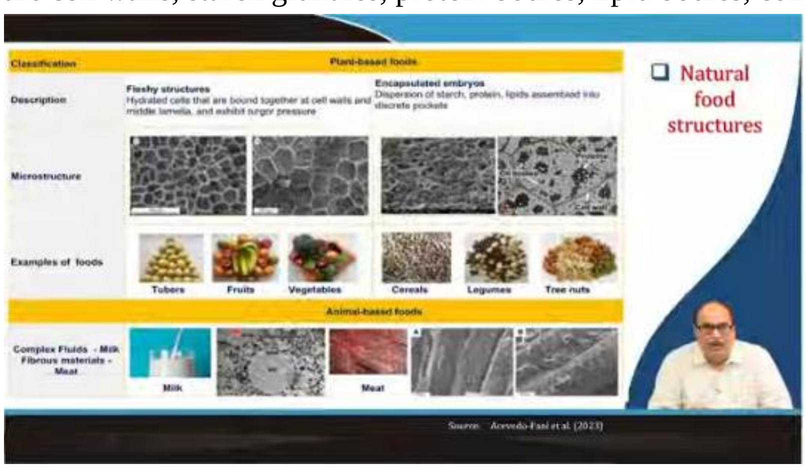
Now we are in the last lecture of the second module. That is, in this lecture, we will discuss food structure and quality relationships.



The concepts we discussed are: what is food structure, what do we mean by food structure, and how food composition and structure are linked with each other food structure and its properties linkage, Oral processing and food structure linkage, and finally, we will also talk about food structure design. So, let us see what food structure means. Food structure describes the organization of several similar or dissimilar structural elements.

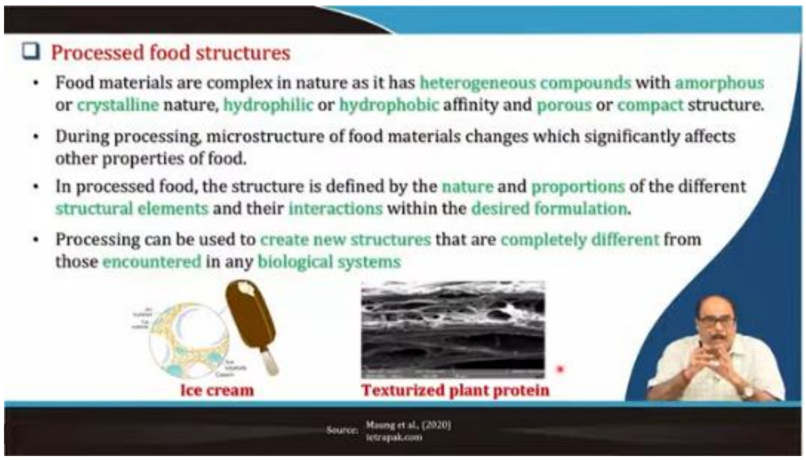


They are bound into a unit and the interrelationship between the individual elements and their groups. The different structural elements in food or other materials consist of various biomaterials, such as proteins, polysaccharides, fats, oils, and so on. And also, these are all of different sizes and shapes. They may range over different length scales, from nanometers to centimetres. So, obviously, how are these molecules, macromolecules, etc are organized naturally in the food system, that is what we consider as food structure. So, food structures are often classified as fibrous structures, like those in meat and meat products. Fleshy materials, like fruits and vegetables, are encapsulated embryos, which is the case for grains and pulses, and complex fluids like milk. So, the principal structural elements present in natural foods are cell walls, starch granules, protein bodies, lipid bodies, cells, and tissues.

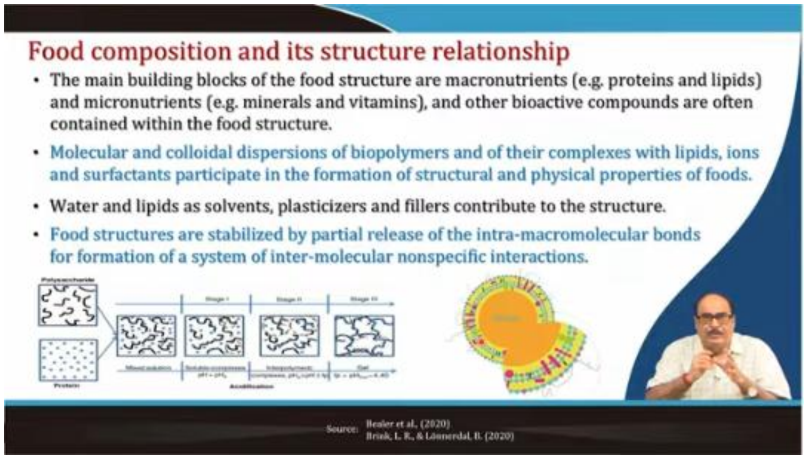


So, in this picture, it has been shown how the structure, the different structures of the natural food materials are present there. Like you can see here that there may be a microstructure, a fleshy structure that is hydrated cells that are bound together at the cell wall and middle lamina exhibit their group pressures, etc. You can see here how these macromolecules are present, or in the encapsulated embryos like dispersion of starch, protein, or oil bodies, etc. lipids assembled into discrete pockets. All these things you can see in the microstructure, of the plant-based foods, etc. So, examples of this may be tubers, fruits, and vegetables. Here, the microstructure is like this. The fleshy structures may be found in the tubers, fruits, and vegetables. The encapsulated embryos may be found in the cereals, legumes, tree nuts, etc., and the complex of fluid like milk where you see all these either in the lipids, cell membrane, etc.

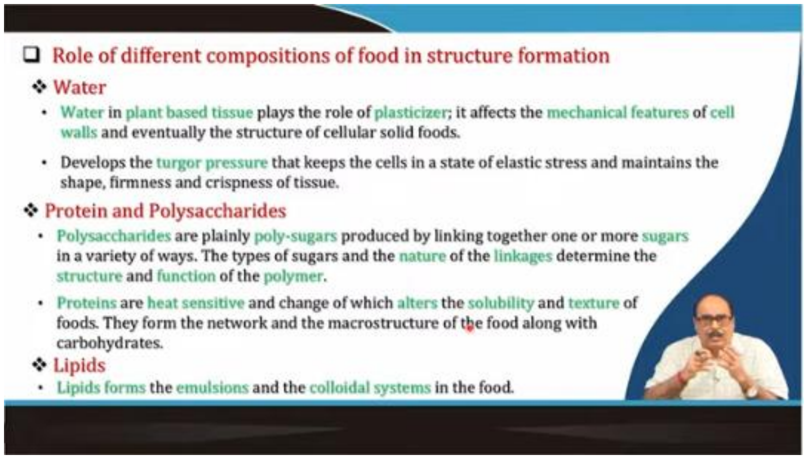
Then, comes meat, which is an animal-based product. Meat is the fibrous material that has a fibrous and layered structure. In, this figure, we can show how by various natural ways these macromolecules, micromolecules, etc., are organized, either they are enclosed in each other or they are the layered fiber or placed in nature in various components. These figures ate taken from a paper 2023. So, that is the natural food structure.



Then, processed food structure, where the food materials are complex in nature, as you have seen in the earlier slides, as it has a heterogeneous compound with amorphous or crystalline nature, hydrophilic or hydrophobic affinity, and porous or compact structure. So, when these materials are exposed to various processing conditions like temperature, thermal processing, non-thermal processing, hydrothermal processing, or any other processing, then these natural structures of the micro, microstructure of the food material, etcetera, change, which significantly affects other properties of the food. So, because of these changes in the even microstructure or other general nature of the natural structure of the material, the properties of the food, properties of the processed food, are entirely different from the natural counterpart of the raw materials. So, in the processed food, the structure is defined by the nature and proportion of the different structural elements and their interactions within the desired formulation. Processing can be used to create altogether a new structure, like you can see how the milk or milk cream or milk fat gives a completely new, very tasty structure in the ice cream, etc. Even if you see ice cream, how these ice crystals and casein molecules, air bubbles, fat crystals, are organized in the milk and then, in the ice cream during freezing or when you put in the freezer, appropriate amount of air bubbles, and the mixing operations give altogether a different structure. Similarly, you can see the plant proteins which are amorphous plant proteins by extrusion or by other methods. They are given a very organized textured layer structure. So, what I am telling to say is there is a processing which can create altogether a completely new structure, which might be entirely different from its natural counterpart, and this new structure altogether may give new properties, improved functionality, improved digestibility, and other characteristics of the food.

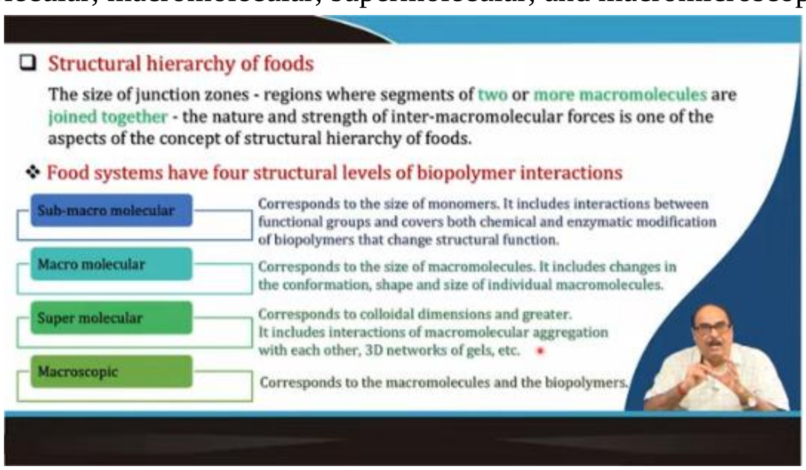


So, the relationship between food composition and its structure, let us talk. The main building blocks of the food structure are macronutrients like proteins and lipids, and also micronutrients like minerals and vitamins. There are other bioactive compounds, which are like antioxidants, phenolics, and other materials. They are all contained within the food structure. So, molecular and colloidal dispersions of biopolymers and their complexes with lipids, ions, and surfactants participate in the formation of structural and physical properties of the food, as you can see here in this picture. Water and lipids are solvents, plasticizers, and fillers, and they contribute to the structure. So, food structures are stabilized by the partial release of the intra-molecular bonds for the formation of a system of intermolecular non-specific interactions. Here you can see how it is organized in a particular polysaccharide, and protein. The two materials are there, and when they are mixed, there is a macromolecule interaction at the macromolecular level. Earlier in these two materials, there were intramolecular bonds, etc. Now, these intramolecular bonds are replaced with the intermolecular bonds which means the polysaccharide and protein interaction. Then it further forms soluble or mixed solution and then soluble complexes depending upon the pH increased. It may again influence because of the pH of the polysaccharide systems and pH of the isoelectric pH, that there may be interpolymeric structure and finally, this whole system may be converted into which were individually, or they might be in the form of flora. Here if you have added water and then you can get into a gel type of material. So, these altogether you get an idea about how this all macromolecules, micromolecules, etc., and their bonds, etc., are organized, and you can get a gel-type material, paste-type material, or other materials which have altogether new characteristics.

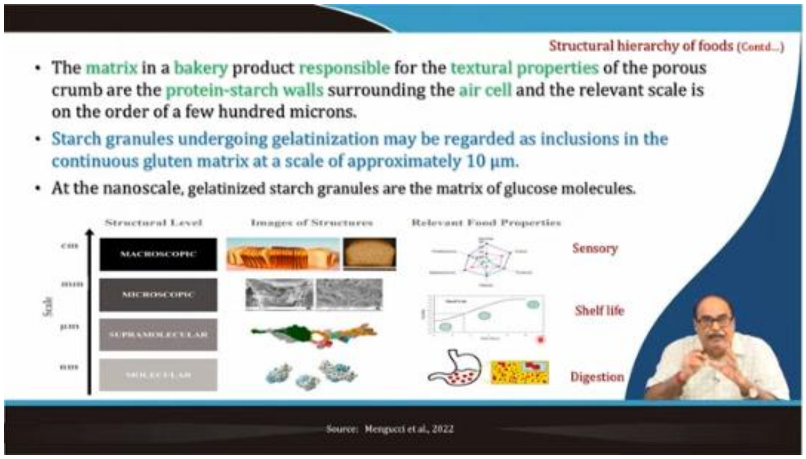


So, the role of different compositions in food in structure formation, like water, which is a major component in food. In particularly plant-based tissues, it plays the role of a plasticizer. It affects the mechanical features of the cell wall and eventually the structure of the cellular solid foods. Water develops the turgor pressure that keeps the cell in a state of elastic stress and maintains the shape, firmness, and crispiness of the tissue. Then proteins and polysaccharides: The polysaccharides are primarily polysugars produced by linking together one or more sugars in a variety of ways. The types of sugars and the nature of the linkages determine the structure and function of the polymer. Proteins are heat-sensitive, and their change alters the solubility and texture of the foods. They form the network and the microstructure of the food along with carbohydrates. Lipids form the emulsions and the colloidal systems in the food.

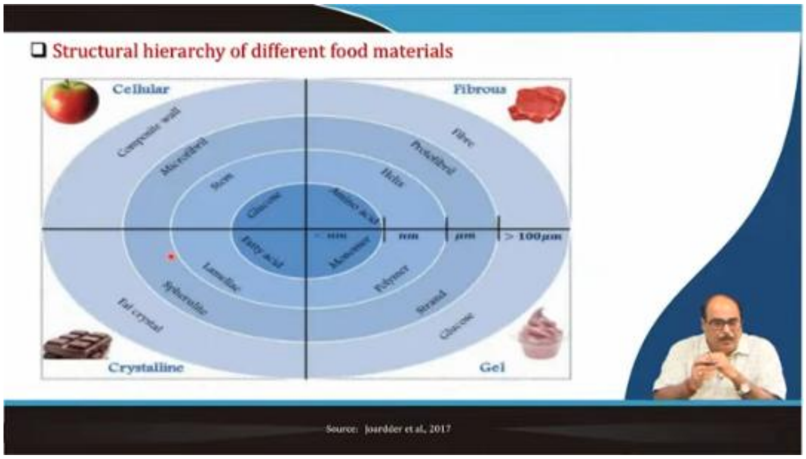
Then, the structural hierarchy of the foods and the size of junction zones. Regions where segments of two or more macromolecules join together. The nature and strength of intermolecular forces are one of the aspects of the concept of the structural hierarchy of the foods. Food systems have four structural levels of biopolymer interactions, which may be sub-macromolecular, macromolecular, supermolecular, and macromicroscopic.



Sub-macromolecular corresponds to the size of the monomers. It includes interactions between functional groups and covers both the chemical and enzymatic modification of biopolymers that change structural function. Macromolecular corresponds to the size of the macromolecules. It includes changes in the conformation, shape, and size of individual macromolecules. The super-macromolecular corresponds to the colloidal dimensions and greater. It includes interactions of macromolecules, aggregation with other 3D networks of gel, etc. The macroscopic corresponds to the macromolecules and the biopolymers.

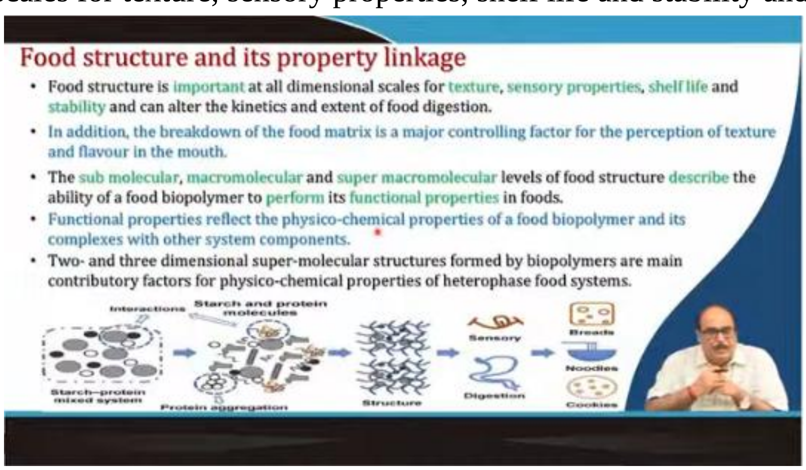


The matrix in a bakery product is responsible for the textural properties of the porous crumbs are the protein-starch wall surrounding by the air cells, and the relevant scale is of the order of a few hundred microns. Starch granules undergoing gelatinization may be regarded as inclusions in the continuous gluten matrix at a scale of approximately 10 micrometers. And at the nanoscale, gelatinized starch granules are the matrix of the glucose molecules. That is how all these characteristics are changed. That is the structural level you can see here. The scale is like molecular nanometer, supramolecular micrometer, microscopic millimeter, and macroscopic centimeter. So, the scale is increasing. You can see images of the structure at the molecular level, and the relevant food properties are important in the digestion system in the stomach or in the colon. Whereas, in the scale of microscopic or even some supramolecular, and microscopic level, this is the structure and they mainly interact, and responsible for shelf-life of even for the processed food materials during their storage, etc. What are the changes at the supramolecular or microscopic levels. At the microscopic level, you see images of the structure like bread and other food material, you can corelate relevant food properties like color, texture, other sensory experiences.



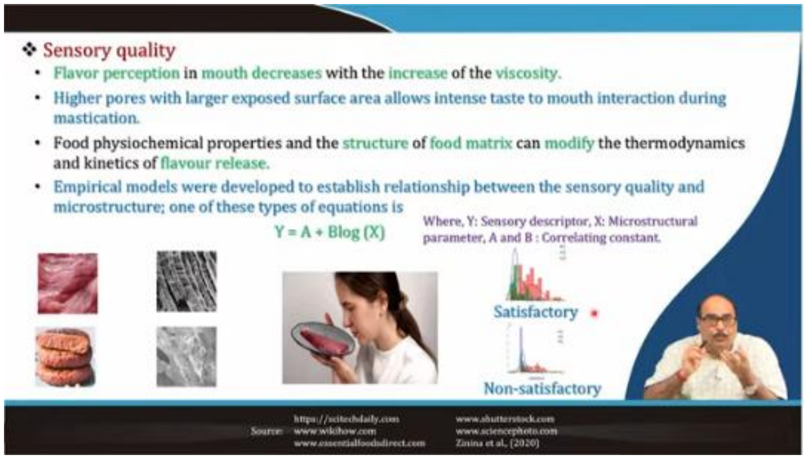
The structural hierarchy of different food materials can also be seen in this picture like the cellular level in the apple or such other fruits, the glucose, stems from here increases in size from the less than nanometer scale to the nanometer scale. Then, from nanometer to micrometer in this range, and then more than the 100 micrometer range in this range. So, glucose, then it stems micro filler and composite walls. Finally, the composite wall, that may be more than 100 micrometers. Similarly, in the fibrous structure, first is the protein amino acid, then the helix structure, then proto fibril and finally, it comes to the fiber state. When the size gets aggregated and the size increases. Similarly, in the monomer layer, polymer strand and glucose, you get the gel material like in the ice cream and so on. In the chocolate, crystalline, fatty acids, lamellae and sacrophilic and fat crystals, etc. So from here you can understand when molecular size increases, how the size increases and how their shape and characteristics and all those things change. This is the structural hierarchy of the different food materials.

Then food structure and its property linkage. This food structure is important at all dimensional scales for texture, sensory properties, shelf life and stability and can alter



the kinetics and extent of food digestion. In addition, the breakdown of the food matrix is a major controlling factor for the perception of texture and flavor in the mouth. The submolecular, macromolecular and supermolecular levels of food structure describe the ability of a food biopolymer to perform its functional properties of food. Functional properties reflect the physicochemical properties of a food biopolymer and its complexes with other food components and two- and three-dimensional supermolecular structures formed by biopolymers are main contributory factors for physicochemical properties of heterogeneous food systems. You can see here that in a food system, there is a starch and protein mixed system if you have it. These are, starch molecules and protein molecules and how there is an interaction between water, starch, and protein molecules or even sometimes there will be water and all. Then, depending upon the conditions when they are put into various processes, etc., and all those things, various conditions favor protein aggregation and the changes in starch and protein molecules interaction, etc., even changes in starch structure. There will be gelatinization, retrogradation, other changes in the starch depending upon the conditions, and then this starch and protein also there is a mixture of how this structural change takes place and then all reorientation, reorganization of these molecules finally comes into some sort of organized structure that is structure of that food material, and that is exactly what you can say it is either sensory characteristics or digestibility characteristics so how and you can say that is the same material that is the maybe wheat flour or some rice flour or some other pulse flour, grain flour, etc. and the other protein and oil sources and starch sources. So, you can see how when these are processed into different stages, how these macromolecules interact with each other, how they form different organized and unorganized structures. Actually, it influences its sensory characteristics, digestibility, and other characteristics and that you can exactly see in the breads, in the noodles, and in the cookies.

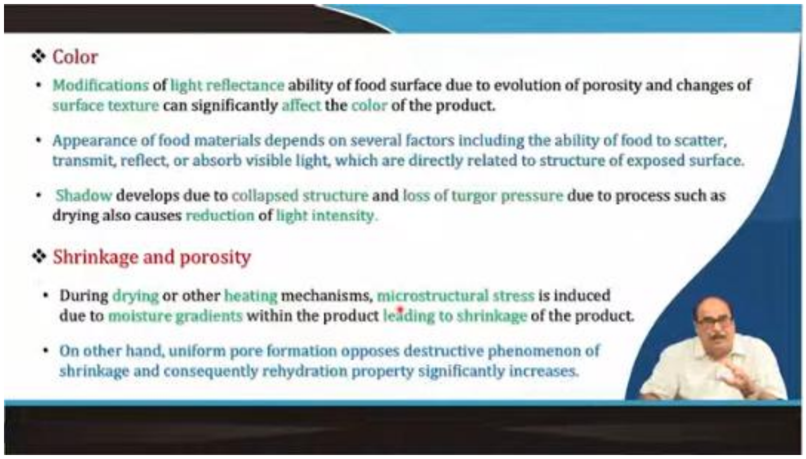
These are even the same raw material used and the same type of processes, etc. but there may be a little bit of difference in the processing conditions. There may be differences in the dough making and all those conditions. And these differences result in the final differences in the end product, the last end product characteristics. And not only the physical characteristics, but also its sensory characteristics or other characteristics, digestibility, nutritional value, and all those things. That is why food structure and its property linkage is very important.



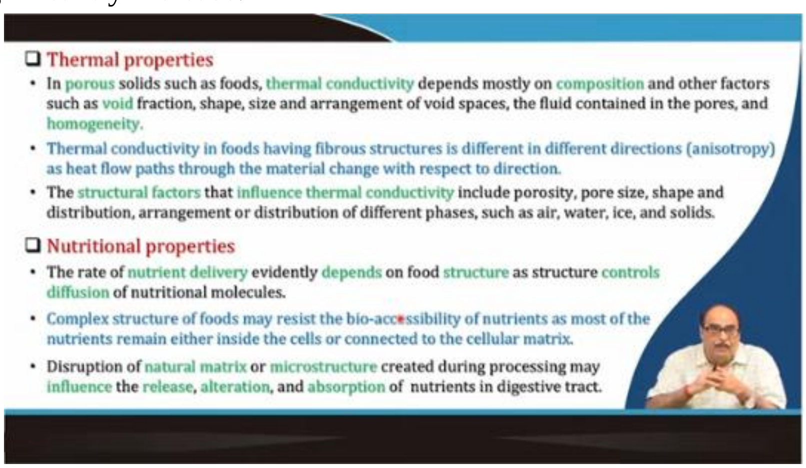
Then the sensory quality, actually flavor perception in the mouth, decreases with an increase in the viscosity. Higher pores with larger exposed surface areas allow intense taste-to-mouth interactions during the mastication process. Food physicochemical properties, structure, and food matrix can modify the thermodynamics and kinetics of the flavor release. Therefore, there are empirical models. These were developed to establish a relationship between the sensory quality and the microstructure and one of these equations may be

$$Y = A + B\log(X)$$

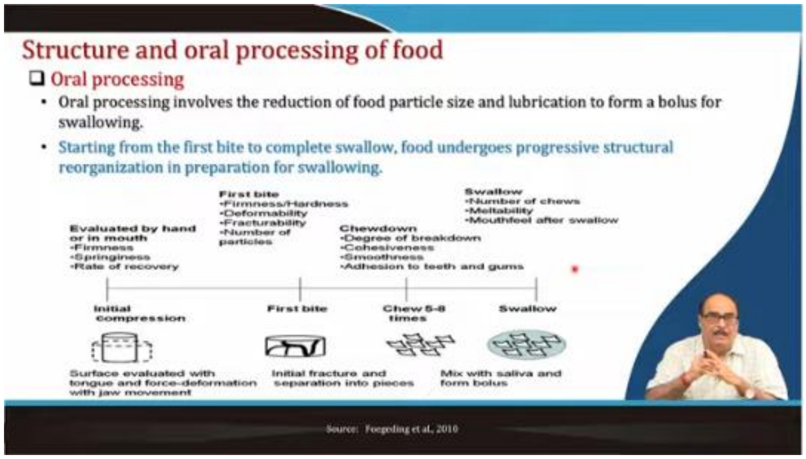
where Y is the sensory descriptor, X is the microstructural parameter, and A and B are the correlating constants. And that is what you can see here: these materials have different structures and different textures, etc. and one is smelling, which depends upon how they are organized, and it may be either satisfactory or non-satisfactory; you can find out using these things. Similarly, in the texture, textural mechanical properties of several foods have been found closely related to their structure. Food structure and its surface properties, as well as rheology, influence food texture. Food structure directly influences the physiological interaction, as you can see here. Physiological interaction occurs during oral processing, such as when one is eating, chewing, or masticating in the mouth, during the oral process. Subsequently, oral perception detects the texture of the food material. That is, when you take any material, you bite it, and then you can determine whether it is hard, soft, or leathery, and all those things. And accordingly, you can judge whether it is good, not good, satisfactory, or not satisfactory. The relationship between food structure and texture anticipation is not straightforward, due to the dynamic features of texture perception and the presence of diversified processes. It may vary with different conditions, different factors, and so on.



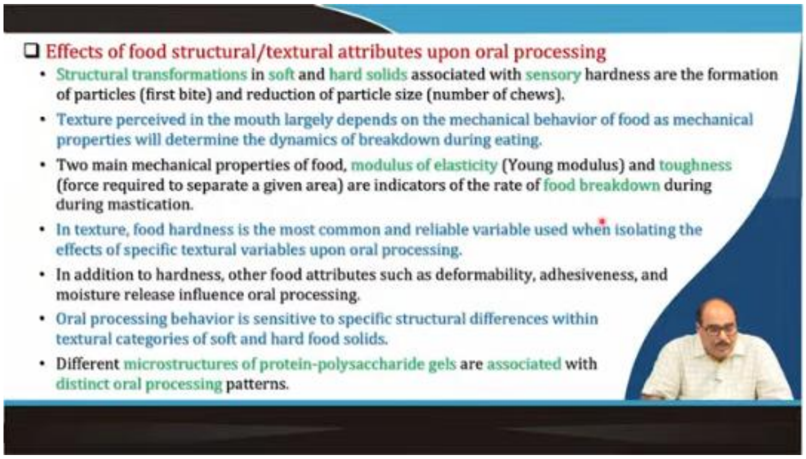
Similarly, the color modifications of light reflectance and the ability of the food surface due to the evolution of porosity and changes in surface texture can significantly affect the color of the product. The appearance of food materials depends on several factors, including the ability of food to scatter, transmit, reflect, or absorb visible light. These are directly related to the structure of the exposed surface. So, shadows developed due to collapsed structure and loss of turgor pressure, due to processes such as drying, also cause a reduction in light intensity. Then, shrinkage and porosity during drying, or other heating processes or mechanisms, microstructural stress is induced due to moisture gradients within the product, leading to shrinkage of the product. On the other hand, uniform pore formation opposes the destructive phenomena of shrinkage, and consequently, rehydration properties significantly increase.



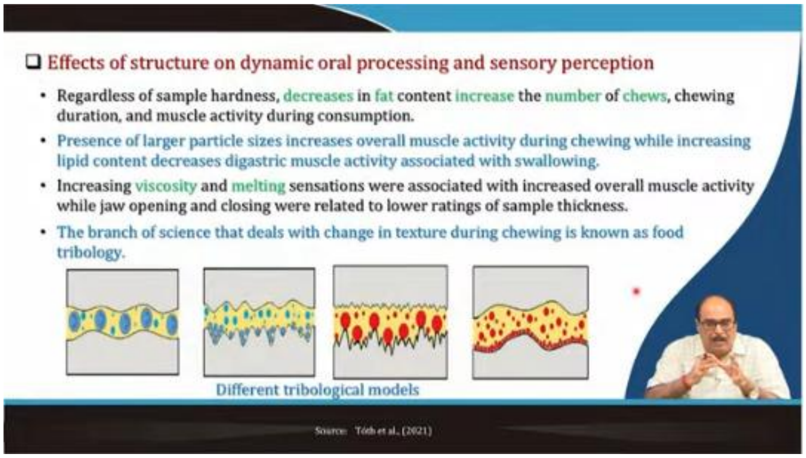
Then, thermal properties, as in porous solids such as foods, thermal conductivity depends mostly on composition and other factors such as void fraction, shape, size, and arrangement of void spaces, the fluid contained in the pores and homogeneity. Thermal conductivity in foods having a fibrous structure is different in different directions. Like heat flow paths through the material change with respect to the direction. The structural factors that influence thermal conductivity include porosity, pore size, shape, and distribution arrangement of the arrangement or distribution of different phases such as air, water, ice, and solids. The nutritional properties that the rate at which nutrient delivery evidently depends on the food structure as structure controls the diffusion of nutritional molecules. The complex structure of food may resist the bio-accessibility of nutrients as most of the nutrients remain either inside the cells or connected to the cellular matrix. So, disruption of the cellular matrix or microstructure created during processing may influence the release, alteration, and absorption of nutrients in the digestive tract.



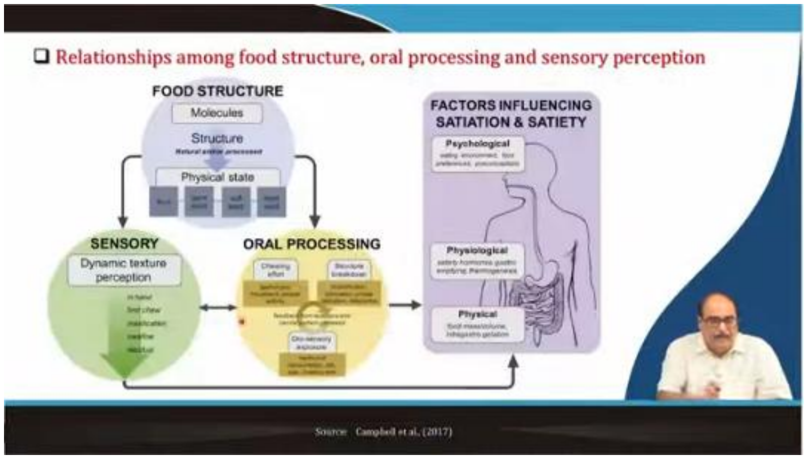
Here comes oral processing into the picture, that is, the structure of oral processing of food. So, oral processing involves the reduction of food products, particle size, and lubrication to form a bolus for swallowing. It starts from the first bite to complete swallow. Food undergoes progressive structural reorganization in preparation for swallowing. Like when you take any food, alright, that is in the hand. So, we just evaluate the food in the hand or even put it into the mouth, then evaluate its firmness and springiness, rate of recovery, etc. that is known as initial compression. That is how the surface is evaluated with the tongue, and the force deformation with the jaw movement, etc. When we put the food in the mouth, and with the movement of the jaw, etc. we feel something like food is hard, soft, liquid food, and all those things. Then, depending upon the type of food, either liquid food, you take the first sip, or solid food, you just bite it. That is first bite. So, by this bite, again, how much force you have to apply with your teeth, which is the firmness, hardness, deformity, fracturability, or number of pieces, etc., all these things. So, initial fracture and separation into pieces, you do it and then, after cutting it, after biting it, we chew the food, either 5 times, 8 times, 10 times, 12 times, depending upon hardness, firmness, etc. and then chewing. Further the food material's structure is broken down from its larger molecules to smaller. It comes to a degree of breakdown, cohesiveness, smoothness, adhesion to the teeth and gums, and all those things are done by chewing because, during chewing and mixing, it is also mixed with saliva and from it, it forms a bolus, and then finally it becomes something you can easily swallow. Now, it is swallowing, whether it is able to swallow or not. It will depend upon the number of chews, meltability, mouthfeel after swallowing, and all those things. All these properties because the food is in a different shape, and you are breaking it down in the mouth by chewing, and then it is changing its characteristic shape and becomes easily swallowable, and you can feel the taste also during this process.



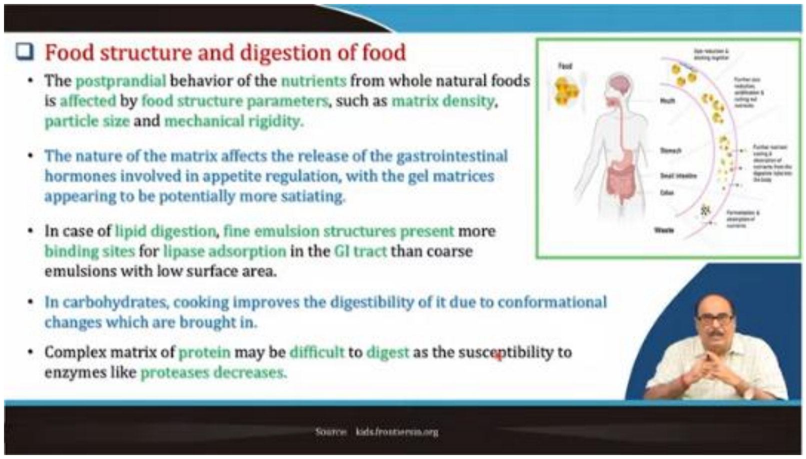
The structural transformation in soft and hard solids associated with sensory hardness or the formation of particles, that is the first bite and reduction of particle size, that is the number of chews. So, texture perceived in the mouth largely depends on the mechanical behavior of food. As mechanical properties determine the dynamics of the breakdown during eating. So, two main mechanical properties of food are the modulus of elasticity, known as young's modulus, and toughness, which is the force required to separate a given area, are found to be the indicators of the rate of food breakdown during mastication. In texture, food hardness is the most common and reliable variable used when isolating the effect of specific textural variables upon oral processing. In addition to hardness, other food attributes, such as deformability, adhesiveness, and moisture release, influence oral processing. Oral processing behavior is sensitive to specific structural differences within textural changes of soft and hard solid foods. So, different microstructures of protein and polysaccharide gels are associated with distinct oral processing patterns.



So, the effect of structure on dynamic oral processing and sensory perceptions. Regardless of sample hardness, a decrease in fat content increases the number of chews, chewing duration, and muscle activity during consumption. The presence of larger particles increases overall muscle activity during chewing, while increasing lipid content decreases digestive muscle activity associated with swallowing. So, increasing viscosity and melting sensations were associated with increased overall muscle activity, while jaw opening and closing were related to lower ratings of sample thickness. So, the branch of science that deals with the changes in texture during chewing is known as food tribology. You can see here different tribological models, etc., of food, which is how it behaves in the mouth.

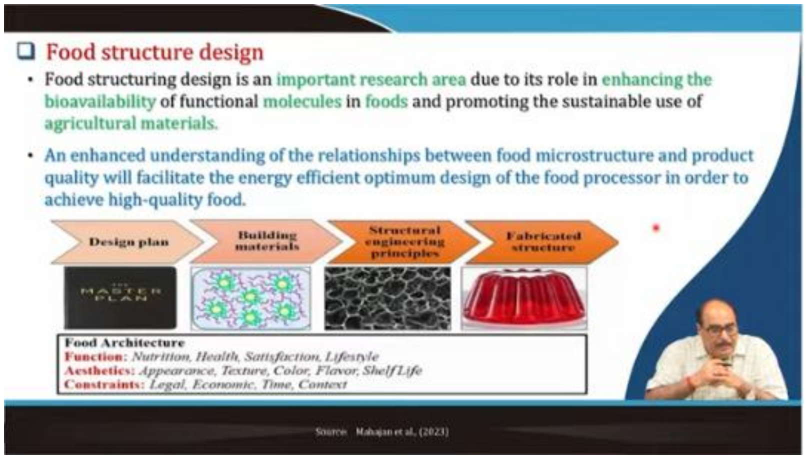


The relationships of food structure, oral processing, and sensory perception, you can see in this slide. That is the food structure or the macromolecular structure, natural or processed food. It defines its physical state, whether it is a fluid, semi-solid, soft solid, or hard solid. All these are its structure. So, all these structures will influence both its sensory characteristics and oral processing. That is oral processing, like chewing effort, Jaw, tongue movement, muscle activity, etc. If it is a hard solid, you have to bite it, you have to chew more, etc. or if it is a liquid form, you do not need to bite, you just have to sip and put it into the mouth, mix with other ingredients, etc. It is structural breakdown, communication, lubrication, phase breaking, and also oral sensory expenditure, like method of consumption, bite size, chewing rate, all these things that is oral processing rate, will influence the food structure and also the food structure's sensory characteristics, dynamic texture perception, that is in hand, first chew, mastication, swallow, and these both sensory characteristics, and oral properties, they are all interrelated, and this food texture. Finally, further, after the oral processing, when it comes into the mouth, as well as sensory perception, this influences the satiety, physiological, eating environment, food preferences and perceptions, then physiological due to satiety hormones, gastric emptying, the thermogenesis and even the physical aspects, such as food mass, volume, intragastric relations, and all those things, that is how they affect food. Accordingly, some food may be easily digested, while some may not be digested, depending on your preferences. So all these physiological psychological and physical factors influence food, the food structure, oral processing, and sensory perceptions, all of which are closely interrelated. Then they finally influence the utilization of food in our system, the digestion process, and, ultimately, after digestion, the utilization of these nutrients for various purposes in the body is influenced.

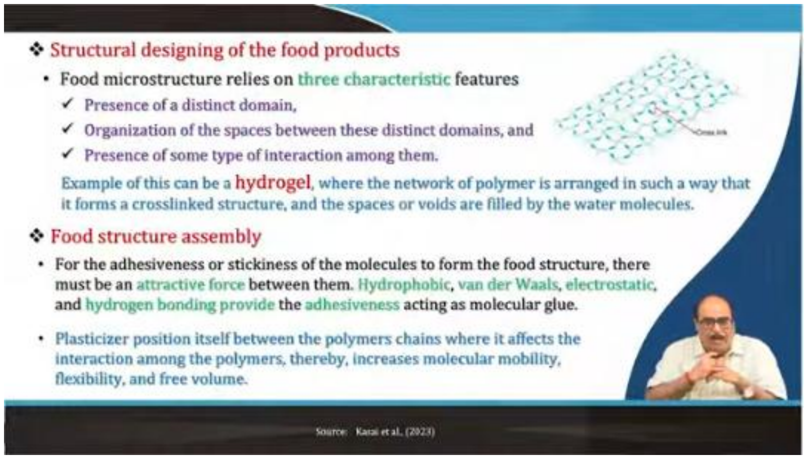


Food structure and digestion of the food: You know that when you take any food, digestion starts from the mouth itself. In the mouth, size reduction and sticking together take place, etc. and you break it down, and then from the mouth, it comes through the esophagus. It comes into the stomach, and in the stomach, there is further size reduction. There may be acidification and extraction of the nutrients, etc., here because in the stomach, a highly acidic environment is present, and then from there it comes to the small intestine, where further nutrient breakdown and absorption of nutrients from the digestive tube into the body take place in the small intestine and, finally, it comes to the Colon, where fermentation and absorption of nutrients take place. In this way, those which were earlier broken down, finally, comes out of the colon as waste material. So, these are the steps in how the food system passes inside. The post-digestive behavior of the nutrients from whole natural foods is affected by the food structure parameters such as matrix density, particle size, and mechanical rigidity. The nature of the matrix affects the release of gastrointestinal hormones involved in appetite regulation and with the gel matrices appearing to be potentially more satiating. In the case of lipid digestion, the fine emulsion structures present more binding sites for lipid absorption in the GI tract than coarse emulsions with low surface area.

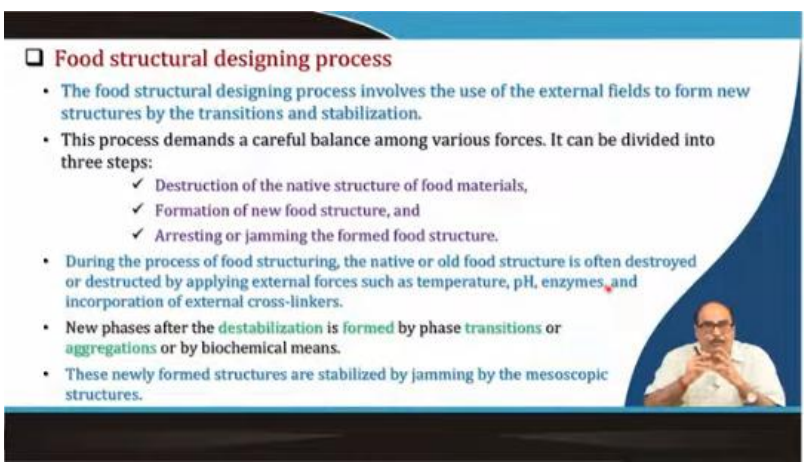
In carbohydrates, cooking improves the digestibility of it due to the conformational changes that are brought in. The complex matrix of protein may be difficult to digest as the susceptibility to enzymes like proteases, etc. decreases. Because of all these things when you take food, depending upon the food structure, you have to break it down into small, so that when it comes into the stomach, when it comes into your large intestine or small intestine, it is properly mixed and properly digested. It should have good digestibility, and it is a macromolecule that is disintegrated and absorbed. Therefore, the structure is very important. If you take just whole material and if you do not chew it, if you do not break it, and take the whole food, swallow it directly without chewing you con not digest it, and it can pass directly through the bowel, or you may experience trouble also during that.So, when food becomes processed, the structure of the food biomolecule, or what structure it forms during processing, that also influence the digestion of the food.



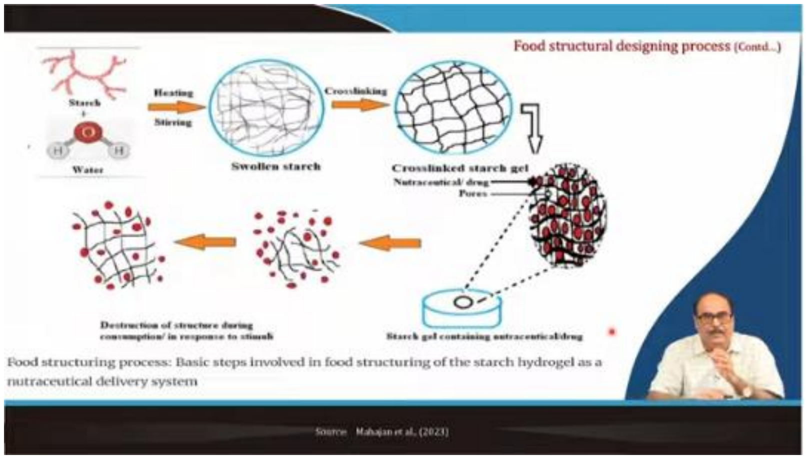
Food structure design is an important research area due to its role in enhancing the bioavailability of functional molecules in food and promoting the sustainable use of agricultural material. An enhanced understanding of the relationship between the food microstructure in the product and product quality will facilitate the energy-efficient optimum design of the food processor in order to achieve high-quality food, and you see that food architecture, like anything, even in building architecture, what you do first is you have a plant design plan then you have building materials, then you understand the structural engineering principles, and then finally, you fabricate the structure. So, in a similar manner, you have to do the same in the case of food as food architecture, which means first, you take the food, you select the food based on nutrition, health, satisfaction, lifestyle, etc., then food function, then aesthetics like its appearance, texture, flavor, color, and all those things in the material, and then structural design. Finally, there are the various constraints like legal, economic, time, context, and then you fabricate the food and use this food, etc. These are the food architecture function, aesthetics, and constraints and the basis of that you take the proper ingredient, shape it into different desirable forms with good digestibility, good color, good shape, and utilize it.



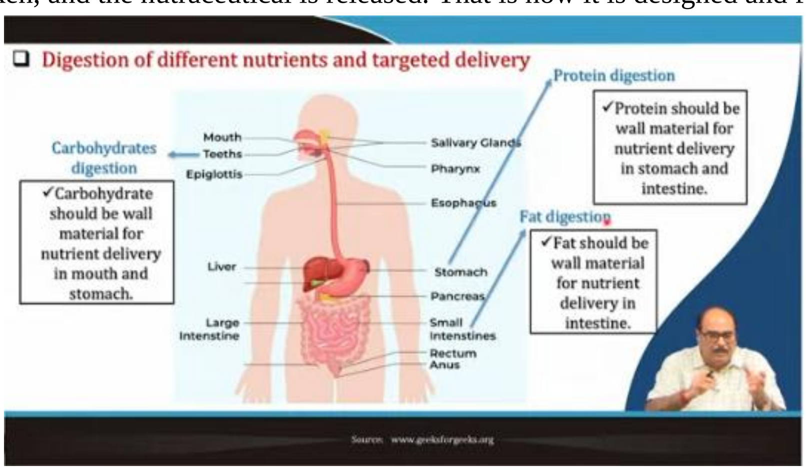
The food structure design: The structural designing of the food part, that is food microstructure, relies on three characteristic features; one, the presence of a distinct domain, the organization of the spaces between these distinct domains, and the presence of some type of interaction among them. The example of this can be seen in a hydrogel where the network of polymers is arranged in such a way that it forms a cross-linked structure and the void spaces inside are filled with water molecules. So, that is the presence of distinct domains, the organization of spaces between these distinct domains, and the presence of some type of interaction among them. So, for the food structure assembly for the adhesiveness or stickiness of the molecules to form food structure, there must be an attractive force between them. Hydrophobic interactions, electrostatic interactions, hydrogen bonding—all these provide the adhesiveness, acting as molecular glue. So, plasticizers position themselves between the polymer chains, where they affect the interaction among the polymers and thereby increase the molecular mobility, flexibility, and free volume.



Now for the food designing, the food structural designing process involves the use of external fields to form new structures through transition and stabilization. The process demands a careful balance among various forces. It can be divided into three steps: destruction of the native structure of the food material, formation of an altogether new food structure, and arresting or jamming the formed food structure. So, during the process of food structuring, the native or old food structure is often destroyed or destructed by applying external forces such as temperature, pH, enzymes, and the incorporation of external cross-links. New phases after the destabilization are formed by phase transitions, aggregation, or by biochemical means and these newly formed structures are stabilized by jamming through the microscopic structures.

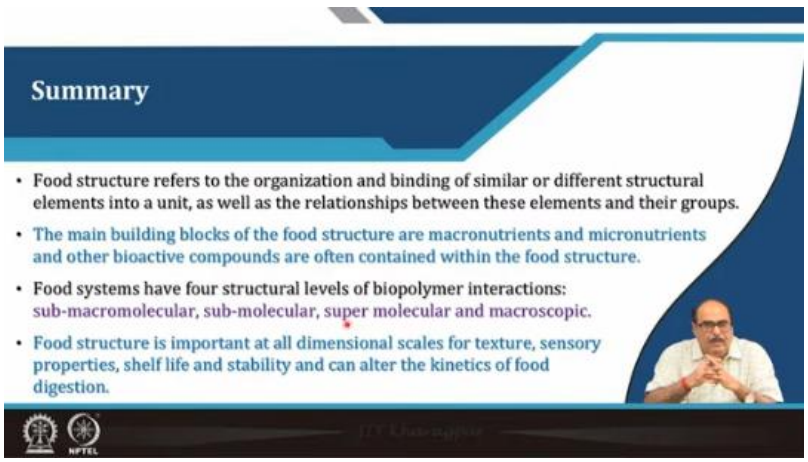


As you can see here, that is structural designing of starch and water mixture. When you heat and stir, then the starch molecule swells mean starch takes the water during the gelatinization process, and water molecules are entrapped into it. There is cross-linking, and cross-linked starch gels are part of the nutraceutical or drug processing and then starch gel forms which containing nutraceuticals, undergoes gelatinization. That is the drug here, and then when it is cooled down, there is a structure of starch during consumption or in response to stimuli—all those are these gels. So, that is the basic steps involved in food structuring of the starch hydrogel as a nutraceutical delivery—that is how it is done. So, whether it is a hydrogel here, a nutraceutical, or a drug, these are entrapped in this cross-linked gel structure, and when you eat or consume it, the gel structure is disturbed, broken, and the nutraceutical is released. That is how it is designed and formed.



Similarly, here you can say that digestion of different nutrients and targeted delivery, if you want, such as in the mouth, teeth, and epiglottis. Here, normally the carbohydrates are digested; the carbohydrate digestion takes place here. So, the carbohydrates would be the wall material for nutrient delivery in the mouth and stomach. If you want, that can be called a microencapsulation or any structural formulation technology you are using. So, this wall material should include a carbohydrate material if you want that particular nutrient to be delivered in the mouth or stomach. Then it comes to protein digestion, as protein digestion generally takes place in the stomach. So, the protein should be the wall material for nutrient delivery in the stomach and in the intestine. Similarly, fat should be the wall material for nutrient delivery in the intestine because fat is normally digested in the intestine. So, in this way, you can take into account that if you are designing for targeted nutritional delivery, these are the various details accordingly, one should select the biomaterial and go for the designing of the food structure.

Finally, we can summarize that food structure refers to the organization and binding of similar or different structural elements into a unit, as well as the relationship between these elements and their groups. The main building blocks of the food structures are macronutrients, micronutrients, and other biotic compounds and they are often combined within the food structure.



Food systems have four structural levels of biopolymer interactions: submolecular, submacromolecular, supermolecular, and macroscopic. Food structures are important at all dimensions and scales of texture and sensory properties, Shelf life, stability, and the kinetics of food digestion can be altered, etc. So, accordingly, the designing of a food structure, that is proper design, etc., whether it is a fog, aerosol, emulsion, hot structure, fibrous structure, fleshy, it becomes very important as far as digestibility, keeping quality, shelf life, other safety, other characteristics, both organoleptic and sensory characteristics, chemical characteristics, nutritional and functional characteristics are all influenced by the structure and design of the food.

These are the references used in this lecture.

Thank you very much.