Plant Developmental Biology
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Lecture - 02
Characteristics of Plant Growth and Development - I

Welcome to the second lecture of Plant Developmental Biology. So, in this lecture we are going to talk, about the Characteristics feature of Plant Growth and Development.

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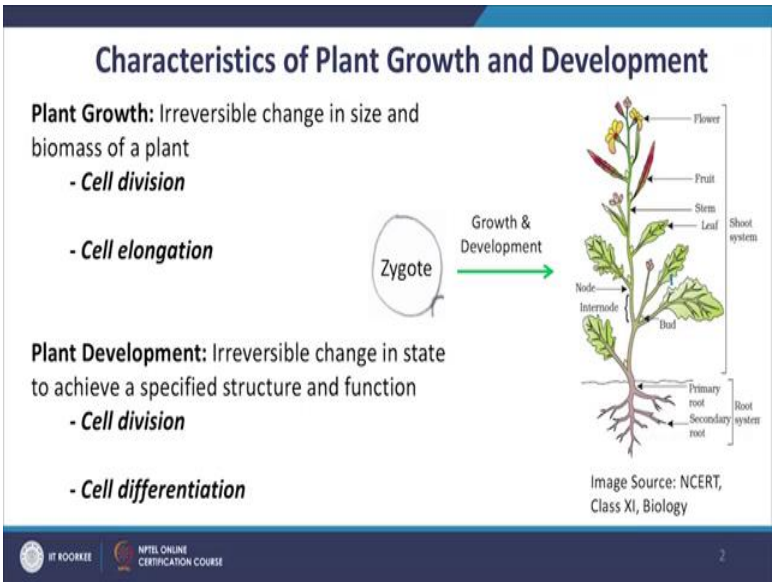

So, if you see the entire process of growth and development, it covers the formation of a complete structure or complete body of a plant, three dimensional structure of a plant from a single cell which is called zygote.

The entire process from a single cell to a multicellular structure is called growth and development and it is very important that in case of plants both growth and developments are highly coordinated. It is because the development is mostly post embryonic. It starts after the germination as you will see in the later part.

So, if you define plant growth, it is defined as irreversible change in the size and biomass of a plant. And development is basically irreversible change in the state to achieve a particular specified structure or specified function.

So, one thing is very clear, you are going to make a very complex multicellular organism and that is starting from a single cell, which means that there has to be a process, a mechanism to generate a large number of cells from the single cell and this process is called cell division.

Cell division means here I am going to talk about the mitosis cell division because during growth and development only mitosis cell divisions are involved except a very small part of the gametes development. So, during the growth there is a process of cell division which generates a large number of cells, and this is important. This is important because if you want to grow you need a large number of cells, but at the same time you cannot just produce the cells, this cells has to go and take a proper identity this is equally important.

For example, if you look at typical plant. The plant has a root system and shoot system and if you look an organ which is placed here it is very different than the organ which is present here. So, the leaf is very different in terms of structure, in terms of anatomy, in terms of cellular organization and in terms of the function.

So, how this all processes or how all this different types of organs are specified is covered in process of development. During the growth of the plant the two major fundamental process which is very important is cell division and cell elongation. Cell division is the process which generate the cell and cell elongation to certain extent it helps in growth of certain organs, but the major contribution for the growth and development is cell division.

Similarly, for development the cells which are coming off after the division they have to take a proper identity, they have to undergo the process of specification. And how this happens? This happens through a very fundamental process which we call cell differentiation.

So, cell differentiation together with the cell division ensures a proper organ formation or development of proper organs. Whereas, cell division and cell elongation these two processes together they ensure proper growth in the plant. Another important thing which is worth to note down here is that where this process of cell division occurs.

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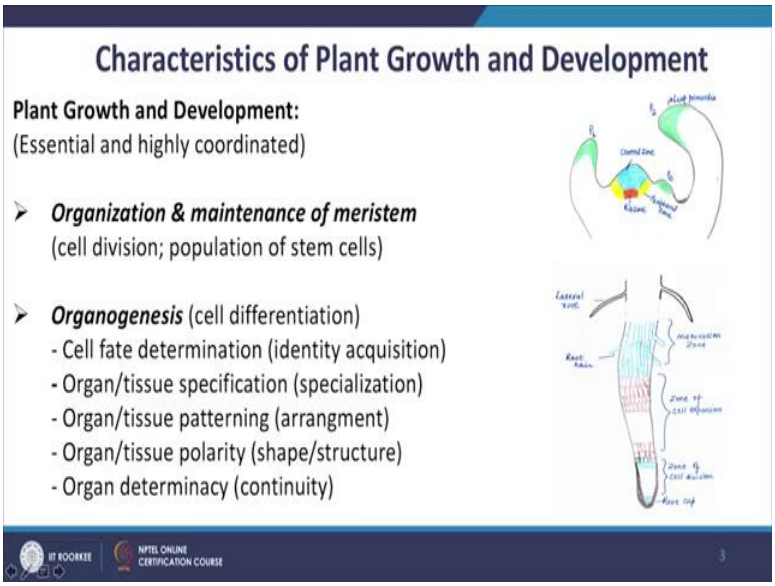

So, in a growing plants there are certain specified position where the process of cell division occurs. One is the shoot apex and another is root apex then we will come in the later slides and you will see, that there are some meristematic activity in the radial pattern, we have meristematic activity at the axial side, we will see in detail.

The process of plant growth and development is achieved by a coordinated cell division and cell differentiation. Two process which has to be running simultaneously in parallel; first is organization and maintenance of the meristem. Meristem is a population of cells which has a stem cell property.

So, stem cell, why you need stem cells? Stem cells are the cells which can undergo the process of cell division without entering in the process of cell differentiation. And the second process which takes place is cell differentiation and results in organogenesis. So, both the process has to be maintained simultaneously. So, there has to be a region, there has to be a mechanism to produce the cell, then there has to be a mechanism that some of the cells they retain their property as a stem cells and the some of the cells they should enter in the process of differentiation.

What is the meaning of differentiation? What occurs during the differentiation? The first thing what happens, once this cells leaves the region where it is meristematic, it enters in the process of cell fate determination. So, the cell has to take a proper fate for the development and this is a stage when the identity is established.

So, let us assume if cell is going to make leaf then it has to take a leaf fate, if it has to make flower it has to take flower fate, but how this happens? Then second process what occurs during the organogenesis is the tissue specification. So, one organ is not made up of a single tissue there are multiple tissue and different tissue has different structure, different function and different organization.

Then the next thing what is being ensured is the patterning, so the tissues are always patterned in a proper manner. For example, epidermis is the outer layer, so it will always remain as an outer layer. The layer which is just below the epidermis has to be cortex or hypodermis, whatever depending on the tissues.

Then another interesting thing what happen during the process of development is the polarity. So, if you look the complete structure or shape of an organ it has polarity. If you look at leaf, leaf at the base is very different than the tip. So, this is the polarity and this is also being established during the process of development.

And the final thing what happens in the development is organ determinacy. Whether this growth or the development should continue or it should stop. This is called determinacy. So, continuity is finally, ensured in the development, if organ is determinate in nature then after a certain time point it will stop. If organ is indeterminate in the nature it will continue to grow.

So, if I take two example here, shoot primary development and root primary development and here tip is the region where meristem is maintained.

At shoot tip the central zone is the region where shoot apical meristem or population of shoot stem cells are present. So, when these stem cells are present in this region, it will only divide, it will undergo the process of cell division and the cell differentiation is inhibited. But once this cells leave this region and enter in the peripheral region then it undergo the process of cell differentiation and depending on the position, signal and information it takes a proper cell fate it undergo the proper process or cell specification and differentiation to make a specific organ.

Similar is the case in case of root. So, if you look the region of root apical meristem here meristem is maintained, but when the this cells enters the initial cells they specifies some tissue those tissues are patterned, if you go to the maturation zone or if you go to the

differentiation zone, then new organs are being formed. This all process are essential as well as highly coordinated.

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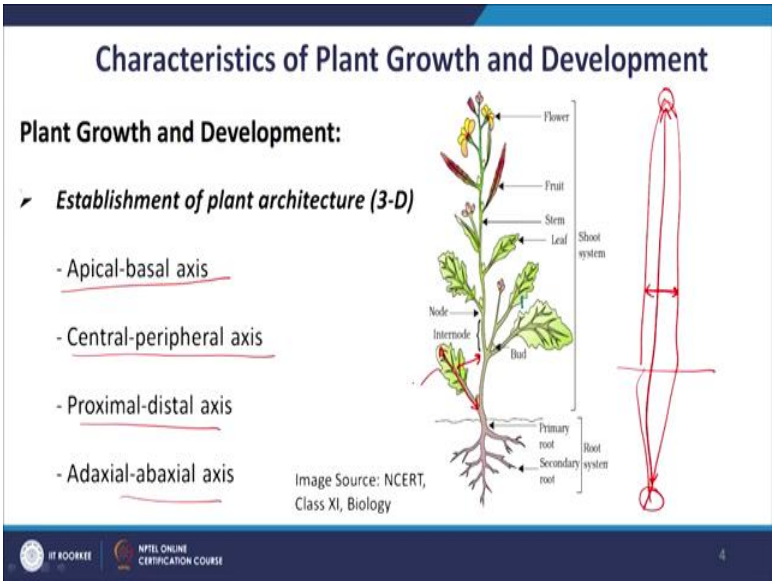

As I said previously that the one of the major function of growth and development is to establish architecture. Plant architecture is very important parameter. It not only provides a proper shape or proper morphological structure, but it also helps in plant to adapt in a different environmental condition. And therefore, the process of development has to be properly organized and this entire process of plant development occurs across the 4 axis.

So, if I draw here, let's consider this is a typical growing plant. So we have a root system, we have a shoot system. The first axis where growth and development occurs is this axis which we called apical-basal axis and this occurs this is mostly responsible for the primary growth. And this is because of the activity of root apical meristem and shoot apical meristem.

Second axis through which growth and development occurs is central peripheral axis or radial axis. So, as we know that during primary growth the major growth occurs across the apical basal axis, but at a certain time point there is another growth which is called secondary growth which starts in this direction. So, the second axis is established as a central peripheral axis

Then certain point at the later stage if you look this structure, a leaf. A leaf has a tip and it has a base and this axis is called proximal and distal axis. This is established with respect to the primary meristem, the growing primary meristem. So, if you look this is the primary axis, and the point which is close to the primary axis is called proximal region and the point which is away from the primary axis is called distal region. And another and final axis across which growth and development occurs is adaxial-abaxial axis. This is particularly important for the organs, so the upper surface of the leaf and lower surface of the leaves they are very different. They have a different characteristic feature, they have a total different developmental program.

And the face which is towards the meristem is called adaxial and the face which is away from the meristem is called abaxial. So, all this growth and development together they occurs in all the three dimensional direction and this gives a proper plant architecture.

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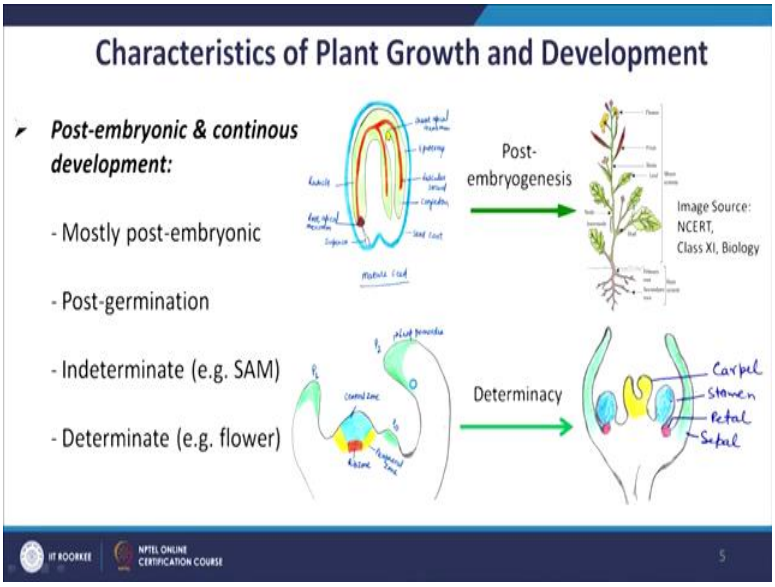

So, now, we will come to the typical characteristic feature of plant growth and development. So, if you remember the first class where we have talked about that, in case of plants the growth the development is continuous first very important thing. So, plant has capability they can grow throughout their life this is very important.

And another very interesting thing is that the most of the development is post embryonic in nature, this is in contrast with the animals. If you look the development of animals most of the development most of the primary development is completed during the

process of embryogenesis. Whereas, if you look the mature seed which contains our embryo there is not much development occurs. The only thing what has occur is the basic body plant is established during the process of embryogenesis.

Shoot apical meristem and root apical meristem. So, basically meristem which is across the apical basal axis is established. Radial meristem is established, the procambium is established and then this embryogenesis has stopped. Now this plant this seed is under dormancy stage. When we take the seed and when we put for the germination, then all the organogenesis or most of the organogenesis start which is as I said it is post embryonic and post germination.

But the question here again I will say the same thing what happens that since seed is a very small structure and embryo is inside the seed once this embryo start elongating. So, this embryo is undergoing the process of both simultaneously growth and development. So, it has to ensure that it achieve the growth at the same time it also has to ensure that all organs are being made properly.

Another very important characteristic feature of growth and development in case of plant is indeterminate versus determinate growth. So, in case of indeterminate growth what happens that, when growth and development is happening and it is not getting terminated. It is happening throughout the life and this is this is a case of typically in case of shoot apical meristem. So, if you look the shoot apical meristems are normally in higher plants or in perennial plants they continuously grow, they grow throughout their life. This kind of growth is called indeterminate growth.

In case of determinate growth this mostly occurs in the lateral organs like leaf, flower where what happens that at a certain time point or when this structure or when the organ has developed certain kind of organs or taken a particular shape or achieved a particular size, then growth is totally stopped or it is terminated this process is called determinate growth.

And sometime this is also reversible sometime indeterminate growth may converted into the determinate growth. For example, if you if you take the case of flower development. So, typically inflorescence is the meristem which is indeterminate in nature, but when the inflorescence meristem makes floral primordia or floral meristem at the flank, the floral meristem after making all this organs which is sepal, petals, stamen and carpel’s once it

has developed the carpel, the growth basically terminates here and the all the meristems which were present here is totally consumed. So, this is a process of gaining determinacy. So, one indeterminate meristem gave rise a determinate meristem this is one very important process in the development of plant organ.

Since all this process are important then they must be tightly regulated. The process of determinacy, process of growth, process of development has to be regulated by certain regulator and needless to say if you disrupt these genetic regulators or if you mutate them you are going to see the developmental defect.

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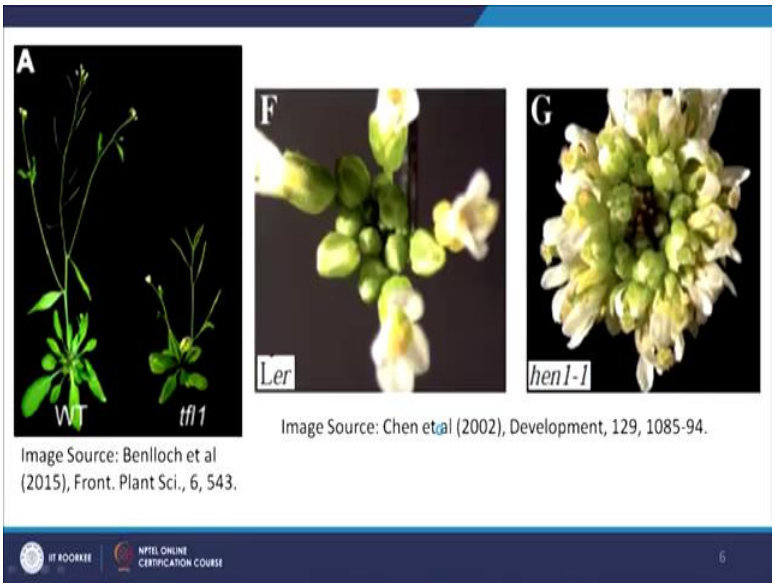

For example, if you take the case of this mutant which is *TFL1* which is *terminal flower1*. So, if you look the wild type Arabidopsis plant, the wild type plants during the vegetative development it makes several leaves which is called rosette leaves and then this plants undergo the process of reproductive developments when this inflorescence are made and then a very special kind of leaves called as cauline leaves.

And during this process when there is a inflorescence meristem identity is established, then inflorescence meristem will start making flowers on the flanks and these flowers once they mature they undergo the process of fertilization and they give rise to the structure which contains the seeds. So, if you look this is the siliques and in the siliques the seeds are there containing the embryo.

A single inflorescence you can clearly find that on the basal side of the inflorescence the organogenesis is almost completed, all the organs are made and the meristems are terminated, but at the same time if you look the tip of the inflorescence still there are the process of organogenesis going on and you can still see some new flowers growing.

But in the mutant background, there is development of only few leaves and then the inflorescence is made. It make some flowers and then get terminated by making a terminal flower that is why it is called terminal flower mutant. So, essentially in this mutant there is a gain of determinacy. It is achieved pre mature before the proper development is completed.

On the other hand if you look this mutant which is *hen1*. In *hen1* mutant, what is happening? There is loss of determinacy. So, if you look this is a, the top view of the Arabidopsis inflorescence. In this inflorescence you have a certain number of flowers and this flowers are determinate in nature, but in the mutant background you can see that the number of flowers are increased, organs are increased which means that they are not being terminated when they are supposed to be. This is a case of loss of determinacy.

So, the process of growth and development has to be genetically regulated and this regulation is very important to give rise a proper and defined plant architecture. So, as you see a typical mature plant, what you will find? You will find that plant has lot of organs, lot of different types of organs and they are not achieved simultaneously some organs are developed at a particular time others are developed slightly later. So, the total architecture or total body plan of a plant is achieved in three major development. The first one is primary growth and development.

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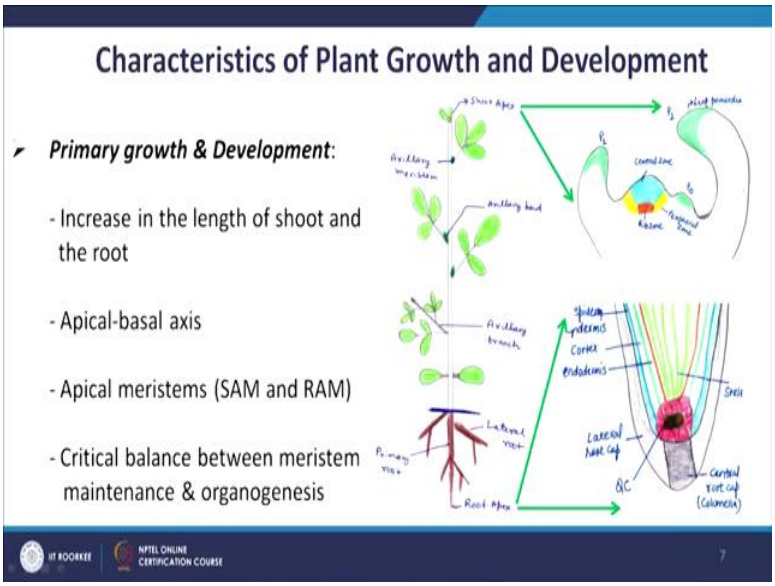

So, during primary growth and development the growth actually occurs across the apical basal axis. As we have seen previously, so the growth is mostly in apical and basal manner. This is because of the activity of shoot apical meristem here and root apical meristem here.

And as I said there has to be a proper balance between the cell division and cell differentiation. In shoot meristem it is for the vegetative organs and after the transition it is required for reproductive organ. In root meristem the stem cells are maintained here and these stem cells are responsible for providing cells for different tissues which are growing in the tip.

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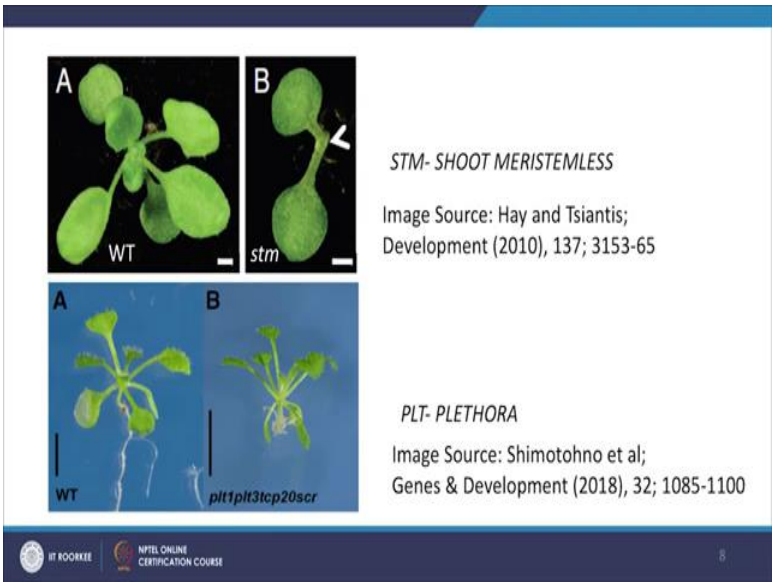

And of course, this also has to be regulated if you see this case this is a mutant which is called *STM*; *STM* is for *SHOOT MERISTEMLESS*. In this mutant the meristem is terminated. If you look here, this is a top view of growing Arabidopsis. This is the region where shoot apical meristems are positioned and you can see this growing shoot apical meristem is allowing all this lateral organs which is leaf here to develop and form.

But in this mutant somehow this meristem is not being maintained for very long period of time which means that since meristem cannot be maintained only very few lateral organs are made and eventually this meristem is terminated.

Similarly, if you look the *plethora* mutants. PLETHORA are very important transcription factor and they are responsible for maintaining root apical meristem activity. In this mutant background the root apical meristem activity is not maintained and the primary root or the meristem cells are getting consumed early and that's why you cannot see a proper root development. So, both the primary growth at the shoot apex as well as the root apex are regulated by very important developmental regulators.

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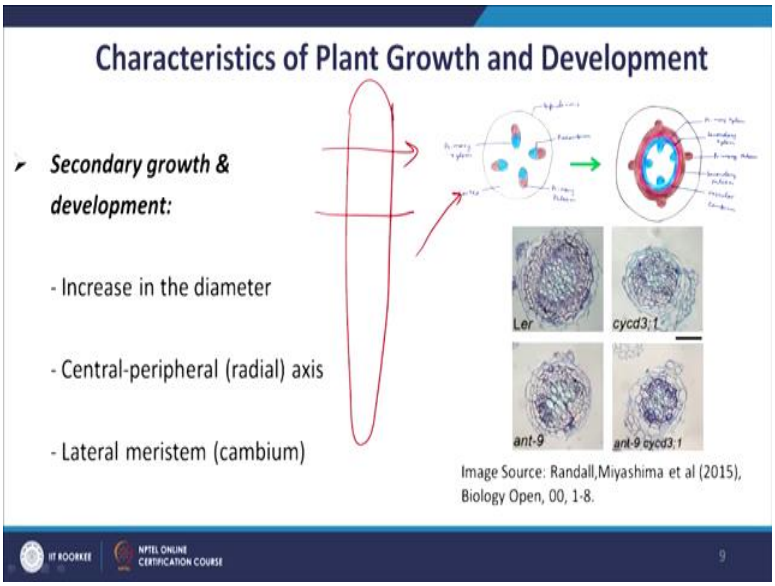

Now, coming to the secondary growth and development. If you recall the previous part of this lecture what we have seen during the process of embryogenesis that apart from the root apical meristem and shoot apical meristem there is another meristem which is being specified which is called procambium which is basically lateral meristem or you can say the radial meristem. But during primary growth this meristems are not getting activated.

So, meristem is there the region has been already marked that this is the region which to undergo the process of secondary growth. Secondary growth is a growth which occurs to increase the diameter of a growing plant. And this happens in the central and peripheral radius.

If you look, typical root or shoot and if you make a cross section at early stage this is the structure.

The procambium meristems they are basically positioned here and they are part of the vascular bundles. Vascular bundles are very important tissues which are going to make the transport system. And in transport system they have a primary phloem, primary xylem and in between there is a tissue called procambium.

So, usually during primary development the procambium is not activated. Only primary phloems and primary xylems are made. But when there is a decision taken place that

now plant should enter the process of secondary growth which typically happens when primary growth is achieved significantly so that they can sustain secondary growth.

And then what happens here? This procambium cells these are actually lateral meristem they get activated and once they activated they start making a kind of ring like structure and then they start producing secondary phloem secondary xylems. And this secondary phloem secondary xylems basically they are in radial in nature and they are responsible for thickening of the stem.

Needless to say that they also need to be regulated. If you look these mutants it is clearly evident that this is a typical wild type Arabidopsis root which is under process of secondary growth. But in this mutant background here secondary growth is already activated, but if you look these different mutants the secondary growth is not so evident as you can see in the wild type. So, this tells that the secondary growth is very important and it is genetically regulated.

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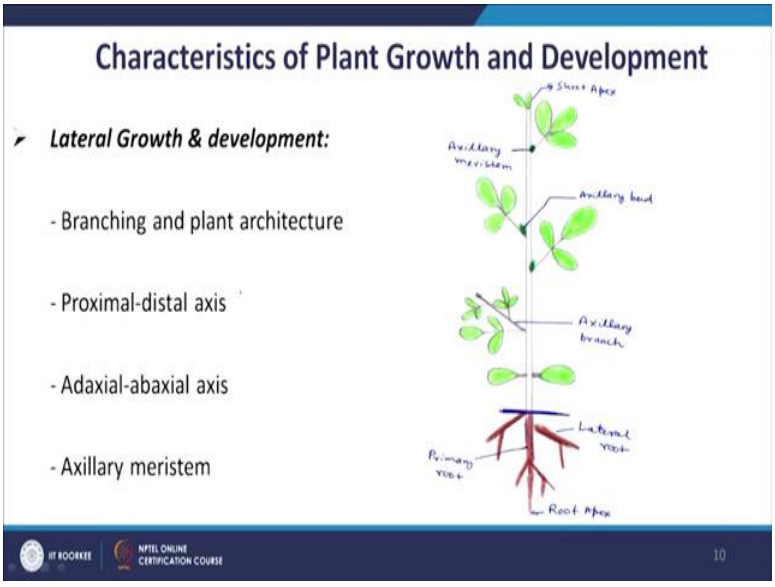

Now, the third growth and development which is lateral growth and lateral development. This occurs most of the time at later stage of the development. And this is the one which completes the architecture. This gives total proper architecture and most important thing what happens during this process is branching. Branching is very important process in plants.

It is important because if you have more branches there is opportunity to produce more seeds, there is opportunity to have more reproductive capability. And another important thing these process occurs across the two axis. Proximal distal axis, abaxial-adaxial axis. And we have this branching process both in the shoot as well as in the root.

So, if you look here in the shoot this is the apex of the shoot, but if you come down there is a place where is some kind of meristematic activity and this meristematic activity is basically called axillary meristem. And this axillary meristem during primary growth they are usually suppressed.

So, meristem are already defined, but they are not getting activated because of a process called apical dominancy in case of plants, but once the decision is being taken place this axillary meristem, they get activated and then they will make axillary buds and these axillary buds they will start making axillary branches and this axillary branches they will have a shoot apical meristem and they will do the process of primary growth they will continue the process very similar to the primary growth.

In root this is your primary root; primary root basically because of the activity of root apical meristem, but at certain point of time in the development a new meristem is being generated here post embryonically and this meristem is called lateral root meristem. And these meristem when they undergo the process organogenesis they makes lot of root branching in this roots are called lateral root they are very important for giving a proper root architecture for increasing the absorption capability of a root by increasing the overall surface area of the root.

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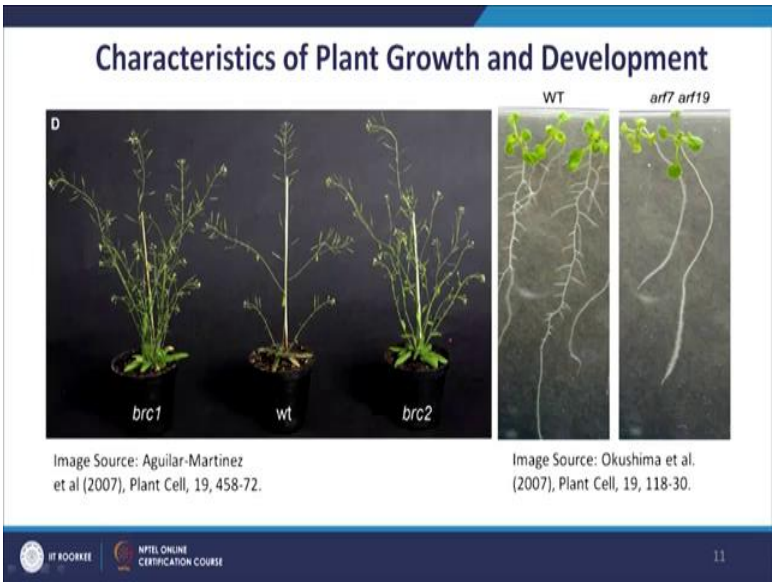

Here are some mutants for this. This is the wild type plants, there are certain amount of branches, but if you look both the mutants this both the mutants the shoot branching is increased. So, this is a kind of loss of apical dominant phenotype.

On the other hand if you look in the root, so these are two transcription factor. This is double mutant of *auxin response factor 7* and *auxin response factor 19*. And in this double mutant what is happening? You can clearly see that the apex meristems are very much working fine. So, you can see the shoot apical meristem is here; root apical meristem is here it is evident by the fact that this mutants are making shoot as well as the root tissues, primary root tissues.

But if you look the wild type at this stage this wild types they have made lot of lateral roots; but these mutants they do not have any lateral roots which tells that there is a specific genetic regulatory modules or there is a regulatory program which is very specific for the lateral root development or for the branching and which is independent of the mechanism or the program which is regulating primary meristematic activity. So, these all together suggest that the growth and development in plants are highly coordinated and highly regulated.

So, to summarize this lecture, so what we have discussed today, we have discuss the process of growth and development and what we learn that the process of development in case of plants are mostly post embryonic and we have discussed the primary growth,

secondary growth and the lateral growths which are characteristic feature of plants growth and development and this all processes together ensures a proper plant architectures. So, now, we will continue this lecture in next class.

Thank you.