

Food Packaging Technology
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Lecture – 30
Edible packaging – Part 1

Hello everybody. Welcome back to another session in the Food Packaging Technology course. We are now in week 6 and module 4. We are starting another very important topic which is biodegradable plastics, edible gums and coatings. This will be taken as a two-part section and it is quite different from what we have studied till now. Now, world wide one of the greatest problems is plastics.

We have pollution problem, environmental problem just because of these plastics that are true everywhere. You have it in the oceans, you have it in the landfills and most of these take years to degrade. So that is where the importance of biodegradable plastics and edible coatings come in place. What is a biodegradable plastic? A plastic that degrades because of the action of naturally occurring microorganisms like the bacteria, fungi and algae.

It's known as biodegradable plastics. Water, carbon dioxide, inorganic compounds or biomass are the major products that you get after decomposition. They are produced by renewable sources and have similar properties like that of your conventional plastics. Your conventional plastics that you have, your PET or PVC or polyethylene. These have certain kinds of as we have learnt, certain kinds of stretching properties, strength, barrier properties.

So these biodegradable plastics have to compete with them, have similar properties and addition be biodegradable. Now this picture here shows you the methods of degradation of biodegradable materials. Can either break down because of the action of microorganisms or under sunlight or a combination of both microorganisms and sunlight. This is a very interesting slide which shows you how long it takes for certain components to degrade naturally with the action of both sunlight and microorganisms. If you look at your normal paper tissues, that takes 2 to 4 weeks to degrade, converted to carbon dioxide and other natural byproducts.

The paper bags take one month to degrade. What about your newspapers? One and a half months. Interestingly an apple takes around two months to degrade while a cardboard box of a larger size takes around two months. Fiber boards are thicker than the paper bags that you see on top which degrades in one month. So, a fiber board can take

two months to degrade.

While the cigarette stubs take 10 to 12 years, your plastic bottles containers can take as long as 50 to 80 years to degrade. And your diapers that is used for children and infants all over the world takes 550 years. It is a very staggering reality that the world is facing. The plastic bags can take 200 to 1000 years. So that is where the importance of biodegradable plastics come in and that is why I said this is a very important topic.

Not only a hot topic today but a topic of research all over. Researchers all over are trying to find out new ways of creating plastics which are biodegradable as well as having a containing property. You cannot actually eliminate plastics from the world today. No food industry can survive without it. But there are alternatives and there are changes that need to be made.

Let's discuss in this section here today. So, for a biobased polymer there are three sources. Those that are extracted from a biomass. Number two, those that can be synthesized from monomers which are later biodegradable. Or number three, those which are produced by microorganisms.

So the first case, those which are produced from biomass, the biomass can either be the polysaccharides which is basically a carbohydrate or it can be produced from proteins. So, you can have these plastics or biodegradable plastics made from polysaccharides or carbohydrates such as starch, cellulose, chitin and chitosan. Or even using proteins such as wheat gluten, soy protein, collagen and gelatin. Now when you talk about synthesized from monomers, you have monomers like the polylactic acid, polycaprolactone, the polylactide, the polyglycolide, polybutylene succinate or the PBAT. All these are again monomers, all these are again natural monomers that can be combined to form polymers that are biodegradable.

A third type of biodegradable plastics is made from microorganisms like your polyhydroxybutyrate or your polyhydroxyalkynolate. You can actually classify the biopolymers based on the method in which they are manufactured. Let's start with the biobased polymers. I told you they can be made from either polysaccharides or from proteins. So, starting with polysaccharides, one of the most important polysaccharides from which these biopolymers are made are starch.

These starches naturally extracted from cereals like your wheat or rice or from tubers like potatoes and cassava. These granules, as we know, starch is composed of both amylose and amylopectin. The native starch is not actually a thermoplastic. You cannot have natural starch which can be heated and formed into any shape. But it can be

converted into a plastic-like material which is known as thermoplastic starch.

You can actually convert it. This is done by using plasticizers at high temperatures of 90 to 180 degrees centigrade. Under shear, *ie* under pressure, this starch will start to melt and flow. And then you can take it for extrusion. You can make it into any shape that you want or you can injection mold it or you can blow mold the whole material to get your biopolymers which have got properties very similar to the thermoplastic polymers.

So starch is one of the major components that is used as a biopolymer. A second component is cellulose. Now cellulose is actually a linear polymer formed by repeating units of cellobios. Now this is a crystalline and insoluble organic solvent. But due to its insolubility and low fluency, it can be transformed into different forms for their application.

And this is again achieved by various degrees of substitution. Now as the substitution degree increases, the mechanical property of the under-degradation rate decreases. Now the cellulose acetate is one of the most important derivatives of cellulose which has got a tensile strength which is very similar to polypropylene. So cellulose is another material that can be used as your biopolymer. A third very important component is chitin or chitosan.

Both chitin and chitosan you get it from the shells of crustaceans. And they can be extruded into films for packaging application and their main use is in edible coating to extend the shelf life of fresh fruits and vegetables. Very commonly used chitosan. It has other application other than food packaging as a wound healing and other properties but as an antimicrobial agent also. So, it can be used as an edible packaging coating for many of your fruits and vegetables.

Now those were some of the polysaccharide-based biopolymers. Now coming to the protein-based biopolymers. Four of them important are wheat gluten, soy protein, collagen and gelatin. Now wheat gluten that is a low cost and readily available byproduct of the fabrication of starch and their degradation speed is the highest as compared to other polymers. Your packaging from wheat gluten can degrade very quickly in nature with no harmful byproduct.

So it is an excellent film forming agent but the problem is it is brittle without a plasticizer. So, you require plasticizers to make it more flexible. Another biopolymer is using soy protein. So, soy protein isolate films can suffer from high moisture sensitivity and low strength.

That is one of the problems. They are not a very good barrier against moisture and they do not have much strength. You can add up to 25% stearic acid and that results in films that have got better tensile and thermal properties and reduce moisture sensitivity. Soy protein isolate glycerol and gel and gum or you can have your carrageenan. They have been reported to be suitable to manufacture biodegradable or edible soy-based packaging trays. But a moisture barrier must be applied to the tray as they are hydrophilic in nature.

So that is one of the disadvantages of using soy protein as a biopolymer. But that can be rectified if you can use a moisture barrier for this. Another protein-based biopolymer can be made using collagen. A collagen is the most abundant protein that you see in nature. Now sausage casings remain the major commercial usage for protein packaging materials.

The future of protein-based biopolymers are very very bright. They can be used for different kinds of food products directly. They can be even consumed and that is the advantage of using this kind of protein-based biopolymers. The second class of forming these biopolymers was by synthesizing it from monomers. So, there are natural monomers from which you can synthesize these polymers which can be biodegradable.

One of the most common one is the PLA or the polylactic acid as a monomer. So, of all the possible biopolymers that have been produced from bio-based materials, polylactic acid is the highest commercial potential and it has been produced in large scale. If you look at any biodegradable plastic bags that you purchase in the market, one of the ingredients will always be polylactic acid. It's very much in use commercially. The second one is the PCL which is the polycaprolactone.

This is a semi-crystalline, completely biodegradable, easy to process and cheap fossil-based polymer. So, if you add these PCL into hydrophilic chitosan polymers, it will increase the hydrophobicity of the blend and low water vapour transmission rate value was observed when you formed films adding this PCL into it. It's another important monomer that you can add in your bio-based polymer. A third type of monomer that you can add is the polylactide aliphatic copolymer, CPLA. One commercialized film produced in Japan, under the trade name of CPLATM, it starts to decompose after two weeks when it is mixed with food.

So in a natural environment, degradation can take place in five to six months. With 12 months, it can be even decomposed completely. So, this is another important monomer that is to be looked off in future. A fourth one is called PGA, polyglycolide. Now production of PGA for packaging application, it's marketed under the name of Kuredux®).

It started in the US in 2011. Now this is certified as a biodegradable plastic in the United States, Europe and in Japan. And it biodegrades or breaks down or decomposes into carbon dioxide and water within one month. That's a rate similar to your cellulose. Another monomer is your PBS, polybutylene succinate. This is mechanical properties which are approximately like your polyethylene or your polypropylene, which is quite good.

And they were first invented in 1990 under the trade name Bionolle in Japan. And PBAT is one of the last monomers that we will discuss today, which is a polybutylene adipate terephthalate. It is flexible, soft, just like the PCL. So, it can be used in the production of both films, filaments, bottles and into molded product. So, this has a versatile, wide range of application.

And this PBAT can be blended with cellulose, starch and other biodegradable polymers. Now that we've seen two methods of making this biobased polymer from the biomass or it can be made from monomers. A third method is by using microorganism. They produce with microorganism. And under that one of the most important is PHB, which is polyhydroxybutyrate.

This undergoes degradation by various bacteria, fungi and algae in different environmental conditions. The hydrological degradation forms 3-hydroxybutyrate acid at a low rate. The copolymer polyhydroxybutyrate valerate is synthesized by adding propionic acid to the feedstock. Okay, so this is tougher and less stiff.

So it's used as a packaging material. It degrades within five to six weeks in a microbiological active environment and ending up or producing carbon dioxide and water in aerobic condition. The anaerobic conditions under the production of methane, the degradation is even faster. A second type which is formed by microorganisms is your PHA, which is polyhydroxyalkylate. This consists of renewable, biodegradable, bio compostable, optically active polyesters that was first identified in 1925. Okay. They were produced in the form of intracellular particles by commonly formed microorganisms that accumulates this PHA as a carbon and energy sink and grown under nutrient stress in the absence of excess carbon.

So in these conditions, PHA is produced by these microorganisms. Under controlled fermentation conditions, some species they can produce up to 90% of their dry mass as a polymer, which is another interesting fact. Now let's look at the production of a biobased films. The two ways in which you can produce it, one is the wet or the solution method and the other is the dry or the thermo-mechanical method. In the wet method, you will

have the whole thing as a solution and that is either you can go in for dipping or spraying and done for coating of products or you can cast it and make films out of these biopolymers.

In the dry method on the other hand, once it is not in liquid form, here thermo-mechanical heat under heat and under pressure, they can be compressed or they can be extruded to form these kinds of films. Now these films, the coatings, some of the parameters that are important for coatings. You can coat your food products with these kinds of biopolymers. Important things in coatings are your density, viscosity, surface tension, temperature, pH. Depending on all this, you can actually change some of the properties of the coatings.

In the case of castings or films, thickness of the cast, the way in which you cast it, the casting speed, the film length, the drying parameters, all that determines the properties of the biopolymer. On the other hand, in dry casting or in dry thermo-mechanical method, the most important factors are for compression, during compression, temperature, pressure, the time of compression, the moles, the additives that you add. These are things again that will control the properties. And when you go for extrusion under high pressure and temperature, what matters is the control of the screws that you use there. The diameter, the speed, the temperature gradient that you use, the polymer feed rate itself.

All these can influence the final plastic biopolymer that you get. Now in these wet solutions, you can finally make edible coatings. And these are usually made from pectin, casein, collagen, gelatin, even lipids, chitosan, sodium alginates, whey protein, gluten. Any of these components can be used to make your biopolymers by the wet method. On the other hand, in dry method for compression, generally they have sodium caseinates, soy, the zine which is from maize, cellulose starch.

These can be used to make biopolymers by the dry method. Your wheat, gluten, whey protein, keratin, starch, pectin, xanthan, all these can be made by the extrusion method to form your biopolymers. When you talk about biodegradable plastics, there are different forms in which they come. They can either be in the form of films or as containers. You can have them as foamed products or as bags. So, any of these forms you can make by using these biopolymers.

It just makes it more versatile in their applications. So, the first one is the biodegradable films that you use. So, this is the most widely used biopackaging that is now used. Originally, it was designed to replace PE or LDPE. There was a widespread use of polyethylene.

To replace that, these biodegradable films came into use. So, they have better properties than non-degradable plastics. And some of the important characteristics of a good biodegradable film is it should allow controlled respiration, number one. It should have good barrier properties. It should maintain structural integrity and prevent or reduce microbial spoilage.

All these are very important. Now blown films that are made from biodegradable films have been used as bags and other packaging applications. PLA was used as a base for this blown film and it's got excellent transparency and mechanical properties. And due to slow crystallization and low melting strength, a single biodegradable polymer cannot be used.

So you need to use combinations. You cannot use a single one. It might not have the mechanical strength that you would want or desire in your film. A next form is your biodegradable containers. So thermoformed containers or tray also has got a number of uses in the food industry today. Now these biodegradable thermoformed trays can be used for packaging vegetables, salads, fruits because a controlled atmosphere is required to maintain this. So, if you can have a controlled atmosphere inside these kinds of containers, they have a longer shelf life.

Now most of the trays that are made from biodegradable polymers, they're brittle and they're resistant to moisture. There's no change in the structural properties of the tray during freezing, which is again important. These trays, if they kept in freezing, you wouldn't want your trays to be broken and become brittle. So, this is another advantage of using these biodegradable containers. Trays that are made from oriented PLA, they were used for storage of mangoes, melons and tropical fruits as reported by Shaikh in 2021.

They found that the shelf life of fruits that was packed was the same as that of the fruits that were packed in pet trees, which is an interesting observation. A third type of form of these biodegradable polymers is your biodegradable foamed products. Now this picture is a representation of the foamed products that you see in many of your packaging. This is for loose fill application, generally to give enough padding and to prevent breakage during your transportation.

So for loose filling applications, starch form has been used. Other techniques have been used for the formation of the foamed products, including loose fill molding. You can even have a foam extrusion can be done. Expandable bead molding can be done and extrusion transfer molding. These are methods in which you can make these foamed products. Numerous foamed products like trays and clamshells that are based on starch

have been used for packaging, but they cannot come in direct contact with the food.

So you need to have a direct food coating that has to be applied on these. Adhesion between the foamed products and the coating is very important. So, the coating that you put on these foamed products is very important so that they do not come off. There is a foam that was developed by Landau Packaging, which is called the green cell foam. And this is a sustainable alternative to PP foams.

This was again reported in 2021. In a moist soil environment, it was found that this foam actually degraded in four weeks' time, which is again very useful research. A fourth type, a very commonly used is your biodegradable bags. This has the largest application in the food industry, mainly because the raw material composition makes them flexible, strong, resistant to breakage, moisture and temperature change. These biodegradable bags can be used for storage and packaging of food products. The bags are completely environmentally friendly and once the function of the package is completed, they can be easily decomposed into carbon dioxide and water or any other products within few weeks.

So it is an excellent alternative to the LDPE or polyethylene bags, which are major menace in the environment today. Now there are few limitations of these biodegradable plastic packages. Major limitation is their performance, processing and the cost. Though there are many researches going on, they still haven't come up to the level of the normally used thermoplastics, but it will be done in the future and that is the hope of the earth today.

Second problem is brittleness. Third, you have a low heat distortion temperature. It may also have poor resistance to the processing operations. Poor barrier properties can be there for some of these. It might not be at least close to the other plastics that are found today.

The cost has declined. Cost was a major drawback in the early days. Cost has declined in the recent years and it will decline as the production volume is increased and process optimization has been achieved. The thing is consumers have to be aware and they should consume such products in larger volumes that will bring down the cost drastically. And another problem is your limited availability. What are the future trends of such biodegradable polymers? There is no doubt that the use of bio-based material for food packaging will increase, partly because of the improvement in mechanical and barrier properties and partly there is a result in decrease in the cost which is compared to your petrochemical polymers and partly because of the improved environmental benefits.

Now the future bio-based food packaging is likely to be blends. You cannot have a single bio-polymer usually. So, you have a blend of polymers and nano-clay in order to achieve the desired barrier and mechanical property that is demanded by the food industry. Cost is no doubt a limitation, the widespread adaptation but as production capacity increases cost will fall. So, the future is bright.

I hope you got a good idea about this topic which is a very relevant topic today. Many researches have to be done, solutions have to be found and that is the only way to a brighter future in the earth. See you all in the next session which is the second part of the same topic. Thank you so much. Thank you.