Cell and Molecular Biology
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Week 02
Cellular Structure
Lecture - 08
Eukaryotic Cells (Part 2)

Hello everyone, this is Dr. Vishal Trivedi from the Department of Biosciences and Bioengineering, IIT Guwahati. And what we were discussing was the cells, and what we have discussed is that the cell is the structure and the functional unit of life. In the previous two lectures, we have discussed the prokaryotic cell as well as the eukaryotic cell. Within the prokaryotic cell, we discuss the different parts of bacterial cells. We talk about the flagella, discuss the genetic material of the bacterial cell, and also briefly discuss the cell wall and Gram staining.

Then in the previous lecture, we discussed eukaryotic cells. And what we have taken is the two eukaryotic cells, the plant cell as well as the animal cell. And we discussed the several types of differences between the plant cell and the animal cell. And subsequent to that, we discussed the cytosol, we discussed the nucleus, we discussed the mitochondria.

So, what we discussed in the previous lecture was the animal cell, and within the animal cell, we discussed the three organelles. We discuss the cytosol, the nucleus, and the mitochondria. In each of these organelles, we discuss their mechanism and their role in cellular physiology. And then we also discuss the different types of structural details of that particular organelle and so on. So now in today's lecture, we are going to start discussing some more organelles from the eukaryotic cell.

So let's start today's lecture. So the first organelle we are going to start discussing is the chloroplast. So chloroplasts are present in plant cells and are completely absent in animal cells, except that they are also present in Euglena, which is considered to be a primitive animal cell. Because the Euglena has two abilities: to synthesize food and to trap its prey, it can also take in food from external sources. So chloroplasts, which are found in plants, algae, and other lower invertebrate animals such as Euglena, contrast with mitochondria.

Chloroplasts have an outer membrane, an inner membrane, and an innermost thylakoid membrane containing light pigments. So what you see here is a typical structure of the chloroplast. What you see here is that it has the outer membrane, then it has the inner membrane, and inside this inner membrane, you have this thylakoid membrane. So these thylakoid membranes actually contain the light pigments. The outer membrane is porous to small molecules, but proteins or large molecules are transported by the TOC.

The TOC stands for the translocon on the outer chloroplast membrane complexes. So, similar to the mitochondria, if you remember, the mitochondria have porins, right, which allow proteins or even small molecules that are less than 5000 Daltons. Compared to here, the outer membrane is also porous to small molecules, but it is not porous to large proteins, and although large proteins have to be moved through facilitated transport. The movement of material passes through the outer membrane and enters the inner membrane through another complex called the TIC, which is referred to as the translocon onto the inner chloroplast membrane. So this is the TOC which is present on the translocon that is present on the outer chloroplast membrane, whereas the TIC which is present on the translocon that is present on the inner chloroplast membrane.

In between the outer and inner membrane is the intermembranous space, which is filled with liquid. The inner membrane of the chloroplast further folds into a flattened membrane system such as the thylakoid. So this is just the structure-wise; the chloroplast is also following a similar kind of structure that is present in the mitochondria. If you recall, the inner membrane in the mitochondria is getting folded, forming the cristae and all of the other kinds of structures, whereas in the case of chloroplasts, it is actually forming the thylakoid membrane. These thylakoid membranes actually contain the photosynthetic pigments, and these pigments are responsible for harvesting sunlight, which is how that energy can be utilized for the dark reactions.

So let's understand the photosynthetic pigments. So the photosynthetic machinery, such as the light-absorbing pigments, the electron carriers, and the ATP-synthesizing machinery, is present on the inner membrane as integral protein complexes. So these are the thylakoid membranes where you have the integral membrane proteins, and all these integral membrane proteins actually have the complexes that are responsible for the light-absorbing complexes like PS1 as well as PS2. And then it also has the electron carriers like cytochrome c and other kinds of electron carriers like the Q electron carriers, and then it has the ATP synthesizing machinery similar to that of the mitochondria. So it also has the ATP synthase, which is also going to participate in the ATP production.

Thylakoid membranes are arranged into a stack of coins called granules. So all these thylakoid membranes, this inner layer is actually being folded into the thylakoid membrane, and then these thylakoid membranes are stacked on top of each other, right? They will be stacked one after the other, and that's how they are actually going to form a coin-like structure, which is called the granum. These granums are actually going to contain these light-absorbing pigments, electron carriers, and the ATP-synthesizing machinery. The granum throughout the chloroplasts are connected by tubules to share the material. So these granules are present in a chloroplast.

So you see that if you have this like a chloroplast, the inner membrane is actually going to fold to form one set of granum, then it is going to be connected, and then it is going to form another set of granum, and then it is going to be connected, and it will form the third layer of granum. So these molecules are going to be connected to the tubules and that's how they are actually able to share the material between the different granums. The overall structure of the chloroplast is similar to that of the mitochondria, but it has a few significant structural and biochemical differences. For example, the thylakoid membrane contains the photosynthetic green pigment which is called chlorophyll. So, let us discuss more about the function, and the major function of the chloroplast is that it actually participates in the reactions called photosynthesis.

What photosynthesis means is that it is a very simple complex structure. Photosynthesis means you have to do the synthesis, and you are going to utilize the light energy, right? Which means you are going to use the light energy to synthesize. So that is called photosynthesis. So let's see how photosynthesis is happening. So photosynthesis is a simulated reaction involving carbon dioxide and water to produce sugar in the presence of solar energy or photons to catalyze the fusion reactions.

So this is the typical photosynthesis reaction where you have carbon dioxide, water, and then you also require energy from the sun, and that is actually going to be combined to give you sugar, and it is also going to give you oxygen. So that sugar can be utilized by the plants for their own growth, and as well as this, sugar can be stored in the form of fruits, which are actually going to be consumed by other animals or organisms. The photosystem present on the thylakoid membrane consists of the two photosystems. You have photosystem 1, which is called PS1, and you also have photosystem 2, which is called PS2. Now these two photosystems are working in accordance with each other so that the electrons or the light energy they absorb from the sun are actually going to be utilized for the generation of ATP.

So, the purpose of photosynthesis is that it is actually going to be used for the synthesis of the two molecules. It is going to be utilized to synthesize ATP, and it is also going to be utilized for the reducing equivalent known as NADPH. This ATP is going to be synthesized by the molecule called ATP synthase, whereas the NADPH is actually going to be formed by the electron transport chain or the electron transport system. Both of these molecules require energy, and that energy is going to be obtained from sunlight. So, PS2 is actually going to absorb the photon from solar energy to excite the electron to a higher energy state and catalyze the breakdown of water into protons and oxygen.

So, this is what is going to happen. So, the first complex that is going to respond to the sunlight is actually the PS2, and PS2 is actually going to take up the sunlight, and that is how it is actually going to catalyze the breakdown of water, which is called water lysis, and it is going to generate protons as well as oxygen. This electron passes through with the and it is also going to have the electron. So, the electrons that are going to be produced during this water lysis are actually going to be passed through multiple electron carriers, and during this, the electrons are exported out of the thylakoid membrane into the lumen. So, what you see here is that it is going to do the photolysis of the water, which is actually going to generate the proton as well as the oxygen.

And on the other hand, the electrons that are going to be excited from the PS2 are actually going to be carried forward throughout the lumens and throughout the thylakoid, and that is how it is also going to be utilized. The proton passes through the ATP synthase and returns back into the stroma to generate ATP. So, what happens is that the eight protons are actually going to be accumulated on this side and then they are actually going to pass through to the ATP synthase, and that is how it is actually going to generate ATP in the lumen. The electrons from the PS2 are eventually being received by the PS1. Being excited under the absorbing proton from the sunlight to a high energy state.

So, that is why the electrons are going to be passed through the different electron carriers and then they will reach PS1, and at PS1 they will again receive sunlight. And then that is how it is actually going to excite these electrons, and ultimately these electrons are going to be utilized for the production of NADPH. The energy associated with these electrons is used to generate the NADPH in the stroma. So what are you going to generate in the stroma? You are going to generate two molecules. You are going to generate both the NADPH and the ATP.

So both ATP and NADPH are actually being utilized for the dark reactions. Hence, as a result of photosynthesis, solar energy is being trapped by the photosynthesis apparatus to generate two molecules: one is ATP, which is the energy currency, and the other is NADPH, which is called the reducing equivalent, into the lumen. Both of them are used to run the Calvin cycle to assimilate environmental carbon dioxide to form sugar. Now, what is going to happen? Right, so these two molecules are going to be utilized for photosynthesis. This actually wants to synthesize the ATP and the NADPH.

And then these two molecules are going to be supplied into the stroma, where they have the enzymes for the Calvin cycle, and that's how the Calvin cycle is going to run in C4 plants, and that's how it is actually going to synthesize the sugar molecule. So ultimately, the carbon dioxide is going to be fixed by the plants into sugar molecules, and it is actually going to produce oxygen. That oxygen is going to be used by the animals for respiration, and this sugar is actually going to be used by the plant for its own growth, while the extra sugar is going to be stored in the form of fruits, which are going to be consumed by the other animals. Now, let us move on to the next organelle. So the next organelle is the organelle of vesicular trafficking.

You know that every cell, just as we do, also has a very, very good trafficking system, so you know what the destination of this particular road is, right? For example, if you want to go from Guwahati to Mumbai, you know what roads you should take to reach Mumbai, or suppose I want to go to Delhi, Kolkata, or any other place, right? Similarly, if you want to distribute the material within the cell, then it also has the vesicular trafficking system. So there are organelles that are responsible for distributing the material within the cell. This could be for the plant cell, or it could be for the animal cell. This material could either be the food particles or the signaling molecules.

So, this could be anything. So the main function of these organelles, which are part of the vesicular trafficking, is to manage the distribution of material, whether it is a food particle or a protein, which is a part of the signal transactions throughout the cell. There are three different organelles, such as the endoplasmic reticulum, Golgi apparatus, and lysosomes, that coordinately work together to maintain the vesicular transport of materials across the cell. Eukaryotic cells take up solid material from outside the cell through a process called endocytosis. So, if it is taking up solid material, then it is called Endocytosis, whereas the uptake of liquid is known as Pinocytosis. Which means that during the nutrition process, when the cell is taking up nutrients, it can actually take in particulate matter; that process is called endocytosis.

If we take the liquid, for example, if it takes water or any other kinds of vitamins and minerals and all those kinds of molecules, then it will be called pinocytosis. Similarly, the material is secreted out of the cell, which is called exocytosis. So, the inside entry is called endocytosis. If the cell is producing some byproducts that are not good for it, then it's also going to throw itself away.

And that process is called exocytosis. In addition, the intravascular system delivers the proteins synthesized in the endoplasmic reticulum to the different organelles. Apart from these three processes, there are two processes where the cell is actually going to receive the material; if it is solid, then it is called endocytosis. If it is liquid, then it is called penocytosis. And if it is a byproduct, then it is called exocytosis. Apart from these three moments of the distribution of the materials, you can also have the distribution of the materials to the different organelles.

For example, you know that all the proteins are being synthesized either inside the endoplasmic reticulum or inside the cytosol. But these proteins may not be required for that particular organelle. It may be required for the lysosome, the mitochondria, and the chloroplast. So that movement is also a responsibility of these organelles which are part of the vesicular trafficking. During endocytosis, the material present outside the cell binds to the cell surface receptor and is trapped in a membranous structure called the endosome.

The endosomal vesicles fuse with the lysosomes to form the endosome. In the late endosome, with the help of lysosomal enzymes, material is digested, and then the endosome fuses with the Golgi bodies to deliver the content for further distribution. In a similar manner, they are doing secretions. The vesicles originate from the Golgi bodies and fuse with the plasma membrane to release the content.

So, this is what you see here. Here we have shown all three processes. One is endocytosis. So if it is a food particle, it is going to be taken up inside, it will be engulfed, and then it is actually going to be first present in the early endosomes. These early endosomes, when they fuse with the lysosome present in the cytosol, will actually form the late endosome. And then these late endosomes are actually going to fuse with the Golgi complexes, and then the Golgi is going to process this particular material that is being taken up from the outside.

And that is how it is actually going to be delivered to the rough endoplasmic reticulum, or it is actually going to be given to the other organelles. The same is true for if, suppose something has to be secreted out, like for example, if something has to be exocytosed or something has to be secreted out. Then that material is going to come out in the form of vesicles, and these vesicles are eventually going to fuse with the plasma membrane, and then this material is going to go out. The same is true for exocytosis, where the Golgi packs this material into vesicles, and then these vesicles fuse with the plasma membrane, releasing this particular content. Now let us study these organelles individually and understand their functions.

The first organelle that is a part of vesicular trafficking is the endoplasmic reticulum. The endoplasmic reticulum is nothing but the roads that are present inside the cell. So what you see here is that the endoplasmic reticulum is present just outside the nucleus, and it is forming a road-like structure. It is forming a road through the cell. So, if you want to send a material that is supposed to go to the mitochondria, then these roads are actually going to lead to the mitochondria, and that is how it can actually deliver that material to the mitochondria.

So the vesicular network starting from the nuclear membrane and spreading throughout the cytosol constitutes the endoplasmic reticulum. There are two different types of endoplasmic reticulum that are present in the cell. You have the rough endoplasmic reticulum, which actually has the protein machinery attached to it, which are ribosomes. So you have the rough endoplasmic reticulum and the smooth endoplasmic reticulum. Rough endoplasmic reticulum has ribosomes attached to it.

So because of this, ribosomes have appearances that look like rough endoplasmic reticulum or rough surfaces. So the rough endoplasmic reticulum has ribosomes attached to it, and it gives a rough appearance, whereas the smooth endoplasmic reticulum is devoid of ribosomes. Protein synthesis on the ribosome attached to the RER is sorted into three different categories: integral membrane proteins, proteins for secretion, and proteins designated for other organelles. So the protein that is being synthesized inside the endoplasmic reticulum actually falls under three different categories. Number one is the protein that is a part of the integral membrane proteins.

Number two, the protein that is for the secretions, and number three, the protein that is for the different organelles. Proteins are synthesized with an N-terminal signal peptide, and these signal peptides are recognized by the signal recognition particle on their target organelles. So the proteins that are designated for the different organelles are synthesized with a signal peptide. Signal peptide is nothing but a kind of address, right? So they are actually having an address. So you can imagine that if I want to post a letter from here at IIT Guwahati to IIT Madras, what I will do is take the letter, have a letter, and then write an address on it.

Similarly, if I have a vesicle and I want to send this vesicle to the mitochondria, what I will do is put the mitochondrial localization sequence, and that is what is called the signal peptide. You remember that when we were talking about the last time we discussed the mitochondria, the porin will not allow the entry of any proteins that are beyond 500 Daltons. But if the protein is beyond 500 daltons, then that protein must have a mitochondrial localization sequence, so you can put a tag; for example, if you add a signal, then this vesicle will go to that destination. For example, if a protein is synthesized with a signal peptide for the mitochondria, it will attach to the signal recognition particle and the receptor on the outer membrane to deliver the protein. The proteins without any signal peptide tags remain in the cytosol.

So, any protein that does not have any kind of tag is actually going to remain within the cytosol. Now, what will the function of the endoplasmic reticulum be? The first function is that it is involved in the synthesis of the steroid hormone within the gonadal cells. Then it is required for detoxification. Remember that the endoplasmic reticulum is a part of vesicular transport. So it can actually do the exocytosis, and that's how it is going to participate in the detoxification.

Then it can also be a calcium sequestration. And that's how it can actually have the calcium signaling. So if you use calcium signaling, the endoplasmic reticulum is actually going to release calcium into the cytosol, and that's how it is actually going to start calcium signaling. Then it is also important for the synthesis of proteins, phospholipids, and carbohydrates. It is possible for the protein sorting for the different organelles, and it is also responsible for the protein modifications such as glycosylation. Some of these things are very, very complicated, and we are not going to discuss them.

For example, glycosylation itself is a big topic. So that we are not covering in detail in this particular course, we will talk about the next organelle, which is the Golgi bodies. The Golgi bodies are actually first visualized by a metallic stain called the Golgi stain, invented by Camillo Golgi, and they are made up of flattened disc-like cisternae arranged in a stacked manner to give three distinct zones. So, this is what you see. This is the Golgi body where you have the disc-like structures.

So, disc-like structures are attached to each other. And that's how it is going to have Golgi bodies. You have three different zones within the Golgi bodies. You have the cis zone, the medial zone, and then the trans zone.

So this is the starting point. You have the CIS zone. So the cis phase is actually receiving the material or vesicle from the endoplasmic reticulum. So this side, from which it actually receives the material from the ER, is called the cis phase or the cis cisternae. Whereas the middle portion is called the medial Golgi, in the medial Golgi you are actually going to have all the processing. It is actually going to have covalent modification with the sugar. So it is going to do the different types of glycosylation and all those kinds of modifications.

And then the top portion you see here is actually the trans-Golgi. That trans-Golgi is actually the face of the Golgi towards the plasma membrane. And this site is actually going to release the sorted vesicles. Whether these vesicles are going to be for different organelles or whether they are for the plasma membrane. Which means whether these vesicles are for the security pathway or whether these vesicles are for the other mitochondria.

and for their designated organelle or to the plasma membrane. So, these are the functions of the Golgi body. You have the protein sorted. So, in the medial Golgi, the proteins will actually receive the protein that has been synthesized by the endoplasmic reticulum, then that protein is going to be sorted within this medial Golgi, and by sorting, these proteins are actually going to be modified differentially. They are going to be tagged with different types of destinations.

For example, it can be a mitochondrial localization sequence. It could be a chloroplast localization sequence. It could be some other kind of localization sequence. Even for the Golgi itself, if the Golgi wants to get some protein, it also has to put in a Golgi localization sequence and ER localization sequences. Although this protein is coming from the ER, it cannot remain within the ER; it has to be received from the Golgi bodies. So all the material will go into the Golgi, then it will be sorted out, and then it is going to be tagged with a particular address, and subsequently it is actually going to be delivered to that particular organelle.

For example, you know, if you are in a home, if you are in your home, and if you send an envelope or if you send a letter, what happens? This letter first goes to the GPO. Then, from the GPO, it will actually go to a different postal address. This will go to the post office. From the postal office, it will go to the postman, and then the postman is actually going to deliver it to the destination.

So, the same is true for vesicular transfecting. If you are at home, this is actually the ER. So, where the synthesis is happening, what will happen then? This is your letter, so this is a protein. So, this is a protein.

Now, this protein will first go to the GPO. GPO is nothing but the Golgi body. Now, from the Golgi bodies, it is actually going to be sorted. It will actually be sorted as per the destination. For example, there are parcels which will go to Mumbai. There are parcels that are going to Delhi.

There are parcels that will go to Kolkata or other cities. So at this point, it is actually going to be sorted and it is actually going to have some kind of stamp that this will go to Kolkata, this will go to Mumbai, this will go to Delhi, and something like that. So then it will reach the daily office, right? And then from the daily office, it will be given to the postman, and then the postman will actually give you the destinations. So this is very important. This is a Golgi body, right? So even if the letter has to come back again, right? It has to come back again to your home, for example; then the GPO has to tag accordingly; only then will it come back. For example, if you are sending a letter to your neighbor? It will not go directly from your place to that neighbor's.

It will go through this process. It will go to that particular postal office and then it will come back to your neighbor's house. So, that is the function of the organelle that is involved in vesicular trafficking. Apart from that, the Golgi is also involved in proteolysis. So, it is also going to degrade the proteins. Now we will talk about the third organelle, which will also be responsible for or be a part of vesicular trafficking, and that organelle is called the lysosome.

Lysosome is an organelle that was discovered by De Duve, and it is popularly known as the suicidal bag. Because the lysosome is filled with different types of hydrolytic enzymes and its inner liquid is very, very acidic, due to their role in autophagy, autophagy means eating yourself. You might have seen many people who are chewing their nails; that is actually autophagy, which means you are chewing your own body. So the same is true for the cell when it cannot produce enough energy because it is not getting nutrition from outside. What it will start doing is, for example, if it has 300 copies of some organelle, it will start utilizing 100 copies.

So it will actually work with the 200 copies of that particular organelle, and the 100 copies it is going to destroy, and that material is actually going to be used for its nutrition; that process is called autophagy. But this is a suicidal pathway, right? And that's why lysosomes are known as the suicidal bags. Autophagy is a cellular process that probably operates in cells during starvation to meet their energy requirements. The lysosomal lumen is extremely acidic and contains proteases and cytolytic enzymes to degrade the ingested material. So if you have a lysosome and you give it any molecule, whether it is a protein, DNA, or bacteria and viruses, any kind of molecule, It is actually going to degrade and it will generate the proteins or peptides.

That is why the lysosome has a very well-defined function. It will degrade the ingested food material for delivery throughout the vesicular systems. So, if you, you know, if you take the food particle from outside, it is going to be delivered to the lysosomes, and what is that lysosome going to do? It is going to degrade the food particles so that they will be present in the form of simple molecules, and it is going to deliver those simple molecules. It has also been present in the defense cells, and it is going to work as a defense organelle as well. So it is actually going to destroy the pathogenic bacteria, viruses, yeast, fungi, and all kinds of pathogenic bacteria.

And then it is also going to degrade the old proteins. The major part of the lysosome is that it actually recycles materials. It is going to recycle the cellular materials as well as the outside material. So, if there are bacteria, if they go into the cell, they are actually going to destroy that particular cell. So, that bacteria will be given to the lysosomes by a very well-defined process. And that anyway, we are going to discuss when we are going to talk about the cellular processes.

When we talk about phagocytosis, we will discuss in detail how bacteria, viruses, and other infectious organisms are delivered to the lysosome and how the lysosome degrades these bacteria. Now let's move on to the next organelle, which is called the plasma membrane. The plasma membrane is nothing but the external membrane, and a plasma membrane is made up of two molecules. It is made up of lipids and proteins. So you know that the lipid has a head and then it also has the aliphatic chain, right? The hydrophobic chain and these head molecules, which are actually polar and hydrophobic.

And because of this particular type of amphipathic character, all these heads are actually arranging themselves. And the lipids are the chains that are actually arranged inside. So if you put this in an aqueous environment, it is actually going to form a membrane like this. And that's how the plasma membrane is made up of lipids as well as proteins.

So what you see here is that these ball-like structures are actually the polar head groups. And what you see here is that this tail-like structure is the hydrophobic tails. And they will be arranged and sandwiched so that they will make sandwich-like structures, and within these sandwich structures, you are going to see the different types of proteins. These proteins could be integral proteins, or they could be peripheral proteins. What you see here is the integral protein because this is present throughout the plasma membrane. Whereas what you see is actually an integral protein that is either present on the outer surface or the inner surface.

Apart from that, the plasma membrane is also going to have different types of receptors; for example, this is a receptor, and this is a receptor. It can also have channels, such as transporters as well as other channels. These transporters and channels are actually going to be used for the delivery of food particles or the delivery of small molecules. Apart from that, it could also have different types of molecules that are attached to the lipid membrane, and that is actually going to be a part of the antigenic role.

So they are going to be the antigenic molecules that are going to be attached. So these are sugar molecules that are present on some of these peripheral proteins, and they are responsible for giving the antigenic features to this particular plasma membrane. Now, what is the function of the plasma membrane? The function of the plasma membrane is that it actually protects the cells from external infections. Then number two is that it is actually responsible for the entry or exit of the molecules, so it is part of the regulatory system that allows the entry and exit of the molecules. Because the plasma membrane is semipermeable, it will allow some molecules to pass through. So they will be selectively permeable and will have some mechanism that will determine whether to allow certain molecules to enter or not, which is actually decided by the plasma membrane.

Apart from that, the plasma membrane is going to have different types of receptors, so they will actually use that for many purposes. The receptors could be for taking up food; for example, you can have the receptors that are for the taking of food, such as the LDL receptor. So that the LDL receptor is going to take up the LDL, which is actually a lipid from outside, and that LDL receptor is going to take up the LDL, and that will be utilized by the cell for its nutrition. Similarly, you can have the insulin receptors. So, the insulin receptor is not going to be used for detecting the insulin that is present in the blood, and that is how it is actually going to lower the blood glucose.

Number three, the receptors are also going to be part of the defense mechanism. So, some of the receptors are going to function, as you know, as recognition particles, or sometimes they are also going to work as a defense mechanism. So, they will be sensing the external molecules and will actually derive the responses from the cell accordingly. So, apart from that, the plasma membrane also has transporters. These transporters are actually going to be used for the different types of delivery of molecules, water, solutes, and small as well as large molecules. So overall, the function of the plasma membrane is to regulate the entry and exit of materials from the cell.

So with this, we have discussed the eukaryotic cell. What have we discussed? We have discussed the two different types of eukaryotic cells. We discussed the plant cell as well as the animal cell, and we also discussed the different organelles that are present in the eukaryotic cell. Initially, we discussed the cytosol, then we discussed the nucleus, and we also discussed the mitochondria; in this particular lecture, we discussed the chloroplast. Then, the organelles of the vesicular trafficking system are discussed: the endoplasmic reticulum, the Golgi bodies, the lysosomes, and finally, the plasma membrane and its functions.

So with this, I would like to conclude my lecture here. In our subsequent lecture, we are going to discuss the cell cycle, how the cell is dividing and increasing its number, and some more aspects related to the cells. So, with this, I would like to conclude my lecture here. Thank you.