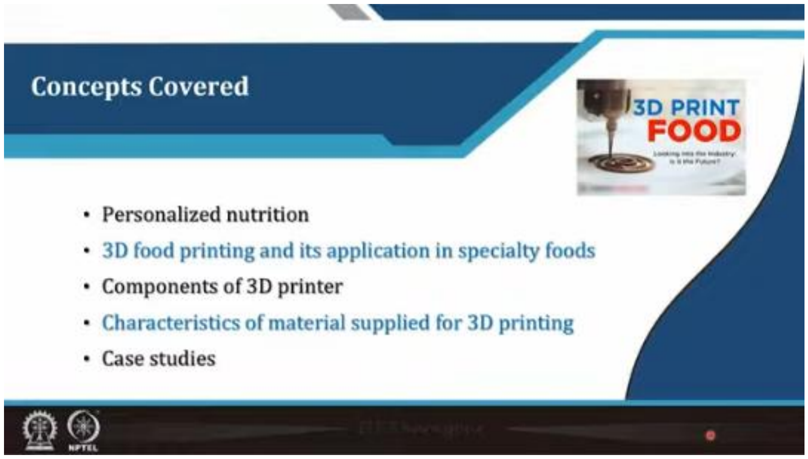
FOOD SCIENCE AND TECHNOLOGY

Lecture50

Lecture 50: 3D Printed foods for personalized nutrition

Hello everyone, Namaste.

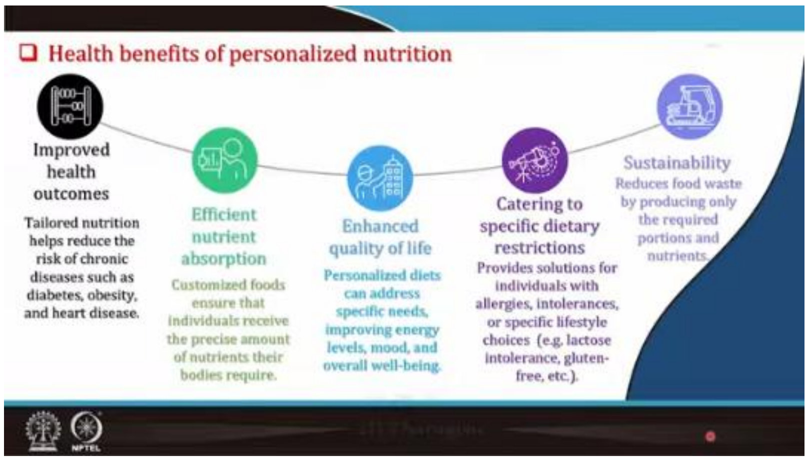
Now, we are in the last lecture of the tenth module. In this lecture today, we will talk about 3D printed foods for personalized nutrition.



We will discuss what personalized nutrition is, 3D printing, and its application in specialty foods. Components of a 3D printer, characteristics of the material supplied for 3D printing, particularly food materials which are suitable for 3D printing, and then we will also take one or two case studies in this regard.

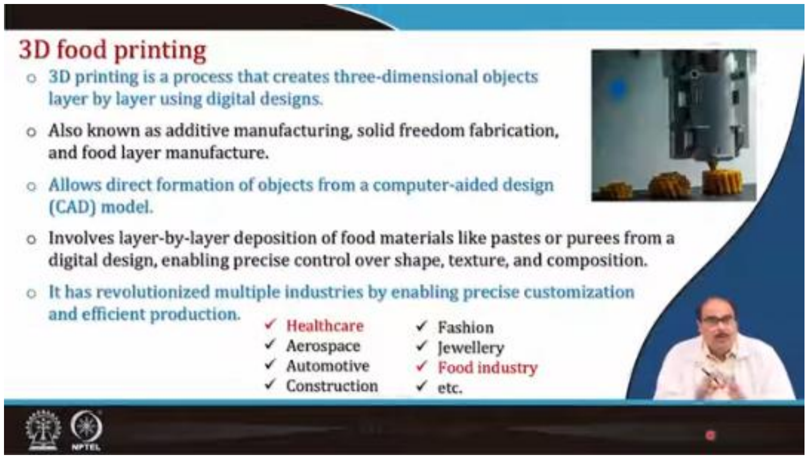
So, let us talk briefly about personalized nutrition. In the earlier class, we discussed some of the specialty foods, or designer foods, their formulation, design, processing, etc. So, here, basically, these personalized nutrition strategies formulate nutritional strategies based on individual characteristics to prevent, manage, and treat diseases while promoting overall health. So, the specific foods are designed foods in the earlier class that we discussed, which are basically focused towards personalized nutrition.

So, unlike broad one-size-fits-all guidelines for healthy eating, personalized nutrition looks at factors such as one's unique metabolism and specific needs to create nutrition advice that is tailored for that individual, he or she. Personalized nutrition aims to optimize health and well-being by delivering food that aligns with the personal dietary needs of a particular individual, as well as what the goals are, that is, what type of food a person needs. What specific characteristics, health-promoting characteristics, disease-preventing characteristics, or such other gut-modulating characteristics, that type of thing is what an individual want. So, those characteristics are infused in that food, and that is why we say it is food for personalized nutrition. So, obviously, it has several health benefits.



Now, let us briefly discuss the health benefits of personalized nutrition. Obviously, as the name itself indicates, it results in improved health outcomes. Tailored nutrition helps reduce the risk of chronic diseases such as diabetes, obesity, and heart diseases, etcetera. Customized foods ensure that individuals receive the precise amount of nutrients their body requires. Also, personalized nutrition enhances the quality of life. Personalized diets can address specific needs, improving energy levels, mood, and overall well-being.

So, personalized nutrition provides solutions for individuals with allergies, intolerances, or other specific lifestyle choices like lactose intolerance, gluten-free diets, and so on. And more importantly, personalized nutrition contributes significantly to sustainability. It reduces food waste by producing only the required portions and nutrients that are in the foods.

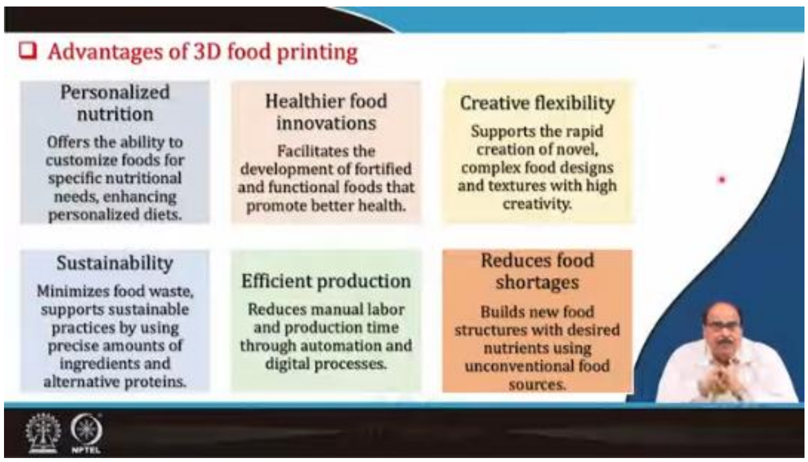


So, now, let us discuss 3D food printing: what is 3D printing? 3D printing is a process that creates three-dimensional objects layer by layer using digital designs. Also, it is known as additive manufacturing, solid freedom fabrication, and food layer manufacturing. It allows direct formation of objects from a computer-aided design model. It involves layer by layer deposition of the food materials like pastes or purees from a digital design, enabling precise control over shape, texture and composition of the food that finally what you want. 3D food printing has revolutionized the multiple industry that is 3D printing particularly. It has revolutionized multiple industries like healthcare industry, aerospace, automotive, construction, fashion, designing and particularly the food industry itself.

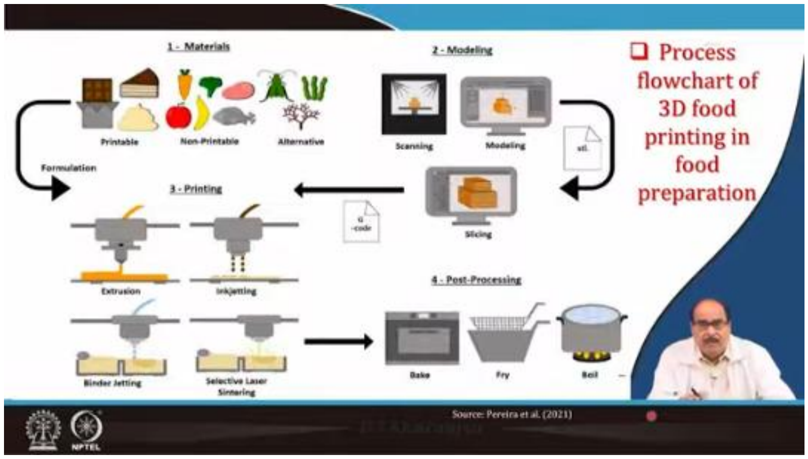
So, the healthcare industry and food industry are the major focus of our lecture here today that means, it the 3D food printing enables precise customization and efficient production of the health foods or personalized nutrition foods and so on.

So, if you look at the global scenario, we find that 3D food printing market is increasing very fast. In 2023, the 3D food printing market was valued at 1 billion US dollar and it is projected to reach around that 3.77 billion US dollar by 2032 and therefore, the projected growth from 2024 to 2032 is proposed to be to be supposed to be at around CAGR of 15.89 percent very fast-growing sector.

So, the market is experiencing substantial growth that is driven by rising demand for personalized nutrition, the emergence of sustainable and functional foods and advancements in edible manufacturing technologies and this has lead. So, when we talk about personalized nutrition, customized nutrition, 3D food printing is the answer.



So, advantages of 3D food printing basically as I told you it can create, it helps creating food for personalized nutrition, offers the ability to customize foods for specific nutritional needs, enhancing personalized diets. It facilitates the development of fortified and functional foods that promote better health. It supports the rapid creation of novel, complex food designs and textures with high creativity. 3D food printing minimizes food waste and supports sustainable practices by using precise amounts of ingredients, alternative proteins, etc. It reduces manual labor and production time through automation and digital processes, which is key in 3D printing. It also reduces food shortages, as 3D printing builds new food structures with desired nutrients using unconventional food sources.

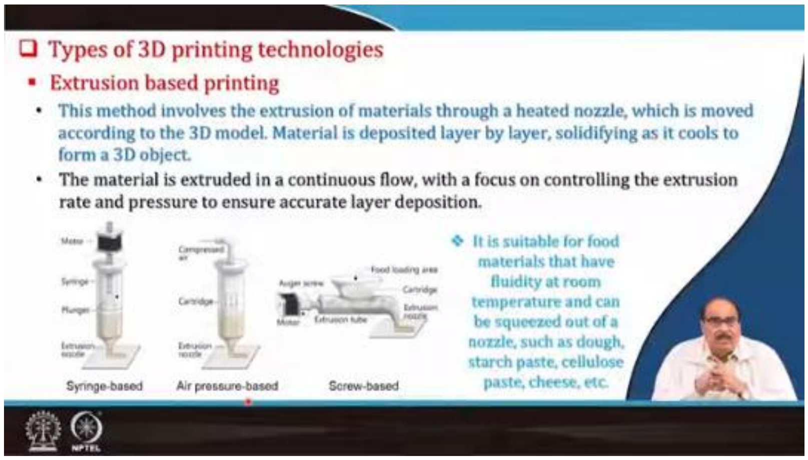


So, if you look at the process flow, that is how one approaches 3D food printing preparation and 3D-printed food production. The first step is to find and select a suitable material, which I will discuss later. There are different types of materials, and obviously, they must be printable. They should have certain characteristics, which we will discuss later. There are also non-printable materials or alternative materials.

Using suitable processing or techniques, they must be converted into a printable form. Once you have selected the ingredients, you proceed to formulation and design processes, as discussed in the earlier class. You must determine the desired outcome of the food, its contents, and its purpose. All these factors require a proper design and an optimal formulation. Once the optimal formulation is selected, it should be routed through the computer for modeling. Means that is you decide that is you give this input and then what type of structure you want, what type of shape you want, what type of 3D matrix you want.

So, all those things like maybe scanning, modeling, slicing etcetera generating computer code. So, that the computer gets a complete information or the controller you can say that, it gets complete information that how to operate the footprint and how it gives the material as well as other inputs to the printer. Then finally, it goes for the 3D printing and the printing may be different types of printer either extrusion, ink jetting, binder jetting, selective laser sintering etcetera that we will discuss again little later little detail of these printers.

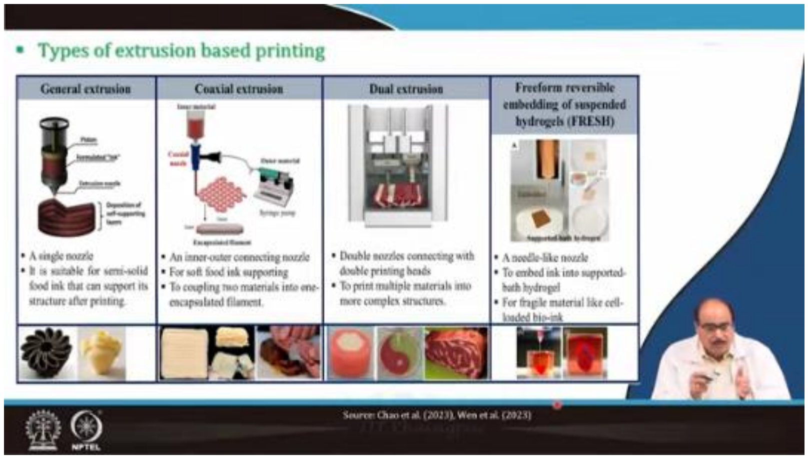
And then finally, the next or last step you can say that the post processing operations, may be some of the 3D printing printed foods might required other operations like baking, frying, boiling, cooking etcetera so that. So, these are the material then modeling, printing and post processing. So, these are the four major main steps or stages of 3D food printing process.



So, let us discuss what are the different types of 3D printing technology and first which is the most commonly used technology for the 3D printing of the food materials is the extrusion-based printing. So, this method basically involves the extrusion of material through a heated nozzle, which is moved according to the 3D model that you have already selected and decided. And then material is deposited layer by layer solidifying as it cools from a 3D object.

The material is extruded in a continuous flow maybe it might be having a syringe based or even air pressure-based system in the syringe base, you see the material there is a motor and with the help of the syringe it is pressed and then there is a extrusion nozzle here. So, it comes out of that nozzle and give the shape, desired shape obviously, that model dictates the machine to do that job. In the case of air pressure based that is basically the compressed air is used to press the material through the extrusion nozzle.

And then screw based in conveyors is that is normal auger screw conveyor, extrusion tube with that food loading area, then it is sent to the cartridges and finally, comes to the extrusion nozzle. Means, the material is extruded in a continuous flow with a focus on controlling the extrusion rate and pressure to ensure accurate layer deposition. And this extrusion-based printing is suitable for food materials that have fluidity at room temperature and can be squeezed out of a nozzle such as dough, starch paste, cellulose paste, cheese etcetera. These types of materials are better suited for the extrusion-based 3D printing.

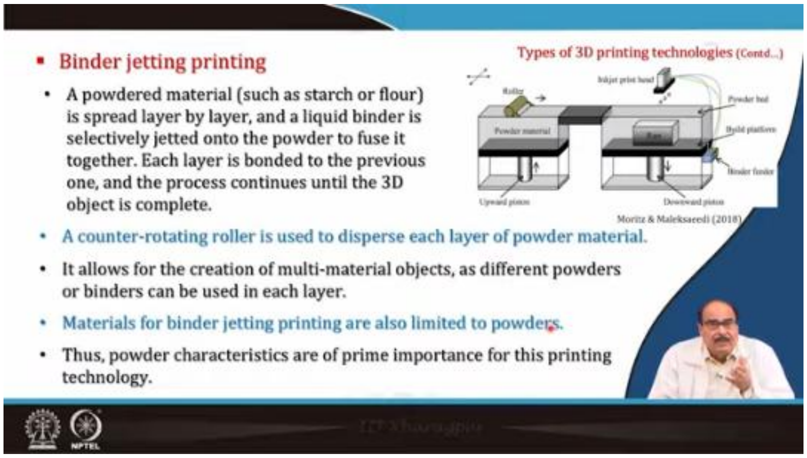


So, the different types of extrusion-based 3D printing may be general extrusion, coaxial extrusion, dual extrusion or freeform reversible embedding of suspended hydrogel that is FRESH extrusion process.

In the general extrusion, you know that there is a piston here that formulated ink is there and then it is pressed through the extrusion nozzle. Means that is here a single nozzle is working all right and it is suitable for semi solid food ink that can support its structure after printing. You can see here in the you can get different designs etcetera that you have already modeled earlier. Then, in the coaxial extrusion there are it has an inner and outer connecting nozzle.

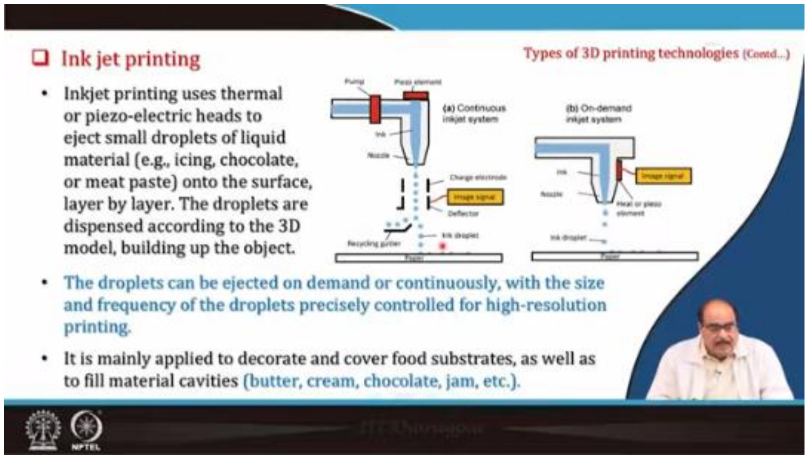
This is the inner material is there coaxial nozzle and the outer material there is a syringe pump. So, the inner material is coming and then outer material is there and both of them there is a pass through again through the model and then it comes to the. Basically, it is useful for soft food ink supporting and it is used to coupling two materials into one encapsulated filament as you can see here encapsulated filament that is inner material is there outer material is there. Then in the dual extrusion there are double nozzles which connect with the double printing heads.

Double nozzles with double printing heads and these are used to print multiple materials into more complex structures as you can see here in the figure etcetera that various snacks every item and all those things, where even the multiple layers multiple structures more complex can be used by making dual extrusion process. Then FRESH extrusion means that is here, there is a needle like nozzle and it is used to embed ink into the supported bath hydrogel, here. So, nozzle is used to embed materials or ink food materials into the bath like hydrogel and it is normally used for fragile material like cell loaded in bio ink and so on.



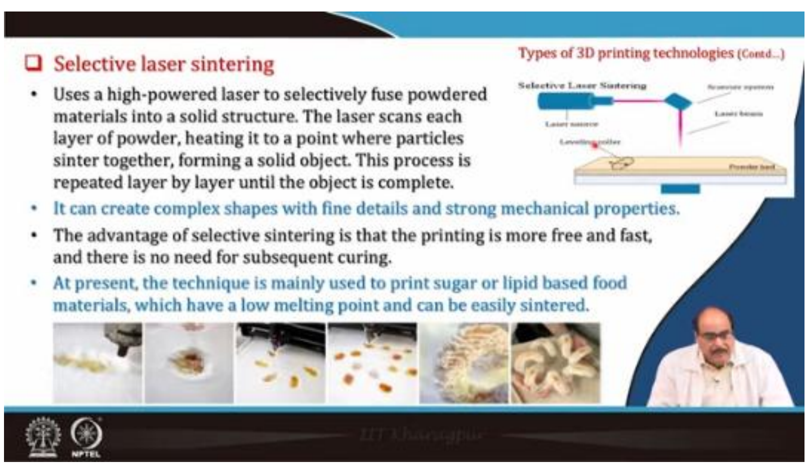
Now, the other type of food printing. 3D printing machine is the binder jetting printer or binder jetting printing. So, here as you can see in this figure, a powdered material such as starch flow or such other material is sprayed layer by layer and a liquid binder is selectively jetted onto the powder to fuse it together. So, each layer is bounded to the previous one and in the process that the process continues until the 3D object is complete.

So, a counter-rotating roller is used here to disperse each layer of powder material. It allows for the creation of multi-material objects as different powders or binders can be used in each layer. The materials for binder jetting printing are also limited to powders. Thus, the powder characteristics are of prime importance for this type of printing technology. Next is the inkjet printing.



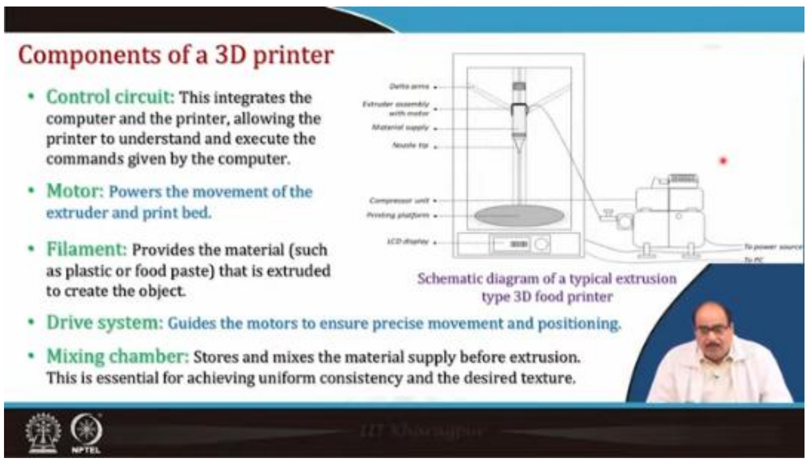
Inkjet printing uses thermal or piezoelectric heads to eject small droplets of liquid materials, for example, icing, chocolate, or meat paste, etc., onto the surface of the food material layer by layer. The droplets are dispersed according to the 3D model of the object. This can be done by ejecting droplets on demand with an on-demand inkjet system, or they can be injected continuously, with the size and frequency of the droplets precisely controlled for high-resolution printing.

It is mainly applied to decorate and cover food substrates, as well as to fill material cavities. For example, cream, chocolates, jams, etc., can be used as fillings in food materials or even as toppings on items like pizza, pie, cake, etc. Thus, this type of inkjet printing is found more suitable. Then comes selective laser printing.



Selective laser printing uses a high-powered laser to selectively fuse powdered materials into a solid structure. There is a sensitive laser sintering process. Here, the scanner system is present. So, the laser beam is coming, and there is a leveling roller here. The laser scans each layer of powder, heating it to a point where particles sinter together, forming a solid object. This process is repeated layer by layer until the object is complete or the material is fully used, resulting in the desired structure. It can create complex shapes with fine details and strong mechanical properties.

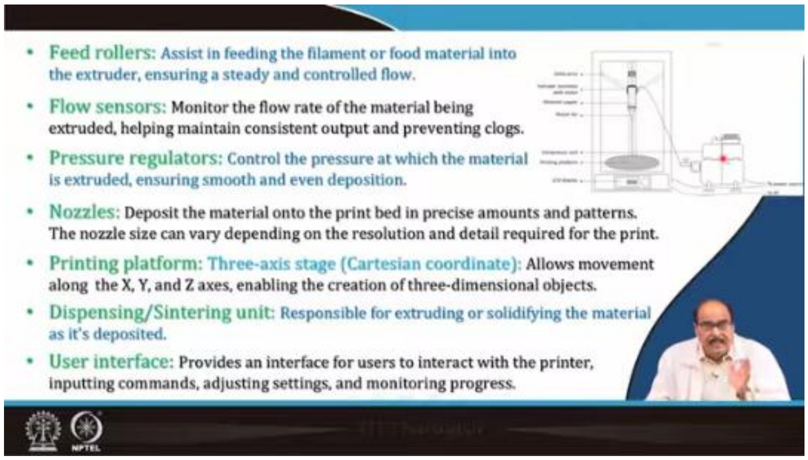
The advantage of selective laser sintering is that the printing is faster and more flexible, and there is no need for subsequent curing with such materials. Currently, this technology is mainly used to print sugar or lipid-based food materials, which have a low melting point and can be easily sintered. So, these are the selective laser-based sintering methods. Now, let us talk about the components of a 3D printer.



Whatever printing methods you are going to use, so, obviously, it must have a complete computer system, including a computer with a circuit power supply system for modeling. It has sensors, such as temperature and pressure sensors, as well as nozzles and an LED/LCD display, etc. So, particularly very important is the control circuit. This circuit integrates the computer and the printer, allowing the printer to understand and execute the commands given by the computer. That is the model, etc., such as what type of food you want, what lattice designs you prefer, and what structures are needed, etc.

All those who want, as we discussed earlier, are fed to the computer, and this computer, via the control circuit, gives the required inputs to the printer. So, the motor that powers the movement of the extruder and the print bed, now that is how it will move, etcetera, is supported by a suitable motor system. Then there are filaments that provide the material, such as plastic or food paste, etcetera, which is extruded or printed to create the object.

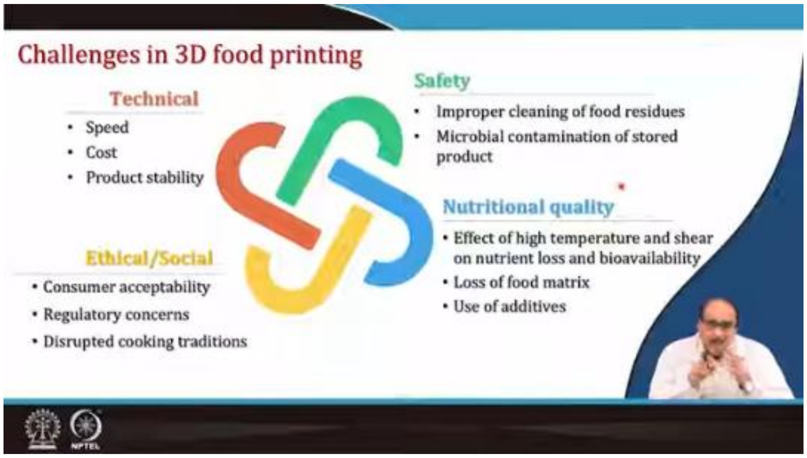
Then there is a drive system that guides the motor to ensure precise movement and positioning of the printer or nozzle, etcetera. Then, the mixing chamber stores and mixes the material supply before extrusion or before sending it to the 3D printing device. This is essential for achieving uniform consistency and the desired texture of the final 3D printed product.



Then there are feed rollers, as you have seen in the earlier systems. These rollers assist in feeding the filament or food materials onto the extruder or such other system, ensuring a steady and controlled flow. There are flow sensors that monitor the flow rate of the material being extruded, helping maintain consistent output and preventing clogs. Pressure regulators control the pressure at which the material is extruded or printed or shaped, ensuring smooth and even deposition.

Then there are nozzles that deposit the material onto the print bed in precise amounts and patterns, that is very important in the precise nutrition we are doing, precise amounts and patterns. The nozzle size can vary depending on the resolution and detail required for the printing. Then there is a printing platform, you can see here, meaning there is a three-axis stage with Cartesian coordinates, and this allows the movement of the material. That is along the X, Y, and Z axes, and therefore, enabling the creation of a three-dimensional object, that is, you can say, the heart of the device. Then, dispensing and sintering units, these are responsible for extruding or solidifying the material as it is deposited.

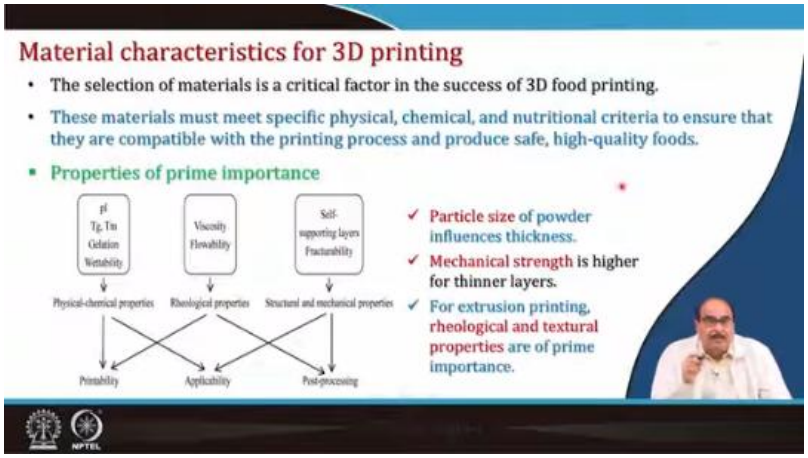
and then user interface that is the LED screen etcetera, LCD display and all those things and all those other user interface materials that provide an interface for user to interact with the printer. input giving or inputting the commands, adjusting setting and monitoring the progress etc. because that is very very important. We want that is it is a customized food for customized nutrition food that is a let us say 1 gram of that food or 10 grams of that food, how much in micro level etc. the particular nutrients, particular component bioactive and other things are having there that can be properly regulated here. So, that is the beauty of this whole system.



However, there are as usual with every process there are also certain challenges in the 3D food printing like first thing is the major technical challenge like the speed of the printer that is different machines that should match with the size of the printing etc., speed and then cost is another factor. Product stability that is 3D printed food, how it is stable particularly the design lattice that is made on the 3D surface that is it must be stable. Printer in the nozzles because in the nozzle etcetera have very small might have very small opening etcetera. So, that becomes another challenge otherwise if it is not properly cleaned. there will be microbial contamination of the stored product etcetera. So, that is again a little challenging.

Then, nutritional quality means the effect of high temperature and shear on nutrient loss and bioavailability. Like sometimes, we need to create pressure and temperature, high temperature, in order to achieve the particular design. So, that may have an adverse effect on the product, or even in the post-printing process, some cooking or other treatments like baking, etc., whatever is applied. So, that may have some effect on the loss of nutrients and bioavailability, which has to be taken care of. There will be a loss of food matrix, or if you want to use additives, etc., that again creates one.

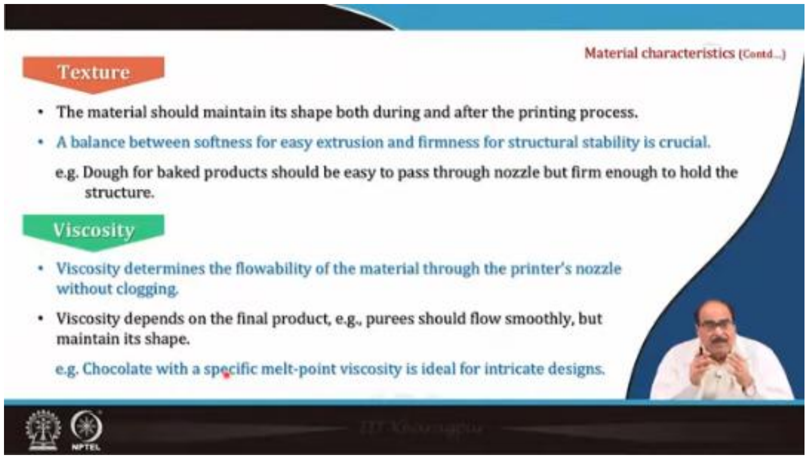
There are ethical or social concerns, like consumer acceptability of 3D-printed foods, regulatory issues, or disrupted cooking traditions, etc. These are some of the social and ethical challenges.



So, the material characteristics, if you talk about 3D printing, obviously, it is the heart of the system. The selection of materials is a critical factor in the process of 3D food printing. The materials must meet specific physical, chemical, and nutritional criteria to ensure they are compatible with the printing process and produce safe, high-quality foods.

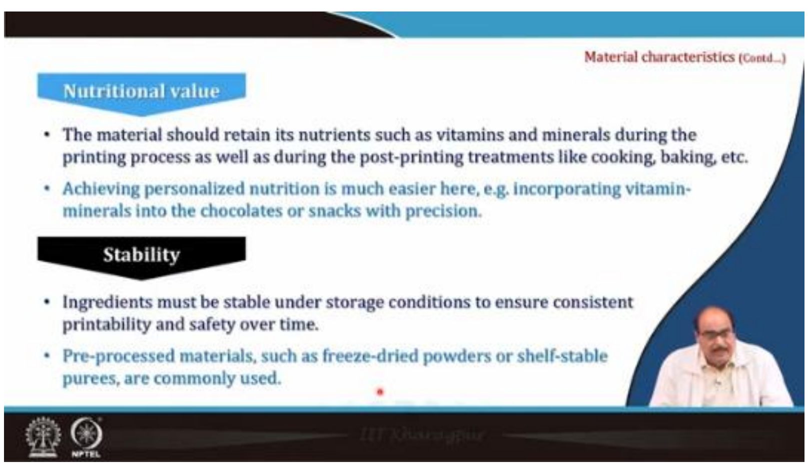
So, the properties of prime importance here may be physicochemical properties such as TG, gelatin, wettability, etc. Rheological properties like viscosity, flowability, or structural and mechanical properties like self-supporting layers, fracturability, and all these properties, for example, physical and chemical properties as well as rheological properties will influence the printability of the material. The rheological properties and structural and mechanical properties will influence the post-processing parameters that might be required for that material. Then, physical and chemical properties and structural and mechanical properties again will influence the applicability of that particular material in the printing process.

And a few examples: if you want to take, like, particle size of powder influences the thickness of the layer that we are getting. Mechanical strength is higher for thinner layers. For extrusion printing, rheological and textural properties are of prime importance.

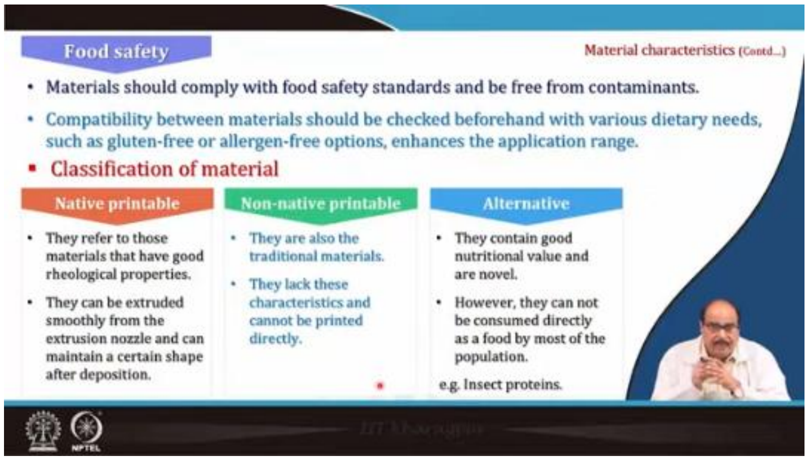


Then, if you take specific characteristics like texture, the material should maintain its shape both during and after the printing process. A balance between softness for easy extrusion and firmness for structural stability is crucial. For example, dough for baked products should be easy to pass through nozzles, but it should be firm enough to hold the structure.

Then, viscosity, viscosity determines the flowability of the material through the printer's nozzle without clogging, which is very important. Viscosity depends on the final product. For example, purees should flow smoothly but maintain their shape. So, what should the material viscosity be? It depends on what type of final product you desire. For example, chocolate with a specific melt viscosity is ideal for intricate designs.

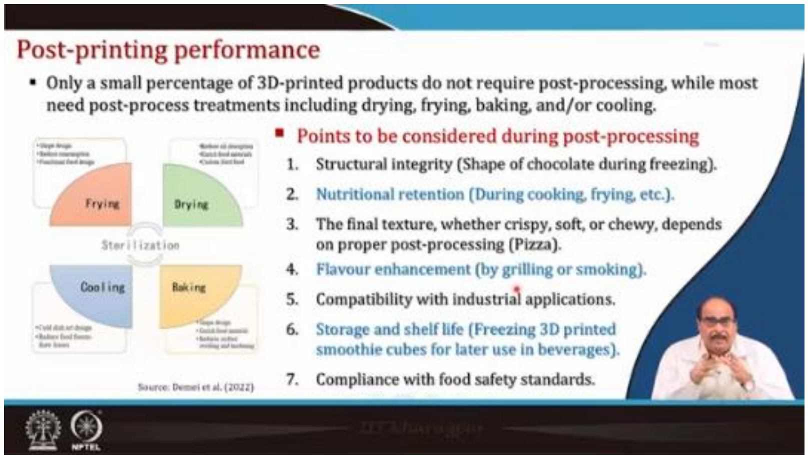


Then, nutritional value, obviously very important, the material should retain its nutrients, such as vitamins and minerals, during the printing process as well as during post-printing treatments like cooking, baking, etcetera. And achieving personalized nutrition is much easier here. For example, incorporating vitamin-minerals into chocolates or snacks with the precision that you can achieve here. Then stability, that is, ingredients must be stable under storage conditions to ensure consistent printability and safety over time. Pre-processed materials such as freeze-dried powders or self-stable purees are commonly used here, which have the particular characteristics.



Then again, like for any process here, food safety is important. Materials should comply with safety standards and should be free from contaminants. Compatibility between materials should be checked beforehand for various dietary needs. Such as gluten-free, allergen-free options, which enhance the application range.

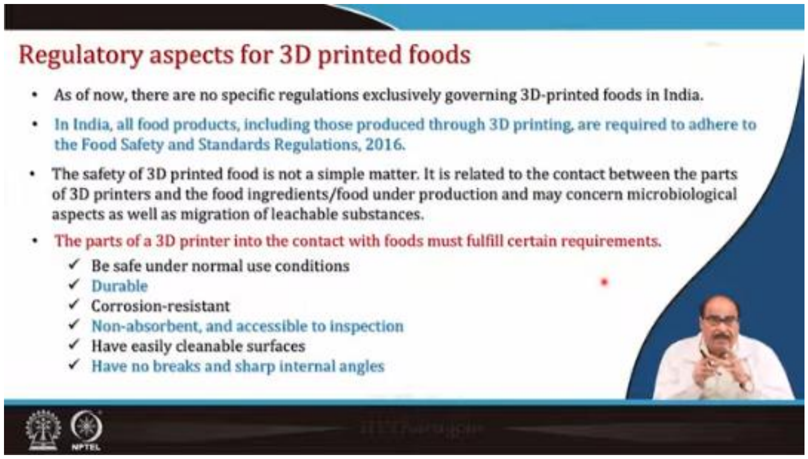
Then, accordingly, depending upon the requirement, such as printability, etcetera; The material can be classified into three categories: native printable, non-native printable, or alternative material. The native printables refer to those materials that have good rheological properties, that is, all the properties needed for printing, these materials have. They can be extruded smoothly from the extrusion nozzle and can maintain a certain shape after deposition. Non-native printable materials are also traditional materials, but they lack these characteristics which are required for printing purposes, and therefore, they cannot be used directly for printing. So, they have to be converted again into a printable form. Alternatives contain good nutritional value and are novel. However, they cannot be consumed directly as food by most of the population, for example, insect proteins, etcetera. So, again, they have to be converted into a suitable printable form.



Then, let us discuss post-printing performances. Like, only a very small percentage of 3D-printed food products at present do not require any post-processing treatment. However, most of the printed food at present, many of them definitely require some post-process treatment. like drying, frying, baking, cooling, cooking, and so on. That is, after the material is prepared using the 3D printer, depending upon the type of material, ingredients, its consistency, and other characteristics used, they may be subjected to various post-process operations. But one has to consider. There are certain important points that should be considered during post-processing of 3D-printed foods.

Number one is that the 3D print post-process treatment should be such that it retains the structural integrity of the material, like the shape of the chocolate during freezing. Then, nutritional retention during cooking, frying, etcetera. The final texture, whether crispy, soft, or chewy, depends on proper post-processing. Like, for example, in the pizza, whatever the crust you have got and whatever the layer that has been given, topping and all those things. So, the final texture, how it is subjected, how it is treated post-processing, that will influence.

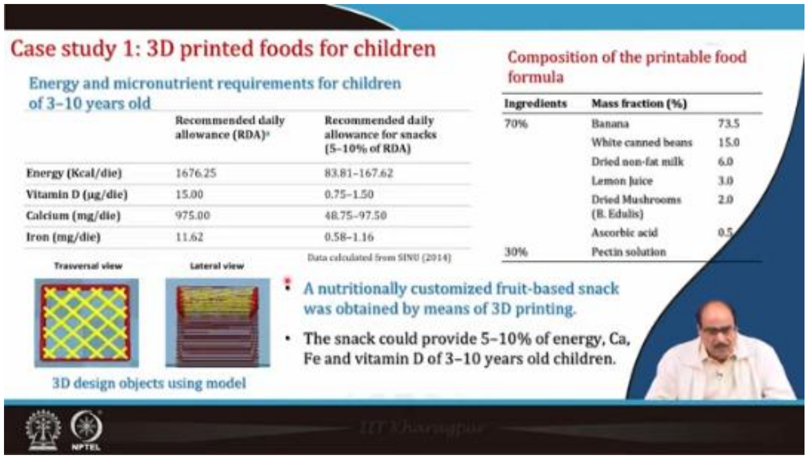
Then, flavor enhancement, like by grilling or by smoking, etcetera. Compatibility with industrial applications is very important, that is, 3D printed food which we have given should be compatible; that is, suppose in large-scale baking, conveying, etcetera. So, it should be consistent with those processes. Then, storage and shelf life of the 3D printed food, like post-processing. Freezing 3D printed smoothie cubes for later use in beverages, etcetera, and then compliance with food safety standards again. So, these are some of the points that must be considered during post-processing of 3D printed foods.



Regarding the regulatory aspects for 3D printed foods, let me tell you, as of now, there are no specific regulations exclusively governing 3D printing of foods in India. In other countries also, in many of the countries, there are no specific rules. However, most of the countries suggest that all these 3D printed foods, they must be treated like other food; that is, they must meet the safety and quality requirements of regulatory agencies like in India, it is the Food Safety and Standards Authority (FSSAI) rules of 2016. So, 3D printed foods also must conform to those regulations and standards. So, the safety of 3D printed foods is not a simple matter, you know, it is related to the correct contact between the parts of the 3D printers and the food ingredients.

Food under production and it may concern microbiological aspects as well as migration of the leachable substances' etcetera. The printer contact surface and food there is a. So, it may act as a potential if the printer is not properly cleaned and all those things. So, it may pose problems. So, it has to be seen the parts of the 3D printer into the contact with the food must fulfill certain requirements that is what are those requirements that is it should be safe under normal use conditions, it should be durable, it should be corrosion resistant.

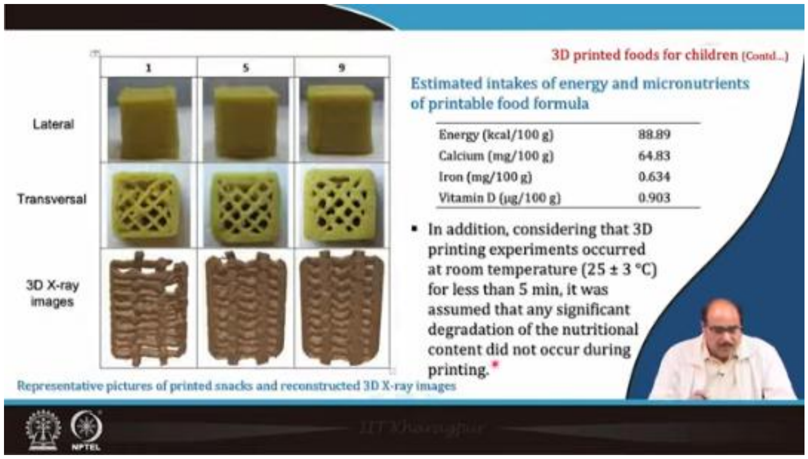
It is non-absorbent and accessible to inspection. It should have easily cleanable surfaces and it should have no breaks and sharp internal angles etcetera. So, now, let us take one or two case studies quickly for that.



So, that is the case study one for 3D printed foods for children. And you know that energy and micronutrient requirements for children of 3 to 10 years old and these are given in the regulations. So, that I have taken one. So, now, you need to that is that you want to give a child that is which should be like energy in a particular proportion calcium, it should be iron etcetera. Then you decide on the basis of that the ingredients, like your composition of the printable food formulation.

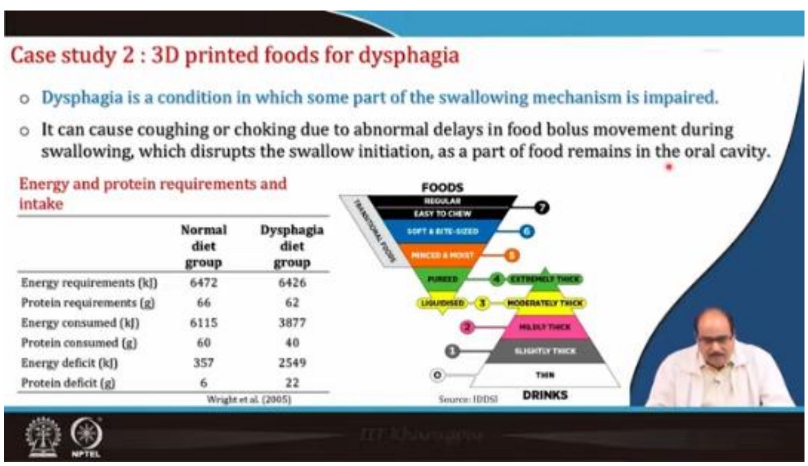
So, like ingredients one has selected for a snack that is a nutritionally customized fruit-based snack by 3D printing and it contains about 70 percent of the ingredient like a mass fraction banana, white canned beans, dried non-fat milk, lemon juice, dried mushrooms and ascorbic acid. And it is a proportion in the formulation it is given by mass fraction percentage like banana is 73.5 percent, white canned beans are 15 percent and similar. And 30 percent is the pectin solution in order to bring into the. desired consistency. So, that it can easily flow through the extruder.

So, the snack could provide which was made by 3D printing, it could provide 5 to 10 percent of energy, calcium, iron and vitamin D of 3 to 10 year old children.



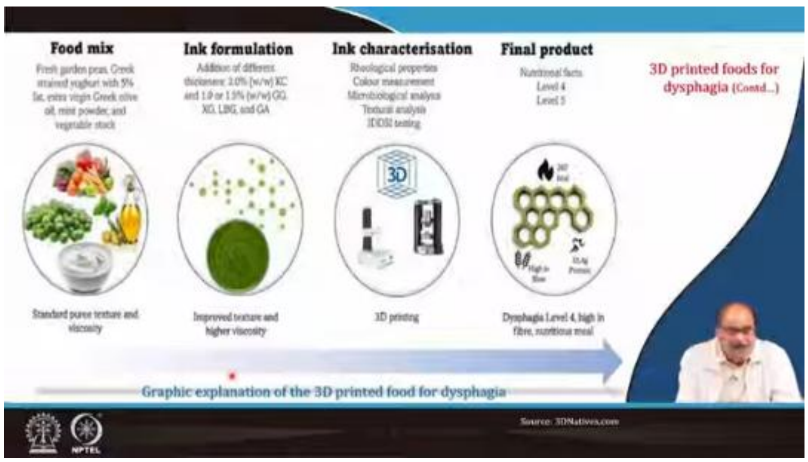
So, this is the view that is the material that were printed like lateral view, transversal view and 3D x-ray images, the respective representative pictures of the printed snacks. And the estimated intakes of energy and micronutrient of the 3D printable food formula was that energy 88.89 kilocalorie per 100 gram and accordingly calcium, iron and vitamin D also precise level, calcium that is 64.83 milligram per 100 grams of the material etcetera.

So, in addition to considering that 3D printing experiments occurred at room temperature in this case and far less than 5 minutes. It was assumed that there is no significant degradation of the nutritional content during the 3D printing or even post processing.



Similarly, we can take another case study for 3D printed foods for dysphagia. You know the dysphagia is a condition in which some parts of the swallowing mechanism are impaired. It can cause coughing or choking due to abnormal delay in food bolus movement during swallowing, and which disrupts the swallow initiation as a part of food retains in the oral cavity. So, energy and protein requirement and intake you can see for the normal diet and dysphagia diet. There it is energy requirement is 6472 kilo joules, then in the dysphagia diet it is little less 6427 kilo joules. Similarly, protein requirement if it is the 66 gram in the normal diet in dysphagia it becomes 62 because of these problems. And also, the energy deficit in the dysphagia food is the 2549 kilo calorie, where in the normal diet it is 357, and protein deficit is the 22 gram in the dysphagia group diet and 6 gram in the normal diets.

So, you have to again use the standard protocol that select the suitable ingredients, design it, give the command to the computer and get the material printed. So, here that is the for this dysphagia food.

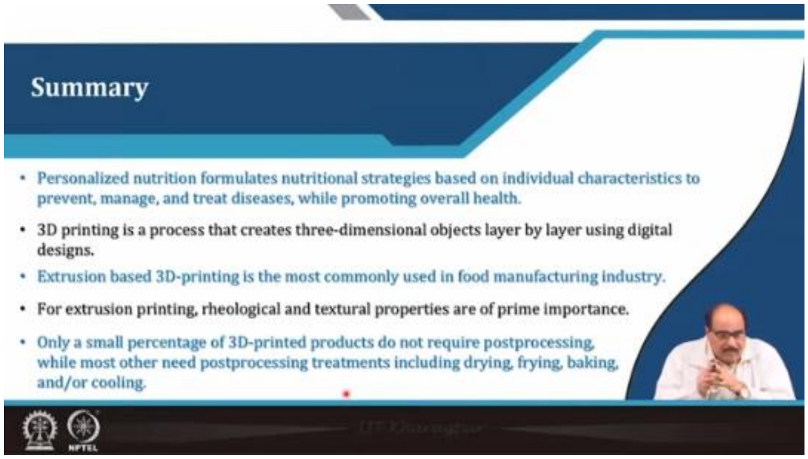


Graphic explanation of the 3D printed food for dysphagia. Number 1 that is you have to decide the ingredients and prepare the food mix that is it may include fresh garden peas, Greek strained yogurt with 5 percent fat, extra virgin Greek olive oil, mint powder and vegetable stock etcetera, and then this ink formulation that is addition of different thickeners like gums and other additives etcetera in maybe 1 or 1.5 percent weight by weight. Guar gum and such other binders or thickeners and all those things and you convert into paste etcetera for improved texture and higher viscosity material. And then this ink characterization, that is rheological properties, color measurement, microbiological analysis, texture, other testing etcetera is done for this, and then finally, it is given for the printing you get the dysphagia level 4 which is needed high in fiber and nutritional meals etcetera. So, you can see the level 4 or level 5, there it has 267 kilo calories 10.4 gram protein and high in fiber. So, this food is printed as per the requirement.

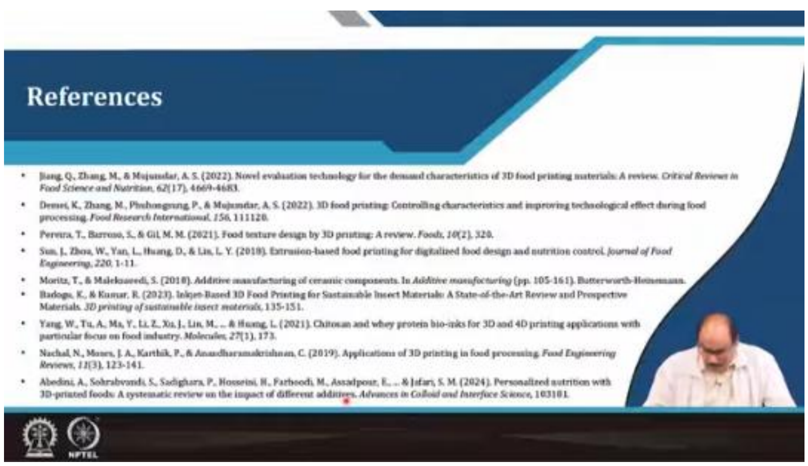
Then finally, let us briefly we will talk about the sustainability in the 3D food printing, that is, it is the future of food printing for the personalized nutrition, customized nutrition. As I told you earlier also, 3D food printing is the answer. It has a very bright future even now the 4D is has come into the practice. People are talking about 4D, 5D processes. Then 3D printing impacts, if you see it has a significant impact that is because it provides high flexibility, then this high flexibility will result in the no hunger or it will provide responsible consumption or even the number 13 is the climate action. And you know that there are such 17 development sustainable development goals set by the UN. So, these 3D printers would they fit into all these 17 or so many of these. Then market innovations like by number 9, number 1 and number 17 that is the partnership, number 9 is the innovation and infrastructure.

Similarly, that this 3D food printing, it gives the customized nutrition and therefore, is fit into the development goal number 2, number 3 and number 17. It customized sensory property that 3D printed foods offer food with the customized sensory property and therefore, it fits into the sustainable goal development goal number 3, number 2 and number 12. This it facilitates 3D printing foods facilitates on demand production. So, it fits into the sustainable goal number 9, number 2, number 12 and number 13.

And finally, consumer co-creation facilitates consumer co-creation and it fits into or supports the Sustainable Development Goals number 2, number 3, and number 12. So, in this way, you can say that, 3D printing offers sustainability in the market. These are all sustainable systems.



So, finally, I would like to summarize: clear personalized nutrition formulates nutritional strategies based on individual characteristics to prevent, manage, and treat diseases while promoting overall health. 3D printing is a process that creates three-dimensional objects layer by layer using digital designs. Extrusion-based 3D printing is the most commonly used method in the food industry for 3D printing of food. For extrusion printing, rheological and textural properties are of prime importance. Only a small portion of 3D printed foods can be consumed directly, but the majority of them require some sort of post-processing treatment like drying, frying, baking, cooking, cooling, and so on.



So, these are the references that we used in this lecture.

So, thank you very much for your patient hearing. Thank you.