Role of Morphogen in Plant Embryo Development

ROLE OF MORPHOGEN IN PLANT EMBRYO DEVELOPMENT

Morphogens are the substance that helps to establish the distribution of cellular response and it occurs in a dose-dependent manner. Morphogen provides position information within a cell, which helps to give rise to spatial patterns. These morphogens diffuse continuously in the cytoplasm to set concentration gradients. In short, morphogens are secreted proteins that form gradient extracellular across the cell.

The establishment of positional information is essential for pattern formation in a developing embryo. The phytohormone auxin is a classic morphogen in plants. Gradients of auxin distribution are required for tissue patterning within the embryo and the root apex. In *de novo* organogenesis, actions of auxin are defined as a morphogenetic trigger, which induces a new developmental fate in plant cells that were originally similar to their neighbors, through a local increase of its concentration. A morphogenetic trigger specifies the site where a new organ will be formed. “Morphogen” are responsible for spatial distribution within the organism which determines gene expression pattern and accordingly the cells respond to differences in the concentration.

Embryo formation in *Arabidopsis thaliana*

Arabidopsis thaliana belongs to the angiosperms or flowering plants, it is a major group of seed-bearing plants. In plants, embryogenesis occurs inside the ovule, and a mature, dormant embryo is enclosed in a seed awaiting germination. During embryogenesis, the shoot–root polarity of the plant body, the apical-basal axis, is established, and the shoot and root meristems are formed.

In Arabidopsis embryo development involves an invariant pattern of cell division and this enables structures in the Arabidopsis seedling to be traced back to groups of cells in the early embryo to provide a fate map.

The fertilized plant egg cell undergoes repeated cell divisions, cell growth, and differentiation to form a multicellular embryo. The first division of the zygote is at right angles to the long axis, dividing it into an apical cell and a basal cell, and establishing an initial polarity that is carried over into the apical-basal polarity of the embryo and into the apical-basal axis of the plant. The basal cell divides to give rise to the suspensor, which attaches the embryo to maternal tissue and is a source of nutrients. The apical cell divides vertically to form a two-celled proembryo, which will give rise to the rest of the embryo. In Arabidopsis, the topmost suspensor cell is recruited into the embryo, where it is known as the hypophysis, and contributes to the embryonic root meristem and root cap.

The next two divisions produce an eight-cell octant-stage embryo, which develops into a globular-stage embryo of around 32 cells. The embryo elongates and the cotyledons start to develop as wing-like structures at one end, while an embryonic root forms at the other. Seedling structures can be traced back to groups of cells in the early embryo to provide a fate map. In Arabidopsis, patterns of cleavage up to the 16-cell stage are highly reproducible, and even at the octant stage, it is possible to make a fate map for the major regions of the seedling along the apical-basal axis.

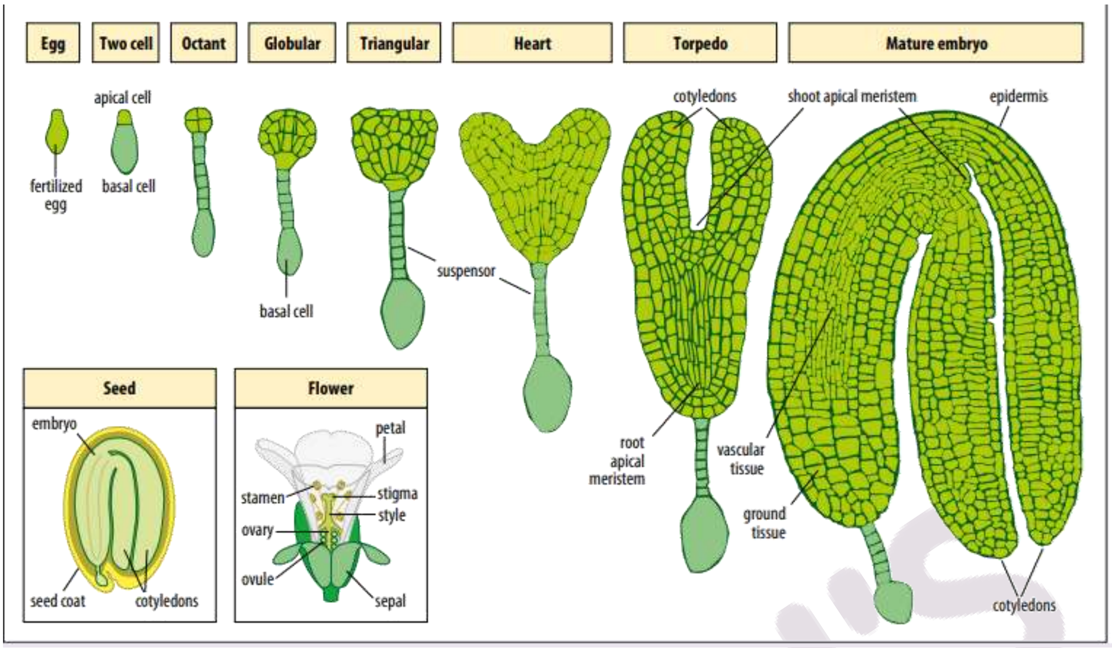

Figure 1. Embryogenesis in plants

Role of auxin as a morphogen

Auxin (indole-3-acetic acid or IAA) is one of the most important and ubiquitous chemical signals in plant development and plant growth. It causes changes in gene expression by promoting the ubiquitination and degradation of transcriptional repressors known as AUX/IAA proteins. Auxin act as a classical morphogen, it forms a concentration gradient and specifies the different fates according to a cell's position along the gradient

Several studies on *Arabidopsis thaliana* suggest that the auxin regulates either directly or indirectly every spatially organized aspect of plant development. Local accumulation of auxin activates both meristematic activity and new apical primordia formation. In the absence of auxin, these bind to proteins called auxin-response factors (ARFs) to block the transcription of so-called auxin-responsive genes. Auxin-stimulated degradation of AUX/ IAA proteins frees the ARFs, which can then activate, or in some cases repress these genes. Auxin-responsive genes include genes involved in the regulation of cell division and cell expansion, as well as genes involved in specifying cell fate.

In Arabidopsis auxin acts in the very first stage of embryogenesis and establishes the apical-basal axis. After the first division of the zygote, it is transported from the basal cell into the apical cell and accumulates. Auxin is transported out of the basal cell by the auxin-efflux protein PIN7. The auxin specifies the apical cell, which gives rise to all the apical embryonic structures such as shoot meristem and cotyledons.

Throughout cell divisions, auxin transport continues into the suspensor cells and base of the developing embryo until the globular-stage embryo of about 32 cells. Embryo's apical cells start auxin production, and the direction of auxin transport is suddenly reversed. PIN7 proteins in the suspensor cells move to the basal faces of the cells. Other PIN genes are activated, and the concerted actions of the PIN proteins cause auxin from the apical region to be transported into the basal region of the globular embryo, from which will develop the hypocotyl, root meristem, and embryonic root.

The establishment and maintenance of the longitudinal pattern of the root meristem have been controlled by varying auxin distribution, and this gradient leads to dramatic patterning defects in the root. IAA accumulation measurement in specific cell types in the root meristem provided direct evidence for auxin gradient establishment with a maximum accumulation in the organizing center region of the root tip. Therefore, auxin distribution is essential for the root meristem specification.

The expression of auxin-inducible transcription factor Plethora PLT in roots is essential for meristematic tissue differentiation**.** Levels of PLT protein correlate with the response of auxin gradient in the root. A high PLT activity is required for the identity and maintenance of the stem cell niche. For cell growth and proliferation in the meristem zone (MZ) intermediate levels of PLT are essential. And for cell expansion in the elongation zone (EZ) low levels are needed. It further allows cell differentiation in the differentiation zone (DZ). The expression of the *PLT* gene is auxin-dependent, other factors also contribute to the PLT gradient.

Role of morphogen gradient

The auxin gradient mechanism which generates the distal root in the *Arabidopsis thaliana* is different from the earlier studied mechanisms. Three distinct mechanisms of morphogen gradient formation are as follows:

i. Source-decay mechanism - In this mechanism, the overall morphogen production is localized at the source and decay.
ii. Unidirectional transport mechanism - In this, morphogen is directly transported to the direction of a ‘dead end’, where maxima will be established.
iii. Reflux-loop mechanism - This mechanism is a combination of a downward and upward flux, which forms a “capacitor” linked to each other through a lateral flux.

Diverse morphogen gradients in terms of spatial and temporal scales are very important and essential for the implications during development.

General concepts of morphogen gradients

To transfer positional information to all the cells morphogen gradients are an important factor within the developing tissue. Concentrations of morphogen should vary appropriately from one tissue to another. So that cells are able to distinguish between different locations and initiate appropriate genetic responses. The distribution of morphogen in space takes the form of an exponential gradient.