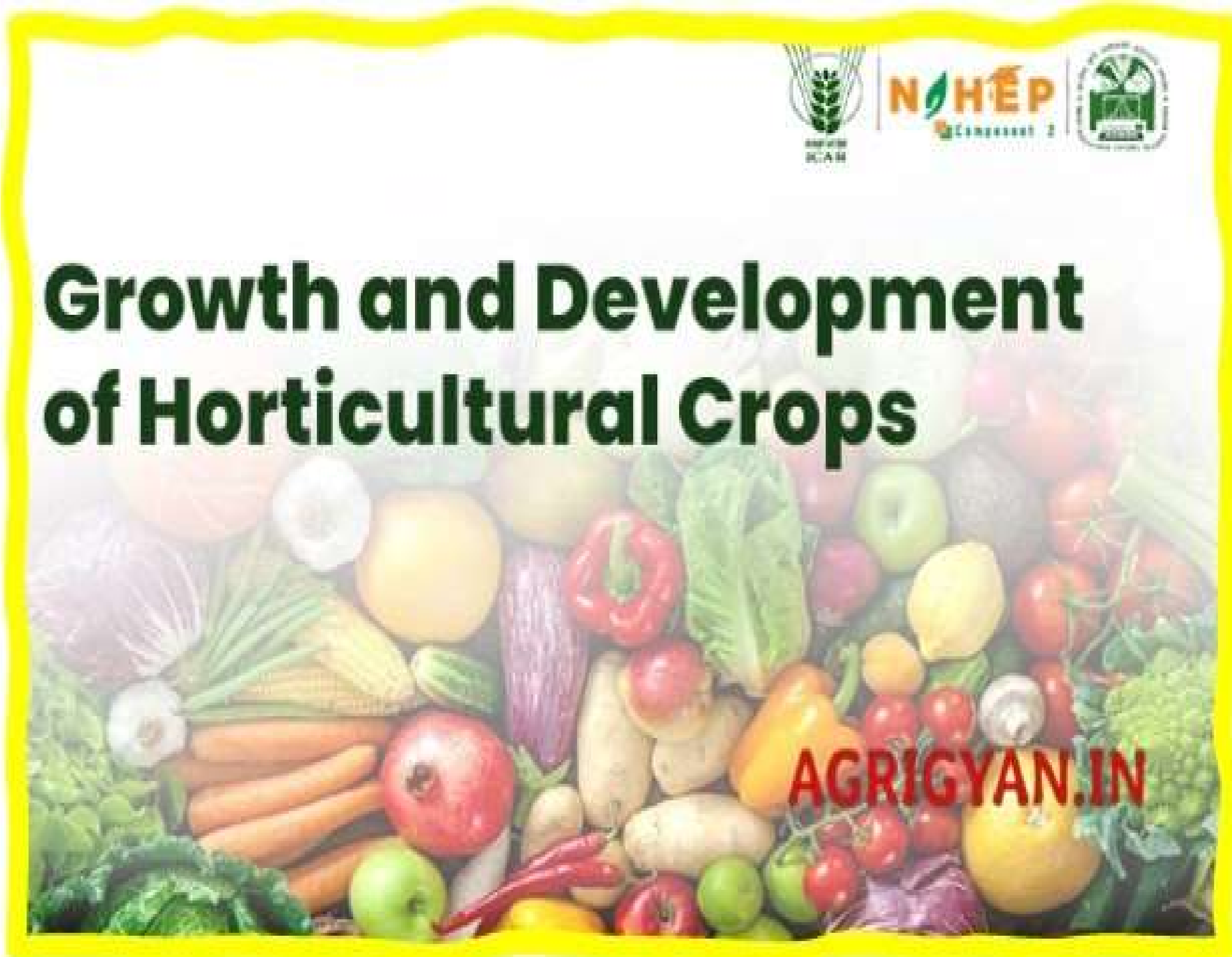
Growth and Development of Horticultural Crops



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Lesson Number	Lesson Name

Course Name	Growth and Development of Horticultural Crops
Lesson 1	Growth and Development of Horticultural Crops
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University/College Name	Bihar Agricultural University, Bhagalpur
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Learning Objectives:

- To learn about growth development of horticultural crops.
- To get the basic idea about growth phases and characteristic feature of growth of the plant

Growth

Growth is defined as an irreversible increase in size and volume of plant accompanied by increase in dry weight. It refers to the quantitative changes of plant parts. It may be evaluated by measurements of mass, length or height, surface area or volume of the plant. Growth is restricted only to living cells and is accomplished by metabolic processes involving synthesize of macromolecules such as nucleic acids, proteins, lipids and polysaccharides at the expense of metabolic energy.

Type of plant growth

On the basis of growth on different organs, it can be classified as

a. **Vegetative growth:** Growth occurs from seed germination till before initiation of floral primordia. Important events during vegetative growth phase are seed germination, seedling emergence, leaf and stem growth etc.

b. **Reproductive growth:** Growth that occurs from initiation of floral primordia till completion of seed formation. The important events during reproductive growth phase are the initiation of floral primordia, flower emergence, anthesis, pollination, fertilization, seed development and maturation.

   Depending on the number of reproductive phases, plant can be grouped as **monocarpic (semelparous)** having one reproductive phase in its entire life span such as banana, pineapple etc and **polycarpic (iteroparous)** having multiple reproductive phase in its life span. Almost all the perennial fruit crops (mango, citrus, guava, grape, pomegranate etc.) are polycarpic in nature.

On the other hand, depending upon the continuity of growth, it is again classified as

a. **Determinate growth (not continuous):** Apical meristem soon becomes differentiated into an inflorescence and growth in term of shoot length becomes stopped. Examples – Mango, Apple.
b. **Indeterminate growth (continuous):** In most of the plants shoot apical meristem remains active throughout the life of the plant and continues to form new tissues and organs. Such type of growth is called indeterminate growth. Examples – Citrus, Guava, Tomato cultivar Arka Vikas, ARTH 4, Arka Saurabh, BSS 90 etc.

Development

It refers to the qualitative changes in plant parts. Example – panicle emergence, formation of flowers, fruit setting, fruit ripening, falling of leaves etc.

Phases of growth

The growth is mainly accomplished in three main phases:

1. **Cell division**
    - In this phase, cells divide and increase in number.

- If the plane of the cell division is transverse, the organ elongates as in stem and root.
- If the plane is longitudinal, then girth or diameter increases.

2. Cell elongation

- Enlargement is not symmetric in all planes, but enlargement is predominantly takes place in longitudinal direction.
- During the process the young cells absorb water due to higher osmotic pressure. As a result turgor pressure increases and cell wall stretches. Before cell division and enlargement nucleic acids, proteins, lipids, carbohydrates and other metabolites are synthesized in the cells which are utilized for synthesis of protoplasm and constituents like mitochondria, ribosomes, plastids, membrane and others.
- During this time protoplasm forms only a thin layer lining of the cell wall and a large vacuole filled with cell sap occupies the centre.
- Stretching of cell wall is made permanent by addition of cell wall materials to the original wall which becomes thicker and capable of further extension.
- New molecules may be inserted between original molecules known as intussusceptions.
- Other method in which new material is deposited by the protoplasm as a lining to the cell wall layers already present is known as apposition.

3. **Cell differentiation**

   - After cell division and enlargement, cells change their shape and the cell wall thickens.
   - Cell differentiation is the process of specialization of cells to perform different functions. Examples - formation of xylem tracheids, sieve elements of phloem, guard cells of stomata from simple parenchymatous cells.

Characteristic Features of Plant Growth

- Growth in plants is restricted to certain zones, recently produced by cell division in a meristem. It is easy to confuse growth (as defined above as an increase in size) with cell division in meristems. Cell division alone does not cause the increment of plants by volume or dry masses, but the cellular products of division also increase in volume and cause growth.
- Root and shoot tips (apices) are meristematic in nature.
- Other meristematic tissues are found in the vascular cambium and just above the nodes of monocots or at the bases of grass leaves.
- The root apical meristems are formed during embryo development while shoot apical meristems are formed during seed develop and are called as primary meristems. However, the vascular cambium and the meristmatic zones of monocot nodes and grass leaves are indistinguishable until after germination. They are known as secondary meristems.
- Some plant structures are determinate which grows to certain size and then stops, eventually undergoing senescence and death. Leaves, flowers, and fruits are good examples of determinate structures. On the other hand, the vegetative stem and root are indeterminate structures. They

grow by meristems that continuously replenish themselves and remaining live. A bristlecone pine that has been growing for 4,000 years could probably yield a cutting that would form roots at its base, producing another tree that might live for another 4,000 years. At the end of the time, another cutting might be taken and so on, potentially forever.

- Some fruit trees have been propagated from stem cuttings for centuries.
- Although indeterminate meristems can be killed, it is potentially immortal. But death is the ultimate fate of determinate structures. When an indeterminate vegetative meristems becomes reproductive (begins to form a flower), it becomes determinate.
- Some crops produce flower and fruit once in their entire life cycle which is termed as monocarpic crop like banana, pineapple etc; while others produce flower and fruit multiple time in their life cycle and termed as polycarpic crop like mango, citrus, sapota, pomegranate etc.
- Most monocarpic species are annuals in nature (live only one year), but there are variations in them. Many annuals germinate from seeds in the spring, grow during the summer and autumn, and die before winter, perpetuating themselves only as seeds like tomato, cape gooseberry etc.
- Typical biennials, such as beet (*Beta vulgaris*), carrot (Daucus carota), and henbane (*Hyoscyamus niger*) germinate in the spring and spend the first season as a vegetative rosette of leaves that dies back in late fall. Such a plant overwinters as a root with its shoot reduced to a compressed apical mersitem surrounded by some remaining protective dead leaves (meristem plus leaves is called as perenniating bud). During the second

summer, the apical meristems form stem cells that elongate and bolt into a flowering stalk.

- The century plant (*Agaves americana*) may exist for a decade or more before flowering and once attain flowering, it may die. Though a monocarpic species, it would be called a perennial because it lives for more than two growing seasons.
- Bamboos (*Bambusa* and other genera) which may live more than half a century before flowering, die after flowering. Hence, it is an excellent example of the extreme monocarpic growth habit.
- Polycarpic plants, perennials by definition, do not convert all their vegetative meristems to determinate reproductive ones.
- Woody perennials (shrubs and trees) may use only some of their axillary buds for the formation of flowers, keeping the terminal buds vegetative. Alternatively, terminal buds may flower while axillary buds remain vegetative. Sometimes, a single meristem forms only one flower like tulip, whereas single grass or Asteraceae meristem forms an inflorescence or head of flowers (for example, sunflower, bottle brush, *Callistemon* sp.)

Growth curve

- A growth curve is a way to visually represent the growth of some phenomena over time, either in the past or into the future or both.
- Growth curves are typically displayed on a set of axes where the x-axis is time and the y-axis quantifies the amount of growth achieved during that time period.
- In plant, growth at all phases is not equal. It is slow at initial phase followed by a rapid growth at middle phase and gradually declines at final

phase and completely stops at the end. Middle phase is the exponential phase of growth where growth is considered to be maximum.

- When growth of the plant is plotted against time, usually 'S' shaped curve is obtained.
- This curve is called as Sigmoid Curve or Grand Period Curve.
- The growth curve remains same whether it is measured in terms of increase in height, fresh weight, dry weight or volume.
- Environmental conditions may alter growth rates but not the sigmoid form of the growth curve.
- In the initial stage, growth rate remains slow called **lag phase**. Then growth increases very fast known as **log phase**, exponential growth phase. Towards the end, growth becomes slowed down called **stationary phase** or steady phase.
- The total time during which this course of growth takes place is called as the 'Grand period of Growth'.
- https://www.toppr.com/ask/question/typical-growth-curve-in-plants-is-2/

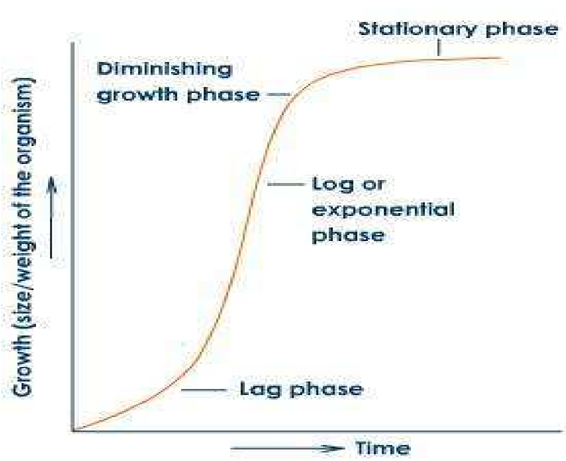

Figure: Sigmoid growth curve of plant

Course Name	Growth and Development of Horticultural Crops
Lesson 2	Growth Analysis
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Learning objectives:

- To learn about different growth parameters
- To get the basic knowledge about how to calculate different growth parameters

Glossary

1. **Net photosynthetic production:** Amount of photosynthates left after the respiration and other biochemical reactions.
2. **Biomass:** Dry weight of whole plant including roots. It is also expressed as organic matter or energy content of plant.
3. **Primary productivity:** Rate of plant production over a certain period of time. It is also measured in terms of increase in dry weight, organic matter, CO_2 assimilation and solar energy fixed.

Introduction

- The analysis of yield influencing factors and plant development as net photosynthate
  accumulation integrated over time is known as growth analysis.
- It can be measured at individual plant level or plant communities.
- The analyses made at individual plantlevel are Relative Growth Rate (RGR), Absolute Growth Rate (AGR),Net Assimilation Rate (NAR), Leaf Area Ratio (LAR), Specific Leaf Area (SLA), Specific Leaf Weight (SLW) and allometry (shoot/root ratio).
- However, Leaf Area Index (LAI), Leaf Area Duration (LAD), Crop Growth Rate (CGR) and Total Dry Matter Accumulation (TDMA) are mainly used for the analysis of growth at plant community level.

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- The technique of growth analysis is advantageous as it helps to find out the relationship between photosynthetic production and rate of increase in dry matter.
- Analysis of growth helps to generate information regarding growth activity of a particular crop and also helps to provide better understanding over the yield potential of the crop.

Parameters used to analyse the growth

1. Leaf Area

It is the surface area of leaf, actively participated in photosynthesis. Total leaf area per plant is often a useful measurement in bio-productivity studies. Area can be measured by graphicmethods, weight method, by using Leaf Area Meter and Linear measurement method(by measuring length and breadthof the leaf)and expressed in cm^2 $plant^{-1}$.

A) Weight method

$$LA = \frac{X}{A} \times B$$

Where

X = known area of leaves

A = dry weight of known area of leaf

B = dry weight of unknown area of all leaves

- Usually the 3rd leaf from the top is used to measure the area as known sample (X) and then dried to get dry weight of known sample (B).

B) Linear measurement method

LA = LBK (cm^2 or m^2)

Where L=maximum length, B=maximum breadth, K=constant (can be worked out by

regression analysis)

K value may not be the same for different varieties in the same species

2. Leaf Area Index (LAI)

Williams (1946) proposed the term, Leaf Area Index (LAI). It is the ratio of the leaf area of the crop to the ground area occupied by the plant over a period of interval of time. The value of LAI should beoptimum at the maximum ground cover area at which crop canopy receives maximum solarradiation and hence, the TDMA will be high.

$$\text{LAI} = \frac{\text{Total leaf area of a plant}}{\text{Ground area occupied by the plant (Spacing)}}$$

3. Leaf Area Ratio (LAR)

The term, Leaf Area Ratio (LAR) was suggested by Radford (1967). It is theratio between the area of leaf to the total plant biomass. It also reflects theleafiness of a plant or amount of leaf area formed per unit of biomass and expressed in $cm^{-2}g^{-1}$ of plant dry weight.

$$\text{LAR} = \frac{\text{Leaf area per plant}}{\text{Plant dry weight}}$$

4. Leaf Weight Ratio (LWR)

The term leaf weight ratio was coined by Kvet*et al.,* 1971.It is the ratio of total leaf dry weight to whole plant dry weight and is expressed in $g\ g^{-1}$.

$$LWR = \frac{\text{Leaf dry weight}}{\text{Plant dry weight}}$$

5. Leaf Area Duration (LAD)

To correlate dry matter yield with LAI, Power *et al.* (1967) integrated the LAIwith time and the new term called as Leaf Area Duration was appeared. It is ability of the plant to maintain the green leaves per unit area of the landover a period of time. It reflects the vitality of leaves and an opportunity for photosynthetic assimilation.It also measures the persistence of the assimilating surface and is expressed in days.

$$LAD = \frac{L1 + L2}{2} X (t2 - t1)$$

L1 = LAI at the first stage

L2 = LAI at the second stage

(t2 - t1) = Time interval between first and second stage in days.

6. Specific Leaf Area (SLA)

Specific leaf area is a measure of the leaf area of the plant to leaf dry weight. It is expressed in cm^2g^{-1} as proposed by Kvet*et al.* (1971).

$$SLA = \frac{\text{Leaf area}}{\text{Leaf dry weight}}$$

Hence, if the SLA is high, the photosynthesizing surface will be high. However norelationship with yield could be expected.

7. Specific Leaf Weight (SLW)

It is a measure of leaf weight per unit leaf area. The term was suggested by Pearce *et al.* (1968) and expressed as gcm^{-2}. More SLW indicatesmore biomass production per unit leaf area and hence, a positive relationship with yield can be expected.

$$SLW = \frac{\text{Leaf weight}}{\text{Leaf area}}$$

8. Net Assimilation Rate (NAR)

The term, NAR was used by Williams (1946). NAR is defined as dry matterincrement per unit leaf area or per unit leaf dry weight per unit of time. The NAR is ameasure of the average photosynthetic efficiency of leaves in a crop community. It is expressed as the grams of dry weight increase per unit dry weight or area per unittime ($g\ g^{-1} day^{-1}$)

$$NAR = \frac{(W2 - W1)}{(t2 - t1)} \times \frac{(\log_e L2 - \log_e L1)}{(L2 - L1)}$$

Where, W1and W2 are dry weight of whole plant at stage 1 and stage 2 respectively.

L1 and L2 are leaf weights or leaf area at stage 1 and stage 2 respectively

t1 – t2 is time interval between stage 1 and stage 2 in days

9. Absolute Growth Rate (AGR)

AGR is the amount of growing material of an individual plant as influenced by theenvironment. It gives absolute values of biomass between two intervals.

It is mainly usedfor a single plant or any plant part of an individual plant e.g. Leaf growth, plant weight etc.

$$AGR = \frac{h2 - h1}{t2 - t1}$$

Where, h1 and h2 are the plant height at stage 1 and stage 2 respectively

t1 – t2 is time interval between stage 1 and stage 2 in days

It is expressed in cm day^{-1}

10. Relative Growth Rate (RGR)

The term RGR was coined by Williams (1946). It is thetotal plant dry weight increase in a time interval in relation to the initial weight or dry matterincrement per unit biomass per unit time.It is expressed in g $g^{-1}day^{-1}$

$$RGR = \frac{\log_e W2 - \log_e W1}{t2 - t1}$$

Where, W1 and W2 are whole plant dry weight at stage 1 and stage 2 respectively

t1 – t2 is time interval between stage 1 and stage 2 in days

11. Crop Growth Rate (CGR)

CGR is a simple and important aid of agriculture productivity. It is the rate ofincrease of dry weight per unit area per unit time. Watson (1958) suggested thefollowing formula of Crop Growth Rate which is expressed in g m^{-2} day^{-1}

$$CGR = \frac{(W2 - W1)}{}$$

ρ (t2 – t1)

Where, W1 and W2 are whole plant dry weight atstage 1 and stage 2 respectively

t1 – t2 is time interval between stage 1 and stage 2 in days

ρ is the ground area on which W1 and W2 are recorded.

CGR of a species are usually closely related to interception of solar radiation and can also be measured by using following formula-

CGR = LAI X NAR

CGR increases as LAI increases to an optimum because of greater lightinterception.

12. Total dry matter production (TDMP)

The TDMP is the biomass accumulated by the whole plant over a period oftime. It is mainly distributed to different parts of the plant such as roots, stems, leavesand the economic parts which control the sink potential.

13. Translocation percentage (TP)

The term translocation percentage indicates the quantum of photosynthatestranslocated from source (leaf or other photosynthetic organs) to sink (fruits or other economic parts of the plant) from flowering to harvest.

$$TP = \frac{\text{Weight of source at flowering} - \text{weight of source at harvest}}{\text{Weight of sink at flowering} - \text{weight of sink at harvest}}$$

14. Light extinction coefficient

It is the ratio of light intercepted by crop between the top and bottom of crop canopyto the LAI.

$$K = \frac{\log_e I / Io}{LAI}$$

Where, Io and I are the light intensity at top and bottom of a population

15. Light Transmission Ratio (LTR)

It is expressed as the ratio of quantum of light intercepted by crop canopy at top to thebottom. Light intensity is expressed in K lux or W m^{-2}

LTR = I / Io

Where, I : light intercepted at the bottom of the crop canopy

Io: light intercepted at the top of the crop canopy

16. Harvest Index (HI)

It reflects the proportion of assimilate distribution between economic yield and total biomass yield and was given by Donald and Hamblin, 1976 as

$$HI = \frac{\text{Weight of economic yield}}{\text{Weight of total biomass}}$$

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1. L.M. Srivastava (2002). Plant Growth and Development: Hormones and Environment. Academic press, San Diego, California, USA. pp. 172-190.
2. J.W.Hart.(1988) Light and Plant Growth. Springer; 1988th edition

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Course Name	Growth and Development of Horticultural Crops
Lesson 3	Factors affecting growth and development of horticultural crops
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University/College Name	Bihar Agricultural University, Bhagalpur
Course Reviewer Name	DR SATESH KUMAR
University/College Name	Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu

Learning Objectives:

- To get the basic knowledge about how different factors affect growth and development of the crops
- To understand the adaptation of the plants towards any influencing factor.

Glossary

- **Cardinal temperature**: cardinal temperatures are the minimum or maximum temperatures through which the limits of growth and development are defined.
- **Photosynthesis**: the process by which green plants and some other organisms use sunlight to synthesize foods from carbon dioxide and water.
- **Biotic**: elating to or resulting from living things, especially in their ecological relations.
- **Abiotic**: physical rather than biological; not derived from living organisms.
- Precipitation: rain, snow, sleet, or hail that falls to the ground.
- **Edaphic**: produced by or influenced by the soil.

Introduction

- The characteristic feature as well the adaptation of any plant to a particular condition is influenced by several factors.
- These factors are mainly classified into two broad groups- Internal factors and external factors.

1. Internal factors

- Genetic factor is mainly considered as internal factor because the basis of plant expression (the gene) is located within the cell.

- The genetic factor determines the characters of a particular plant, but the extent to which this is expressed is influenced by the environment.
- The increase in crop yields and other desirable characters are related to genetic makeup of the plant and not influenced significantly by the environmental factors.
- Similarly, precocity in bearing, resistance to different biotic and abiotic stresses, fruit quality are also less influenced by environmental factors since they are governed by genetic make-up of the crop.

2. External factors

- It includes climatic, edaphic, biotic, physiographic and socio-economic factors.

A. Climatic factors

Precipitation, temperature, relative humidity, solar radiation, wind velocity and atmospheric gases are the variable climatic factors which influences the crop growth and yield and ultimately the yield potential of the crop.

1. Precipitation

Precipitation includes all water which falls from atmosphere in the form of rainfall, snow, hail, fog and dew.

- Rainfall is one of the most important factor influencing the vegetation
- Total precipitation in amount and distribution greatly affects the choice of a cultivated species in a particular place.
- In heavy and evenly distributed rainfall areas, banana, tea, coffee and rubber can grow suitably.

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- Low and uneven distribution of rainfall is common feature of dryland farming which enforce the farmers to grow crops like ber, aonla, date palm etc.
- Distribution of rainfall is more important than the total rainfall for longer growing period especially in dryland farming.

2. Temperature

- Temperature is the measure of intensity of heat energy. The range of temperature for maximum growth of most of the horticultural crops is between 15-40 °C
- Plant growth and development in the form of seed germination, leaf emergence, leaf expansion, emergence of flowers etc are highly influenced by the temperature.
- Physiological and biochemical processes within the plants are governed by air temperature.
- Diffusion rates of gases and liquids within the plant changes with temperature.
- Solubility of different substances in plant is also dependant on temperature.
- The maximum, minimum and optimum temperature requirement of different crops is called as cardinal temperatures. Cardinal temperature for different fruit crops are as follows-

S.N	Crop	Maximum, temperature (°C)	Minimum temperature (°C)	Optimum temperature (°C)
1	Mango	48	20	24-27

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2	Banana	35	15	20-30
3	Sapota	35	10	24-27
4	Guava	40	10	23-28
5	Bael	48	-8	25-30

3. Relative humidity

- Water is present in the atmosphere in the form of invisible water vapour, commonly known as humidity. Relative humidity is the ratio between the amounts of moisture present in the air to the saturation capacity of the air at a particular temperature.
- If relative humidity is 100%, it means that the entire space of the atmosphere is filled with water and there is no soil evaporation and plant transpiration.
- It influences the water requirement of the crop significantly.
- In general, RH of 40-60% is suitable for most of the horticultural crops.
- Very few crops perform well under high RH (above 80%) conditions like Rambutan, Carambola, Banana, Pineapple etc.

4. Solar radiation

- From germination to harvesting and even at post-harvest stage also, plant need light or solar radiation for their proper growth and development.
- Production of biomass through photosynthesis is highly dependent on solar energy.
- All physical process taking place in the soil, plant and

environment are dependent on light

- Photosynthetically active radiation (PAR – 0.4-0.7 p) is essential for the production of carbohydrates and ultimately the plant biomass.
    i. 0.4 to 0.5 p : Blue - Violet – Active
    ii. 0.5 to 0.6 p : Orange - Red – Active
    iii. 0.6 to 0.7 p: Green - Yellow – low active
- Photoperiodism (response of plant to day length) also influences the plant growth and development significantly. On the basis of photoperiodism, plants are classified in the following three groups-
    1. **Long day plants -** Passion fruit, Banana, Apple
    2. **Short day plants** - Strawberry, Pineapple, Coffee
    3. **Day neutral plants**- Papaya, Guava

5. Wind Velocity

- The basic function of wind is to carry moisture and heat along with fresh CO_2 for photosynthesis.
- Wind dispersal of pollen and seeds is a natural and necessary event for several horticultural crops.
- Wind movement @4-6 km h^{-1} is suitable for most of the crops.
- At higher wind velocity, mechanical damage like fall of leaves, breakage of twigs and sometimes damage to the entire crops like banana, papaya etc happens.

6. Atmospheric gases

- The composition of atmospheric gases are CO_2 – 0.03%, O_2 –

20.95%, N_2 – 78.09%, Argon – 0.93% and others – 0.02%.

- CO_2 is very important one particularly for photosynthesis of the plant. CO_2 is absorbed by the plant by the process of diffusion from leaves through stomata. However, it is returned to atmosphere during decomposition of organic matter, and respiration.
- O_2 is important for respiration of both plant and animal while it is released by the plant during photosynthesis.
- N is an important and major plant nutrient. Atmospheric N is fixed in the soil by lightning, rainfall and N-fixing microbes and make them available to the plant.
- However, other gases like SO_2, CO, CH_4, HF released to atmosphere are very toxic to the plant.

B. Edaphic factors

Plant grown in the soil is completely influenced by various soil factors such as soil moisture, aeration, temperature, organic matter content, nutrient status, microbial population and soil reaction.

1. **Soil moisture**

- Water is the principal component for the growing plant which is absorbed by the plant from the soil through their well-developed root system.
- It is essential for photosynthesis.
- Soil moisture that ranged between field capacity to permanent wilting point, is available to the plant.
- Clay soil has more available soil moisture as compared to sandy

soil.

- Further, soil water helps in the activation of different bio-chemical and biological reactions including mineralization.
- Nutrient availability and mobility increases with the increase of soil moisture content.

2. **Soil aeration**

- Aeration in soil is very essential for the absorption of water through roots.
- Germination is inhibited in the absence of O_2 as it is required by the roots and microorganisms present in the soil for respiration.
- Soil air also helps to make the nutrients available to the plants by breaking down the insoluble minerals to soluble salts.

3. **Soil temperature**

- Temperature influences the rate of absorption of water and nutrients from the soil.
- It affects the germination of seeds and rate of growth of underground portion of the crops like potato, tapioca, sweet potato etc.
- It also controls the microbial activities and the biological process involved in the nutrient availability.

4. **Available nutrients in the soil**

- The mineral content present in the soil is derived from the weathering of rocks and minerals.
- It supplies the nutrients to the plants in the form of Ca, Mg, S, Mn, Fe, K etc.

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5. **Soil organic matter**

- Soil organic matter improves the texture of the soil resulting in improved water holding capacity of the soil.
- It also act as an important source of food for different microorganisms
- Organic acids released during decomposition of organic matter accelerate the mineralization processes resulting in increased availability of nutrients to the plant.

6. **Microbial population**

- The raw organic matter in the soil is mainly decomposed by different microorganism present in the soil and makes the nutrient available to the plant
- Atmospheric nitrogen is fixed by microorganisms in the soil and make it available to the plants through symbiotic and non-symbiotic association.

7. **Soil reaction (pH)**

- Soil pH influences the crop growth significantly and neutral soil with pH 7.0 is best suited for most of the horticultural crops.
- The fruit crops suitable for acidic soil (pH < 7.0) are Strawberry, Raspberry, Fig, Bael, Plum
- The fruit crops suitable for alkaline and saline soil (pH >7.0) are Datepalm, Ber, Aonla, Guava, Coconut, Khirni etc.

C. Biotic factors

- Soil fauna like protozoans, nematodes, snails and insects helps in the decomposition of organic matter for their own living.

- Insects and nematodes causes damage to the plant resulting in poor yield. Similarly, different fungi, bacteria and virus also causes significant damage to the plants. Hence, they are considered as harmful organisms.
- Honey bees and wasps helps in cross pollination resulting in improved yield of the crop. Hence, they are considered as beneficial organisms.
- Earthworms facilitates the aeration and drainage of the soil which ultimately improves the plant growth and developmental processes by easy uptake of water and nutrients from the soil.
- Large animals (cattle, goats etc.) cause damage to the crops by grazing.

D. Topographic factors

- Increase in altitude causes decrease in temperature, increase in precipitation and increase in wind velocity which ultimately affect the plant growth and developmental process significantly.
- Steepness in slope causes leaching of nutrients from top soil, resulting in poor crop yield.

E. Socio-economic factors

- To satisfy the food and fodder requirement of farm household, appropriate choice of crops and their varieties (pest and disease resistance, high yield) is done by human intervention.
- The economic condition of the farmers greatly decides the input/resource mobilizing ability on which the growth and development of the crop is greatly dependent.

Course Name	Growth and Development of Horticultural Crops
Lesson 4	Applications of Plant Growth Regulators in Horticulture
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Course Reviewer Name	DR SATESH KUMAR
University/College Name	Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu

Learning Objectives:

- To know about the role of plant growth regulators in horticulture
- To get basic idea about the exact timing for application of a particular PGR

Glossary

1. **Plant growth regulators (PGRs):** It refers to both natural as well as synthetic compounds which affect the growth and developmental process in plants. It includes plant hormones, synthetic and physiologically active growth substances, growth inhibitors, synthetic enzymes, vitamins, organic acid and other compounds which affect the biological activity of the plant system.
2. **Plant bio-regulators (PBRs):** It refers to organic compounds other than nutrients which in small quantities promote, inhibit or otherwise modify the physiological process of the plant.
3. **Plant hormones or phytohormones:** It refers to the compounds, produced within the plant system which usually move within the plant from the site of production to the site of action and regulate plant physiological process in physiologically very low concentration.

Introduction:

- Phytohormones are classified into five broad groups- Auxin, Gibberellins, Cytokinins, Ethylene and Abscisic acid.
- However, apart from these other phytohormones are brassinosteroides, jasmonic acid, oligosaccharides, fusicoccin has also been reported as plant hormones.

Applications of plant growth regulators in horticulture

1. Propagation:

- Most of the fruit crops are propagated asexually except papaya, cape gooseberry, phalsa, mangosteen. Sexual propagation is the only means for hybridization and rootstock production. Poor seed germination in some of the fruit crop is major hindrance for sexual propagation.
- Gibberellins (200-500 ppm) are mostly used for seed germination and substitution of chilling requirement.
- Application of IBA @ 500-1250 ppm for soft wood, 1000- 3000 ppm for semi hardwood and 2000-5000 ppm for hardwood cutting is common for the initiation of rooting in cutting in different fruit crops.
- Apart from auxin, a large number of physiologically and chemically unrelated compounds such as phenols and allied simple aromatic compounds, glucosides, growth inhibiting, growth retarding and ethylene producing chemicals significantly influence the rooting in cuttings.
- In a few cases, growth retardant such as SADH has also proved beneficial in root induction. GA has antagonistic effect on rooting in cutting.

2. Use in micropropagation:

- Auxin and cytokinin are used to support basic level of growth of explants grown under in vitro condition. For shoot initiation high cytokinin: auxin (BA: IAA) ratio is required while for root induction high auxin: cytokinin (IBA: BA) is essential. Usually 0.1 and 1.0 mg/l Benzyl Adenine (BA) helps in terminal and lateral shoot formation in almond-peach hybrid under in vitro condition, respectively while 0.1-0.2 mg/l IBA is most suitable for root induction.

- Somatic embryogenesis from nucallar explants occur in the presence of 2,4-D at low concentration.

3. Breaking of seed and bud dormancy:

- Seeds of many fruit crops often require an extended period of after ripening at low temperature before germination. Breaking of rest is very important to overcome dormancy. GA_3 (200-500 ppm) is used for accelerating seed germination in different fruit crops.
- The treatment of GA_3 (200 ppm) significantly reduced/substituted the period of seed stratification.
- Termination of bud rest by GA_3 (200-250 ppm) spray is a common practice in temperate fruit. It also successfully reduces the period of chilling requirement.

4. Control of vigour:

- In fruit crops, tree size control is important for producing dwarf trees suitable for high density orcharding. The use of different growth retardant like SADH/ paclobutrazal is effective in reducing the growth of apple, apricot, lemon, litchi, mango, pear, peach, plum.

5. Flowering:

- Ethylene is the active principle responsible for flowering in pineapple. Apart from this Acetylene, calcium carbide, ethephon, NAA are other chemicals which helps in floral induction in fruit crops. NAA @ 10- 15 ppm alone and Ethrel or ethephon @ 25 ppm in combination of urea (2%) and

$CaCO_3$ (0.04%) is very effective for the induction of flowering in pineapple.

- Paclobutrazal (PP_{333}) has shown great promise for regulating flowering fruiting in mango. PP_{333} (800-1000 ppm) alone or in combination of urea (2%) successfully induced vegetative flush in fruiting shoot of mango simultaneously.
- NAA replaces girdling for improved flowering by mobilization of assimilates in the tree while SADH promotes flowering in apple, pear, peach, lemon, blue berry and reduced shoot growth. Grape and lemon respond to cycocel (CCC) treatment for increased flowering.

6. **Parthenocarpic fruit development:**

- In general, auxins (IAA, IBA, phenoxy acetic acid) -induce parthenocarpy in fruit crop particularly in pineapple, citrus, banana etc. In apple, pear, peach, apricot, almond- GA_3 while in Grape- cytokinin and 4-CPA is commonly used to induce parthenocarpy.
- In mango- BA @ 250 ppm at anthesis followed by GA_3 @250 ppm and β-NoA @ 10 ppm at fortnight interval

7. **Fruit thining**:

- Auxins at higher concentration (100-300 ppm). In grape- GA_3 @ 40-60 ppm at post-bloom stage

8. **Fruit growth and maturity:**

- Auxins- increase fruit size. In grape- GA_3 (40-60 ppm) alone or in combination with brassino steroids after fruit set increases fruit sized and shape.

9. Control of fruit drop:

- Auxins (2,4-D, NAA, 2,4,5-T) at low concentration (10-30 ppm) is very effective for preventing fruit drop in different fruit crops

10. **Improvement of fruit quality:**

- In grape- GA_3 (40-60 ppm) at colour break stage increase TSS and sugar content and reduced acidity.

11. Fruit ripening:

- Ethylene @ 250 ppm at fruit maturity is effective for ripening of fruits. Ethephon @ 1000 ppm- causes de greening in citrus while Cycocle (500 ppm) applied twice at 15 days interval at early maturity in Kagzi lime- results harvesting 20 day earlier.

12. Harvesting:

- Ethrel- in temperate fruit while cycloheximide- in mango, citrus is most effective for this purpose.
- However, GA_3 10 ppm inhibit de greening process and extending the shelf life of the fruit

References

1. Amarjit Basra. 2000.Plant Growth Regulators in Agriculture and Horticulture: Their Role and commercial Uses. CRC Press, 264p

2. L.G. Nickell 2011. Plant Growth Regulators Publisher : Springer Publication

Course Name	Growth and Development of Horticultural Crops
Lesson 5	Auxin
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Learning objectives

- To get basic knowledge about auxins in details.
- To know about the role of auxins in horticulture.

Glossary

Anther: The top of a stamen's filament; divided into pollen sacs in which the pollen grains form

apical meristem: A meristem (embryonic tissue) at the tip of a shoot or root that is responsible for increasing the plant's length.

Auxins: A group of hormones involved in controlling plant growth and other functions; once thought responsible for phototropism by causing the cells on the shaded side of a plant to elongate, thereby causing the plant to bend toward the light.

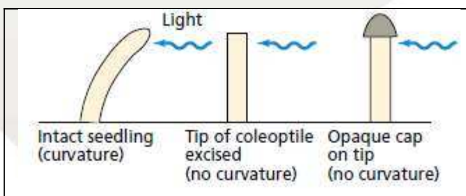
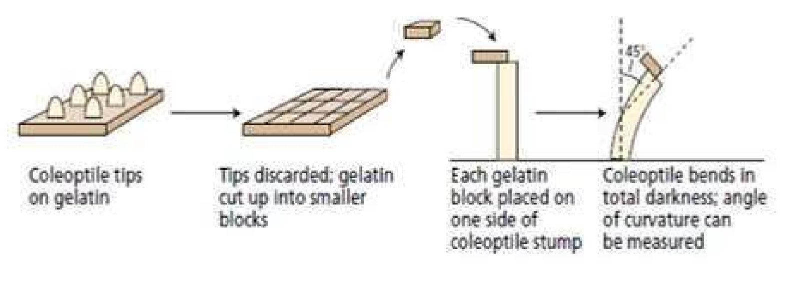
Axillary buds: Buds borne in the axil (where the leaf meets the stem) of a stem.

Introduction

- Auxin is considered as the first plant hormone.
- The event of discovery of auxin started with the study of Charles Darwin and his son Francis during last quarter of the 19th century on tropisms.
- Darwin illuminated the coleoptile of canary grass (*Phalaris canariensis*) from one side and observed that the coleoptile bent towards the light source. While cutting the tip portion of the coleoptile and placing an opaque cap at the tip, he found no response. Form this, he concluded that the light perception occurred in the tip only. Since, the bending occurred at the sub-terminal portion of the coleoptile, he concluded that some sort of signal is

produced in the tip, travels to the growth zone, and causes the shaded side to grow faster than the illuminated side. The results of their experiments were published in 1881 in a remarkable book entitled "*The Power of Movement in Plants*".

- During the year 1926, Frits Went placed the cut coleoptile tips on the agar plate and collected the diffusate and placed this agar block long with the diffusates on the cut coleoptile. He observed the same curvature even in dark which was observed by Darwin initially. He also developed a method for determining the amount of this growth substance He also developed a method for determining the amount of this growth substance which is active in very small amounts in the Avena coleptile tips. This method or the bioassay is commonly known as Avena Curvature Test and the diffusate was eventually named as auxin.
- In Greek 'auxein' meaning "to increase" or "to grow."

	
Darwin (1880)	**Went (1926)**

Biosynthesis of auxin (IAA):

- In 1935, Thimann demonstrated that a fungus *Rhizopus suinus* could convert an amino acid tryptophan (trp) into indole-3 acetic acid (IAA). Since then, it is generally considered that tryptophan is primary precursor of IAA in plants.

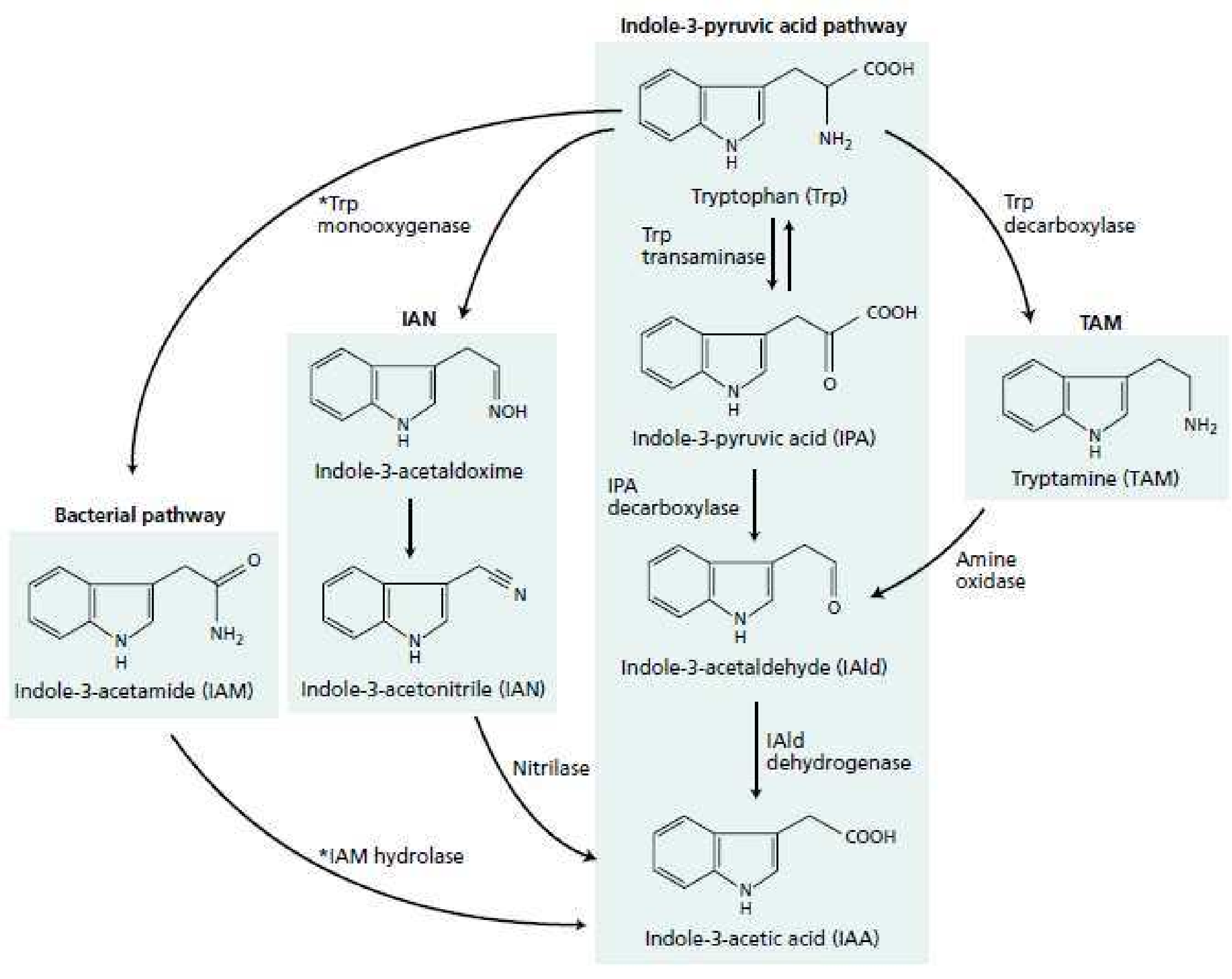
- The indole-3-acetic acid (IAA) can be formed from tryptophan by 3 different pathways-

1. **The IPA pathway:**
   - The indole-3-pyruvic acid (IPA) pathway is probably the most common tryptophan-dependent pathways for the production of IAA.
   - It involves a deamination reaction to produce IPA followed by a decarboxylation reaction to produce indole-3-acetaldehyde (IAld) which is then oxidized to IAA.
   - The enzymes involved in this pathway are Tryptophan transaminase, IPA decarboxylase and IAld dehydrogenase.
2. **The TAM pathway:**
   - The tryptamine (TAM) pathway is similar to the IPA pathway, except that the order of the deamination and decarboxylation reactions is reversed, and different enzymes are involved.
   - Species that do not utilize the IPA pathway possess the TAM pathway.
   - In tomato), both the IPA and the TAM pathways occurs simultaneously.
   - The enzymes involved in this pathway are Tryptophan decarboxylase, Amine oxidase and IAld dehydrogenase.
3. **The IAN pathway:**
   - In the indole-3-acetonitrile (IAN) pathway tryptophan is first converted to indole-3-acetaldoxime and then to indole-3-acetonitrile which ultimately converted to IAA.
   - The enzymes involved in this pathway are Tryptophan monooxygenase and nitrilase.

- The IAN pathway is very important in only three plant families: the Brassicaceae (mustard family), Poaceae (grass family), and Musaceae (banana family). However, the activities of nitrilase- like genes have recently been identified in the Cucurbitaceae (squash family), Solanaceae (tobacco family), Fabaceae (legumes), and Rosaceae (rose family).

4. Bacterial pathway:

- Another tryptophan-dependent biosynthetic pathway- one that uses indole-3-acetamide (IAM) as an intermediate -is observed in various pathogenic bacteria, such as *Pseudomonas savastanoi* and *Agrobacterium tumefaciens*.
- This pathway involves the two enzymes tryptophan monooxygenase and IAM hydrolase. The auxins produced by these bacteria often elicit morphological changes in their plant hosts.



Tryptophan-dependent pathways of IAA biosynthesis in plants and bacteria

Transportation of auxin in plant

- Auxin is the only plant growth hormone known to be transported polarly.
- In stems, polar transportation of auxin is basipetal *i.e.*, from apex towards base.
- Recently it has been recognized that a significant amount of auxin transport also occurs in the phloem, and that the phloem is probably the principal route by which auxin is transported acropetally (*i.e.,* toward the tip) in the root.

- Polar transport of auxin in coleus stem sections to be both basipetal and acropetal in the ratio of 3:1.

Regulation of auxin in plant system

- Within the plant, the auxins may be present in two forms-free auxins and bound auxins.
- Free auxins are those which can be easily extracted by various organic solvents such as diethyl ether or those which are easily diffusible, similar to that obtained in agar block from cut coleoptiles tip.
- Bound auxins on the other hand, need more drastic methods for their extraction from plants such as hydrolysis, autolysis, enzymolysis etc., and are not easily diffusible.
- Bound auxins occur in plant as complexes (conjugated auxins) usually with carbohydrates such as glucose, arabinose or sugar alcohols, or proteins or amino acids such as aspartate, glutamate or with inositol.
- The free form of auxin is biologically active form of the hormone while the bound or
- Conjugated form (which predominates in plants) is considered to be biologically inactive form.
- The metabolism of bound or conjugated auxin might be a major contributing factor in controlling level of free auxin in plants.

Site of IAA synthesis

- Young tissues, shoot tips, young bud, young leaves, young fruit and immature seeds are the sites of IAA synthesis.

- Within cell, it is synthesized in the plastids. However, some literature also suggested that IAA biosynthesis can occurred in cytoplasm too.

Natural auxins:

- Indole-3-acetic acid (IAA), Indole-3-butyric acid (IBA), 4-chloroindole-3-acetic acid (4-Cl-IAA) and phenyl acetic acid (PAA) are the naturally occurring auxins.

Synthetic auxins:

- 2,4-dichlorophenoxy acetic acid (2,4-D), 2,4,5-trichlorophenoxy acetic acid (2,4,5-T), 2-methyl-4-chlorophenoxyacetic acid (MCPA), Naphthalene acetic acid (NAA), 2,3,6-trichlorobenzoic acid (2,3,6-TCBA) and Methoxy-3,6-dichlorobenzoic acid (Dicomba) are the synthetic auxins.

Auxin inhibitors:

- Several synthetic compounds are known which inhibit the action of IAA in a competitive manner; however, the inhibitory action is overcome by supplying excess IAA. These compounds are known as antiauxins. Eg. – α-(ρ-chlorophenoxy) isobutyric acid (PCIB).
- However, some compounds inhibit the basipetal or polar transportation of IAA within the plant system. They are called as auxin inhibitor. Eg.- Triiodobenzoic acid (TIBA), naphthylphthalamic acid (NPA) etc.

Physiological effect of auxin in plant system

1. Apical Dominance

- In most of the higher plants, the growing apical bud inhibits the growth of lateral (axillary) buds - a phenomenon called apical dominance.
- Removal of the shoot apex (decapitation) usually results in the growth of one or more of the lateral buds.
- It was found that auxin (IAA) is the responsible PGR for this apical dominance and removal of auxin by decapitation of apical bud helps to growth the lateral bud underneath.

2. Formation of Lateral and Adventitious Roots

1. Although elongation of the primary root is inhibited by auxin concentrations greater than 10^{-8} M, but initiation of lateral (branch) roots and adventitious roots is stimulated by high auxin levels.
2. Lateral roots are commonly found above the elongation and root hair zone and originate from small groups of cells in the pericycle. Auxin stimulates these pericycle cells to divide.
3. The dividing cells gradually form into a root apex, and the lateral root grows through the root cortex and epidermis.
4. Adventitious roots (roots originating from nonroot tissue) can arise in a variety of tissue locations from clusters of mature cells that renew their cell division activity. These dividing cells develop into a root apical meristem in a manner somewhat analogous to the formation of lateral roots.
5. In horticulture, the stimulatory effect of auxin on the formation of adventitious roots has been very useful for the vegetative propagation of plants by cuttings. Layering.

3. Delays in onset of abscission

- The shedding of leaves, flowers, and fruits from the living plant is known as abscission. These parts abscise in a region called the abscission zone, which is located near the base of the petiole of leaves.
- Auxin levels are high in young leaves, progressively decrease in maturing leaves, and are relatively low in senescing leaves when the abscission process begins.
- During the early stage of leaf abscission, application of IAA inhibits leaf drop.
- However, application of auxin at later stage hasten the process of abscission, probably by inducing the bio-synthesis of ethylene.

4. Floral Bud Development

- Polar auxin transportation in the inflorescence meristem is required for normal floral development.
- In the absence of the auxin efflux carriers, the meristem is starved for auxin, and normal phyllotaxis and floral development are disrupted.

5. Fruit Development

- Auxin is involved in the regulation of fruit development.
- Auxin is produced in pollen and in the endosperm and the embryo of developing seeds, and the initial stimulus for fruit growth may result from pollination. Successful pollination initiates ovule growth, which is known as fruit set. After fertilization, fruit growth may depend on auxin produced in developing seeds. The endosperm may contribute auxin during the initial stage of fruit growth, and the developing embryo may take over as the main auxin source during the later stages.

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6. Vascular Differentiation

- The relative amounts of xylem and phloem formation is regulated by the auxin concentration.
- High auxin concentrations induce the differentiation of xylem while low auxin concentration induce phloem formation.
- The regeneration of vascular tissue following wounding is also controlled by auxin produced by the young leaf directly above the wound site.
- Vascular differentiation is polar and occurs from leaves to roots. In woody perennials, auxin produced by growing buds in the spring stimulates activation of the cambium in a basipetal direction. The new round of secondary growth begins at the smallest twigs and progresses downward toward the root tip.

Commercial application of auxin

- Auxins have been used commercially in agriculture and horticulture for more than 50 years.
- The early commercial uses included prevention of fruit and leaf drop, promotion of flowering in pineapple, induction of parthenocarpic fruit, thinning of fruit, and rooting of cuttings for plant propagation.
- Rooting is enhanced if the excised leaf or stem cutting is dipped in an auxin solution, which increases the initiation of adventitious roots at the cut end.
- In stimulating the formation of parthenocarpic fruits, auxin may act primarily to induce fruit set, which in turn may trigger the endogenous production of auxin by certain fruit tissues to complete the developmental process.

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- Ethylene is also involved in fruit development, and some of the effects of auxin on fruiting may result from the promotion of ethylene synthesis.
- Auxins are also widely used as herbicides. 2,4-D and Dicamba are probably the most widely used synthetic auxins as herbicides.
- Synthetic auxins are very effective because they are not metabolized by the plant as quickly as IAA. Because maize and other monocotyledons can rapidly inactivate synthetic auxins by conjugation, these auxins are used by farmers for the control of dicot weeds or broad-leaved weeds.

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Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Course Name	Growth and Development of Horticultural Crops
Lesson 6	Gibberellins
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Course Reviewer Name	DR SATESH KUMAR
University/College Name	Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu

Learning Objectives:

- To get basic knowledge about gibberellin in details
- To know about the role of gibberllin in horticulture

Glossary:

- **Dormancy**
- A period of inactivity or physiological rest, especially in bulbs, buds, seeds, and spores.
- **Germination**
  The beginning or resumption of growth of a seed, embryo, or spore, including pollen grain on a stigma; the sprouting of a seed.
- **Apical dominance**
  The influence of a terminal bud (apical bud) in suppressing the growth of lateral buds.
- **Apical meristem**
  The tissues at the tip of roots and shoots where cells divide, giving rise to new growth.

Introduction:

- A young Japanese scientist Kurosawa worked on rice seedlings infected by the fungus *Gibberella fujikuroi* (asexual stage of *Fusarium monoliforme*). These infected rice seedlings grew taller and turned very thin and pale.
- This is commonly known as 'Bakanae disease' (meaning foolish) prevailed in Japan for over a century.
- In 1926, Kurosawa succeeded in obtaining a filtered extract of this fungus which could cause the symptoms of the Bakanae disease in healthy rice seedlings.

- In 1935, Yabuta and Hayashi purified the active compound from the fungal extract which was quite heat stable and gave it the name gibberellin.

Biosynthesis of Gibberellin:

- Gibberellins are tetracyclic diterpenoids made up of four isoprenoid units, synthesized by a branch of the terpenoid pathway.
- The gibberellin biosynthetic pathway can be divided into three stages-

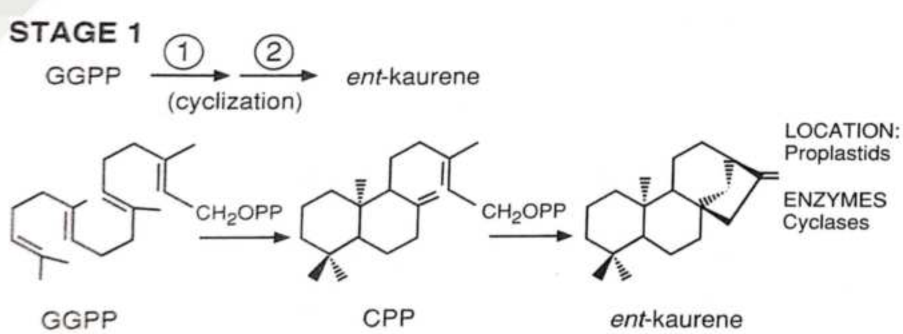
Stage 1: Production of terpenoid precursors and ent-kaurene in plastids

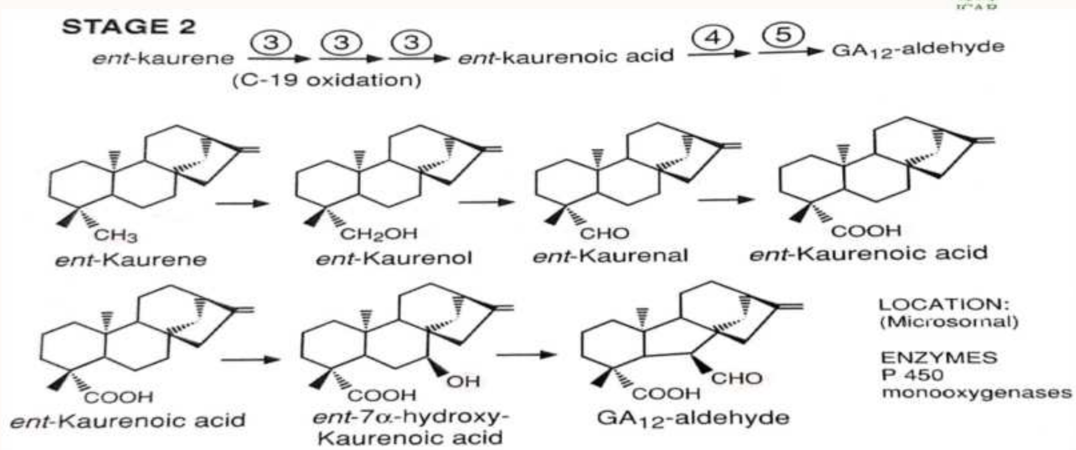
- The basic biological isoprene unit is isopentenyl diphosphate (IPP).
- IPP used in gibberellin biosynthesis in green tissues are synthesized in plastids from glyceraldehyde-3-phosphate and pyruvate.
- Once synthesized, the IPP isoprene units are added successively to produce intermediates of 10 carbons (geranyl diphosphate), 15 carbons (farnesyl diphosphate), and 20 carbons (geranylgeranyl diphosphate, GGPP). GGPP is a precursor of many terpenoid compounds, including carotenoids and many essential oils, and it is only after GGPP that the pathway becomes specific for gibberellins.
- The cyclization reactions that convert GGPP to ent-kaurene represent the first step that is specific for the gibberellin biosynthesis. Two enzymes that catalyze the reactions are localized in the proplastids of meristematic shoot tissues, and they are not present in the mature chloroplasts. Thus, leaves

lose their ability to synthesize gibberellins from IPP once their chloroplasts mature.

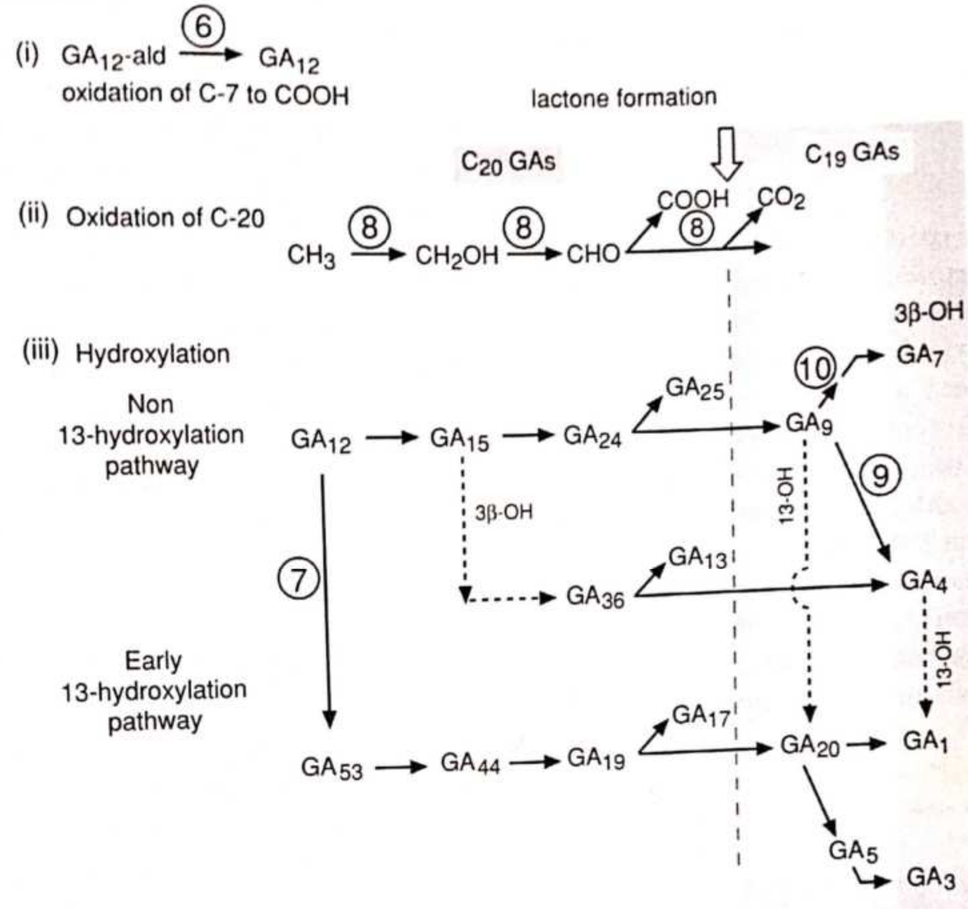
Stage 2: Oxidation reactions on the ER form GA_{12} and GA_{53}

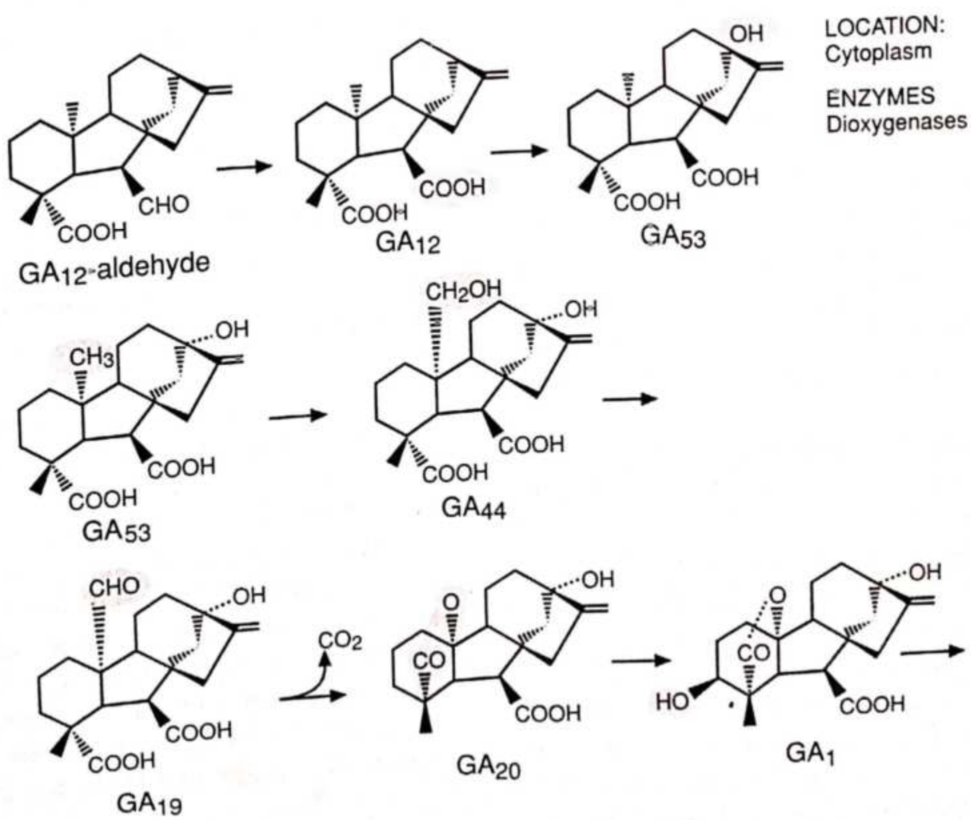
- In the second stage of gibberellin biosynthesis, a methyl group on ent-kaurene is oxidized to a carboxylic acid, followed by contraction of the B ring from a six- carbon to a five-carbon ring to give GA_{12}-aldehyde. GA-aldehyde is then oxidized to GA_{12}, the first gibberellin in the pathway in all plants and thus it is called as the precursor of all the other gibberellins.
- Many gibberellins in plant systems are also hydroxylated on carbon 13 position. The hydroxylation of at carbon 13 position of GA_{12}, helps to synthesize GA_{53}. All the enzymes involved in this particular reaction are monooxygenases that utilize cytochrome P_{450}.
- These P450 monooxygenases are localized on the endoplasmic reticulum. Kaurene is transported from the plastid to the endoplasmic reticulum, and is oxidized to produce kaurenoic acid by kaurene oxidase, which is associated with the plastid envelope.
- Further conversions to GA_{12} take place on the endoplasmic reticulum.




STAGE 2
ent-kaurene
(C-19 oxidation)
ent-kaurenoic acid
GA12-aldehyde
CH3
ent-Kaurene
CH2OH
ent-Kaurenol
CHO
ent-Kaurenal
COOH
ent-Kaurenoic acid
COOH
ent-Kaurenoic acid
COOH
OH
ent-7α-hydroxy-
Kaurenoic acid
COOH
CHO
GA12-aldehyde
LOCATION:
(Microsomal)
ENZYMES
P 450
monooxygenases

STAGE 3


(i) GA12-ald ⑥ GA12
oxidation of C-7 to COOH
lactone formation
C20 GAs
C19 GAs
(ii) Oxidation of C-20
CH3 ⑧ CH2OH ⑧ CHO
COOH ⑧ CO2
(iii) Hydroxylation
Non 13-hydroxylation pathway
Early 13-hydroxylation pathway
3β-OH
GA7
⑩
GA12
GA15
GA24
GA25
GA9
⑨
3β-OH
13-OH
⑦
GA36
GA13
GA4
13-OH
GA53
GA44
GA19
GA17
GA20
GA1
GA5
GA3


GA12-aldehyde
CHO
COOH
GA12
GA53
OH
LOCATION:
Cytoplasm
ENZYMES
Dioxygenases
CH3
CH2OH
GA44
CHO
CO2
GA19
GA20
GA1
HO
CO
O

Stage 3: Formation of all other gibberellins from GA_{12} or GA_{53} in the cytosol

- All subsequent steps in the pathway are carried out by a group of soluble dioxygenases in the cytosol. These enzymes require 2-oxoglutarate and molecular oxygen as co-substrates, and they use Fe^{2+} and ascorbate as cofactors.
- The specific steps in the modification of GA_{12} vary from species to species, and between organs of the same species.
- Two basic chemical changes that occur in most plants are
  - Hydroxylation at carbon 13 position (on the endoplasmic reticulum) or carbon 3 position or both.
  - A successive oxidation at carbon 20 position ($CH_2 \rightarrow CH_2OH \rightarrow CHO$).
- The final step of this oxidation is the loss of carbon at carbon 20 position as CO_2.
- When these reactions involves in gibberellin biosynthesis, initially hydroxylation at C-13 position occurs, resulting the synthesis of GA_{20}.
- GA_{20} is then converted to the biologically active form- GA_1 by hydroxylation of carbon at C-3 position. Finally, GA_1 is inactivated by its conversion to GA_8 by a hydroxylation at C-2 position.
- This hydroxylation can also remove GA_{20} from the biosynthetic pathway by converting it to GA_{29}.

Site of gibberellin biosynthesis

- Young tissues, shoot apices, young leaves, developing fruit and seeds, young root are the sites of GA biosynthesis.

- Besides, young meristematic area in root and shoot tips, procambial or cambial tissues, elongating stems and floral parts are also the important site for GA biosynthesis.
- Within cell, the conversion of GGDP to ent-kaurine (stage 1) occurs in plastid while conversion of ent-kaurine to GA_{12} aldehyde (stage 2) occurs in endoplasmic reticulum. However, the synthesis of different GAs from GA_{12} aldehyde (stage 3) occurs in cytoplasm.

Transportation of gibberellin in plant

- Gibberellins are manly present in the phloem and xylem exudates of a wide range of plants.
- Unlike auxins, the transport of gibberellins in plants is non-polar.
- It is believed that gibberellins are translocated through phloem according to a flow pattern which is similar to those of carbohydrates and other organic solutes.
- However, the transportation of gibberellins may also occur in xylem due to its lateral movement between the two vascular tissues *i.e.* xylem and phloem.
- The gibberellins are not translocated in plant as free molecules but probably in their bound form as gibberellins-glycosides.

Gibberellin inhibitors:

- Several synthetic compounds, known as growth retardants, inhibit stem elongation by inhibiting GA biosynthesis. On the basis of the specific activity of such inhibitory chemicals, they are grouped into three different classes-

- Quaternary ammonium and phosphonium compound - Block the biosynthesis of ent-kaurine from GGDP by inhibiting the activity of coplyl diphosphate synthase. Example- Quaternary ammonium compound (AMO-1618, Chlormequat chloride or CCC, mepiquat chloride), phosphonium (Chlorophonium chloride).
- Nitrogen containing heterocyclic compounds- Inhibit the oxidation of ent-kaurine to ent-kaurinic acid by suppressing the activity of P_{450} monooxygenases. Example-ancymidol, paclobutrazal, uniconazol.
- Acylcyclo-hexanediones – Inhibit de-oxygenase activity by competing for the binding site for the co-substrate 2-oxoglutarate which ultimately inhibit the biosynthesis of different GAs from GA_{12}-aldehyde (Stage 3). Example-Prohexadione-Ca, trinexapac-ethyl.

Physiological effect of gibberellins in plant system

1. Growth of the plant

- Applied gibberellin promotes internodal elongation in a wide range of species.
- However, the most dramatic stimulations are seen in dwarf and rosette species, as well as members of the grass family.
- Exogenous GA_3 application causes such extreme stem elongation in dwarf plants that they resemble the tallest varieties of the same species.
- However, decrease in stem thickness, a decrease in leaf size, and a pale green color of the leaves are also observes simultaneously.

- Although stem growth may be dramatically enhanced by GAs, gibberellins have no direct effect on root growth.

2. Transition from Juvenile to Adult Phases

- Many woody perennials do not flower until they reach a certain stage of maturity; up to that stage they are said to be in juvenile phase.
- Applied gibberellins (GA_4 + GA_7) can regulate this juvenility in both directions, depending on the species.

3. Floral Initiation and Sex Determination

- Gibberellin can be used as the substitute for the long day or cold requirement for flowering in many plants, especially rosette species. Gibberellin is thus a component of the flowering stimulus in some plants.
- In dicots such as cucumber, hemp and spinach, gibberellin application promotes the formation of staminate flowers and inhibitors of gibberellin biosynthesis promote the formation of pistillate flowers. However, in monocot like maize, application of exogenous gibberellic acid to the tassels helps to induce pistillate flowers.

4. Fruit Set

- Applications of gibberellins can cause fruit set (the initiation of fruit growth following pollination) and growth of some fruits, in cases where auxin may have no effect. For example, stimulation of fruit set by gibberellin has been observed in apple (*Malus sylvestris*).

5. Promote Seed Germination

- Seed germination may require gibberellins for one of several possible steps: the activation of vegetative growth of the embryo, the weakening of a growth-constraining endosperm layer surrounding the embryo, and the mobilization of stored food reserves of the endosperm.

- Some seeds, particularly those of wild plants, require light or cold to induce germination. In such seeds, this dormancy can often be overcome by application of gibberellin.

6. **Activate several enzymes**
    - Gibberellin application also stimulates the production of numerous hydrolases, notably α-amylase. This aspect of gibberellin action has led to its use in the brewing industry for the production of malt.

Commercial application of gibberellins

- The major uses of gibberellins as spray or dip, are to manage fruit crops, to malt barley and to increase sugar content in sugarcane.
- In some crops a reduction in height is desirable, and this can be accomplished by the use of gibberellin synthesis inhibitors.
- A major use of gibberellins is to increase the stalk length of seedless grapes. Because of the shortness of the individual fruit stalks, bunches of seedless grapes are too compact and the growth of the berries are restricted. Gibberellin stimulates the stalks to grow longer, thereby allowing the grapes to grow larger by alleviating compaction and it promotes elongation of the fruit.
- A mixture of benzyladenine and $GA_4 + GA_7$ can cause apple fruit to elongate and is used to improve the shape of Delicious-type apples under certain

conditions. Although this treatment does not affect yield or taste, it is considered commercially desirable.

- In citrus fruits, gibberellins delay senescence, allowing the fruits to be left on the tree longer to extend the market period.
- Gibberellin helps in malting of barley. Malting is the first step in the brewing process. During malting, barley seeds are allowed to germinate at temperatures that maximize the production of hydrolytic enzymes by the aleurone layer.
- Gibberellin is sometimes used to speed up the malting process. The germinated seeds are then dried and pulverized to produce malt, consisting a mixture of amylolytic (starch-degrading) enzymes and partly digested starch. During the subsequent mashing step, water is added and the amylases in the malt convert the residual starch, as well as added starch to the disaccharide maltose which is converted to glucose by the enzyme maltase. The resulting wort is then boiled to stop the reaction. In the final step, yeast converts the glucose in the wort to ethanol by fermentation.

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Course Name	Growth and Development of Horticultural Crops
Lesson 7	Cytokinin
Course Creator Name	MANOJ KUNDU
University/College Name	Bihar Agricultural University, Bhagalpur
Course Reviewer Name	DR SATESH KUMAR
University/College Name	Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu

Learning Objectives:

- To get basic knowledge about cytokinin in details
- To know about the role of cytokinin in horticulture

Glossary:

Synthesized: To synthesize a substance means to produce it by means of chemical or biological reactions.

Callus: Soft tissue that forms over a wounded or cut plant surface, leading to healing. A callus arises from cells of the cambium.

Biologically active: Therapeutically or prophylactically active or having diagnostic properties.

Hydroxylated : Describes a chemical process that introduces a hydroxyl group (-OH) into an organic compound.

Cleave: Split or sever (something), especially along a natural line or grain.

Introduction:

- In 1913, German scientist Haberlandt reported that certain diffusible factors from phloem tissue could cause cell division in potato tuber.
- Later on, in the year 1921 he discovered that the healing of cut surface of plant tissues by cell division was prevented when the cut surfaces were washed with water.
- Both these two observations suggested that there are certain soluble substance present in the plant tissue that promoted the cell division.
- In 1956, Carl Miller discovered that a substituted adenine, 6- furfuryl amino purine obtained from autoclaved herring sperm DNA was far more potent than adenine in promoting cell division in tobacco pith explants. This substance was named as kinetin.

- But this kinetin does not synthesized naturally in the plant system.
- Later on, in 1963, D.S. Letham isolated a substance from sweet corn kernels that had high cell division promoting capacity in callus culture. The substance was N^6 substituted adenine [6-(4-hydroxy-3-methyl-*trans*-2-enylamino) purine] and was given the name zeatin from the name *Zea mays.*
- Since, then several naturally occurring as well as synthetic cytokinin were discovered. However, zeatin is the most biologically active cytokinin among all the naturally occurring cytokinins.
- Although kinetin has profound influences in inducing cell division, still it has not been isolated from any plant. But, certain substances which show kinetin like activity have in fact been isolated from a variety of higher plants. These substances are collectively called as cytokinins.

Natural cytokinins:

- *Trans*-zeatin- most biologically active form
- *Cis*-zeatin
- Dihydrozeatin and its ribosyl derivetives
- Isopentenyladenine**-** least free occurrence

Synthetic cytokinins:

- Benzyl adenine (BA) or 6-benzylaminopurine
- Diphenyl urea
- Forchlorofenuron
- Thidiazuron

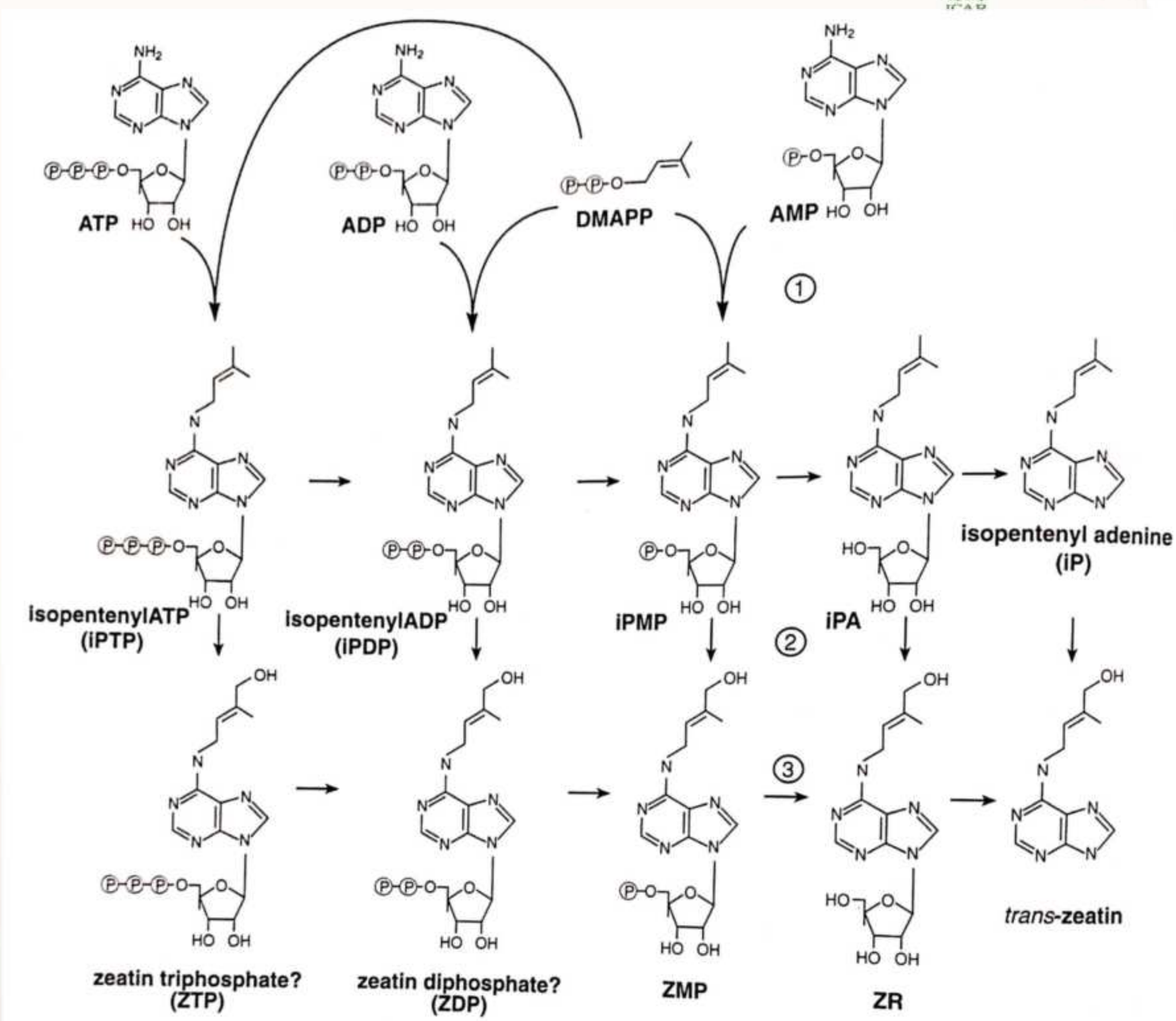
Anticytokinins:

- 3-methyl-7-(3-methylbutylamino) pyrazolo [4,3-d] pyrimidine

- 4- (cyclopentylamino)-2- methylthio-pyrrolo [2,3-d] pyrimidine

Biosynthesis of Cytokinin:

- The first step in cytokinin biosynthesis is the transfer of the isopentenyl group of dimethylallyl diphosphate (DMAPP) to an adenosine moiety (ATP, ADP or AMP) by the enzyme isopentenyl transferase to give rise to corresponding isopentenyl adenosine-tri-, di- or monophosphates (iPTP, iPDP or iPMP).
- The tri- or diphosphate are thought to convert to iPMP.
- Hence, iPMPis known as the immediate precursor for biosynthesis of natural cytokinin
- In second step, iPMP is hydroxylated at C-4 position to give rise to zeatin monophosphate (ZMP).
- P450 monooxygenase play the key role for the hydroxylation at C-4 position.
- Similar hydroxylation can also occurs in iPTP or iPDP to yield corresponding zeatin tri- or diphosphate (ZTP or ZDP) which on subsequent dephosphorylation give rise to ZMP.
- In third step, ZMP is converted to zeatin ribose which in then cleaved to give rise to zeatin and sugar or cleaved directly to give zeatin and sugar prosphate.
- Similarly iPMP gives rise to iPA and iP which can also be hydroxylated to ZR and zeatin, respectively.



Schematic representation of cytokinin biosynthesis

Site of cytokinin biosynthesis

- Young and meristematic tissues: root apices, developing shoot bud, cambial tissues, developing seeds (especially in liquid endosperm), young fruit- where cell division occurs at higher frequency.

Distribution of cytokinin within the plant system

- Among different natural cytokinin, zeatin is the most widely distributed cytokinin in the plant system.

- *Trans*-zeatin is the most active form of zeatin as compared to its *cis* form, although both the forms are free form.

Transportation of cytokinin in plant

- Root apical meristems are the major sites of synthesis of the free cytokinins. The cytokinins synthesized in roots appear to move through the xylem into the shoot, along with the water and minerals taken up by the roots.

Regulation of cytokinin

- Cytokinin oxidases degrade cytokinin irreversibly and may play a role in regulation of the levels of cytokinin within the plant.
- Conjugation of both the side chain and the adenosine moiety to sugars (mostly glucose) also may play a role in the regulation of cytokinin levels and may target sub-pools of the hormone for distinct roles such as transport.
- Cytokinins are also inter-converted among the free base and the nucleoside and nucleotide forms.

Physiological effect of cytokinin in plant system

1. **Cell Division in Shoots and Roots**
    - Cytokinins regulate cell division by affecting the controls that govern the passage of the cell through the cell division cycle.
    - Cytokinins were discovered in relation to their ability to stimulate cell division in tissues supplied with an optimal level of auxin.

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2. **Regulates Morphogenesis in Cultured Tissues**
   - High auxin:cytokinin ratio accelerate the root formation process while low auxin:cytokinin ratio led to the formation of shoots.
   - High auxin:cytokinin ratio in the tumor cells causes the proliferation of roots instead of undifferentiated callus tissue
3. **Modify Apical Dominance and Promote Lateral Bud Growth**
   - Physiological studies indicate that cytokinins play a role in initiating the growth of lateral buds. For example, direct applications of cytokinins to the axillary buds of many species stimulate cell division activity and growth of the buds.
4. **Delay Leaf Senescence**
   - Although applied cytokinins do not prevent senescence completely, their effects can be dramatic, particularly when the cytokinin is sprayed directly on the intact plant.
   - If only one leaf is treated, it remains green although other leaves of similar developmental age have yellowed and dropped off the plant.
5. . **Promote Movement of Nutrients**
   - Cytokinins influence the movement of nutrients into leaves from other parts of the plant, a phenomenon known as cytokinin-induced nutrient mobilization.
6. **Promote Chloroplast Development**
   - If the etiolated leaves are treated with cytokinin before being illuminated, they form chloroplasts with more extensive grana and chlorophyll. Photosynthetic enzymes are also synthesized at a greater rate upon illumination. It suggests that cytokinins along with other

factors such as light, nutrition etc. regulate the synthesis of photosynthetic pigments and proteins.

7. **Promote Cell Expansion in Leaves and Cotyledons**
   - The promotion of cell enlargement by cytokinins is most clearly demonstrated in the cotyledons of dicots with leafy cotyledons such as mustard, cucumber and sunflower. The cotyledons of these species expand as a result of cell enlargement during seedling growth. Cytokinin treatment promotes additional cell expansion, with no increase in the dry weight of the treated cotyledons.
8. **Regulate Growth of Stems and Roots**
   - Although endogenous cytokinins are clearly required for normal cell proliferation in the apical meristem resulting normal shoot growth but applied cytokinins typically inhibit the process of cell elongation in both stems and roots.

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1. L.M. Srivastava (2002). Plant Growth and Development: Hormones and Environment. Academic press, San Diego, California, USA. pp. 191-204.
2. L Taiz, E Zeiger (2002). Plant Physiology (3rd end.). Sunderland: Sinauer Associates, pp. 493-517.

Course Name	Growth and Development of Horticultural Crops
Lesson 8	Ethylene
Course Creator Name	MANOJ KUNDU
University/College Name	Bihar Agricultural University, Bhagalpur
Course Reviewer Name	DR SATESH KUMAR
University/College Name	Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu

Learning Objectives:

- To get basic knowledge about ethylene in details
- To know about the role of ethylene in horticulture

Glossary:

Biosynthesis: The production of complex molecules within living organisms or cells.

Inhibitor: A substance which slows down or prevents a particular chemical reaction or other process or which reduces the activity of a particular reactant, catalyst, or enzyme.

Antagonize: The action of any organism that suppresses or interferes with the normal growth and activity of a plant pathogen.

Permeability: The state, condition, or property of a material (such as a biological membrane) to allow the passage of molecules through it.

Adventitious: A root growing on the stem, leaf, or other body parts apart from the usual the basal root system of the plant, particularly the radicle or root branches.

Introduction:

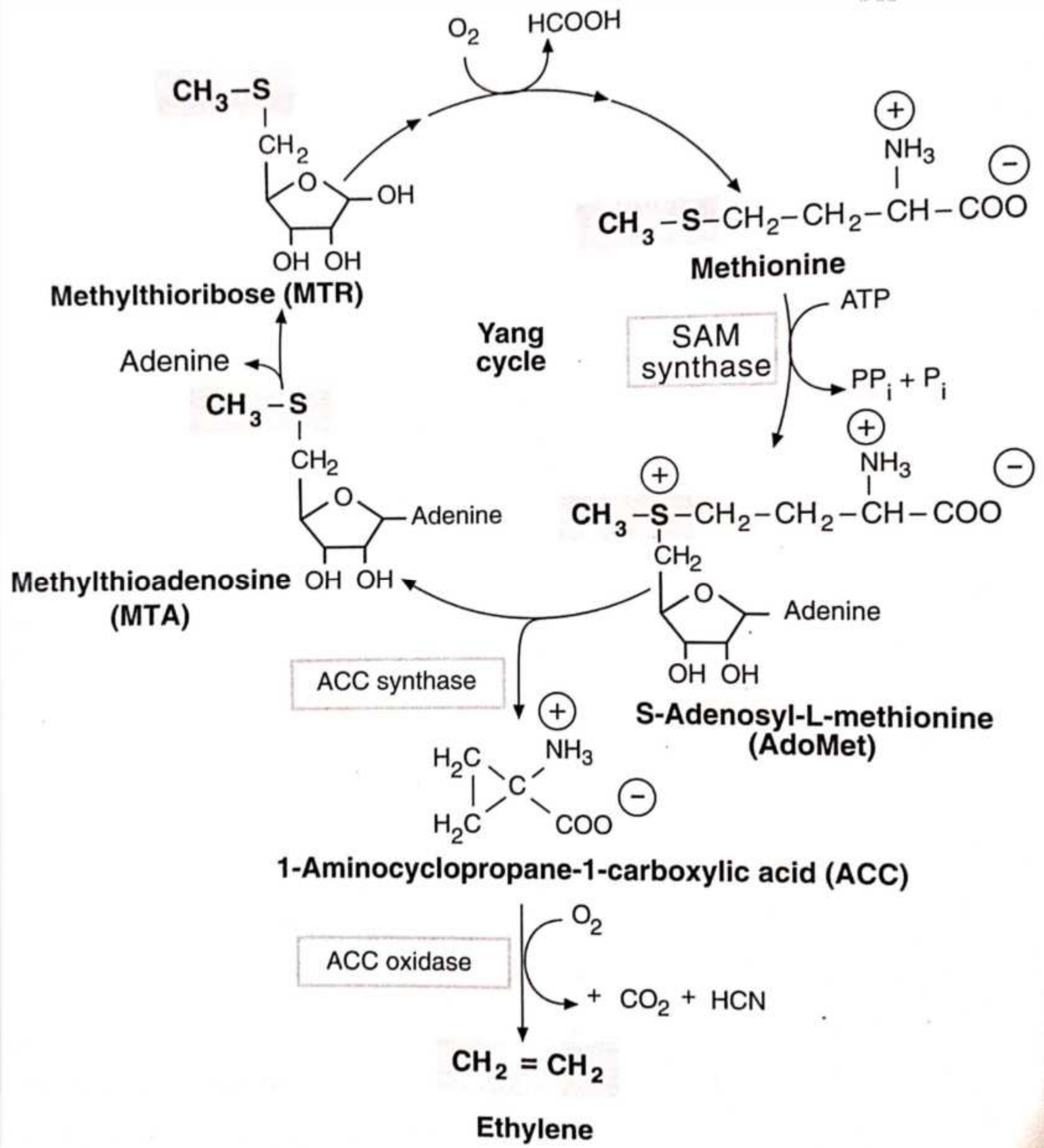
- Ethylene is the only gaseous hormone which also known as ripening hormone.
- During the nineteenth century, when coal gas was used for street illumination, it was observed that trees in the vicinity of street lamps defoliated more extensively than other trees. It was found that coal gas and air pollutants affect plant growth and development and ethylene was identified as the active component of coal gas.

- In 1901, Dimitry Neljubov, observed reduced stem elongation, increased lateral growth of dark-grown pea seedlings (triple response) growing in the laboratory. When the plants were allowed to grow in fresh air, they regained their normal morphology. Later on, Neljubov identified ethylene, which was present in the laboratory air from coal gas, as the molecule causing the response.
- The first indication for ethylene as a natural product of plant tissues was published by H. H. Cousins in 1910 when he observed premature ripening of banana due to its storage with orange. Although oranges synthesize relatively little ethylene compared to other fruits, but these oranges were infected with the fungus *Penicillium,* which produces copious amounts of ethylene resulting premature banana ripening.
- In 1934, R. Gane and others identified ethylene chemically as a natural product of plant metabolism, and because of its dramatic effects on the plant it was classified as a hormone.

Biosynthesis of ethylene:

- Ethylene biosynthesis pathway was worked out in 1970s by Shang Fa Yang and his colleagues at University of California. Hence, ethylene biosynthesis path way is indicated as Yang cycle.
- As per Yang cycle, methionine, a sulphur containing amino acid is converted to S-Adenosyl-L-Methionine (SAM) using ATP. The adenosine moiety of ATP is added to methionine with the release of PPi and inorganic phosphate in a reaction catalysed by SAM synthase.

- Then SAM is cleaved to give rise to 1-aminocyclopropane-1-carboxylic acid (ACC) and methylthioadenosine (MTA) with the help of the enzyme ACC synthase.
- Then, ACC is oxidatively decarboxylated by ACC oxidase to produce ethylene.
- MAT is cleaved by a nucleosidase to give rise to adenine and methylthioribose (MTR)
- This MTR through a complicated series of reaction again converted to methionine.



Schematic representation of ethylene biosynthesis (Yang Cycle)

Inhibitors of ethylene synthesis:

- Aminoethoxy-vinylglycine (AVG) and aminooxy acetic acid (AOA) block the conversion of SAM to ACC synthesis by inhibiting the activity of ACC synthase enzyme.

- The cobalt ion (Co^{2+}) is also an inhibitor of the ethylene biosynthetic pathway, blocking the conversion of ACC to ethylene

.

Inhibitors of ethylene action:

- Most of the effects of ethylene can be antagonized by specific ethylene inhibitors.
- Silver ions (Ag^+) applied as silver nitrate ($AgNO_3$) or silver thiosulfate [$Ag(S_2O_3)_2^3$] are potent inhibitors of ethylene action.
- Silver is very specific; the inhibition it causes cannot be induced by any other metal ion.
- Carbon dioxide at high concentrations (5-10%) also inhibits many effects of ethylene, such as the induction of fruit ripening, although CO_2 is less efficient than Ag^+. This effect of CO_2 has often been exploited in the storage of fruits, whose ripening is delayed at elevated CO_2 concentrations. The high concentrations of CO_2 required for inhibition make it unlikely that CO_2 acts as an ethylene antagonist under natural conditions.
- The volatile compound trans-cyclooctene, but not its isomer cis-cyclooctene, is a strong competitive inhibitor of ethylene binding which is thought to act by competing with ethylene for binding to the receptor.
- A novel inhibitor, 1-methylcyclopropene (1-MCP) and its derivative 3,3-diMCP, were found that binds almost irreversibly to the ethylene receptor. MCP shows tremendous promise in commercial applications.

- However, $KMnO_4$ act as an effective absorbent of ethylene which can reduce the concentration of ethylene in apple storage area from 250 to 10 µl L^{-1}.

Physiological effect of ethylene in plant system

1. **Abscission and senescence:**
   - Causes changes associated with pre-abcission and ageing of leaves, petioles, flowers and fruit by increasing the activity of different cell wall destroying enzymes like phospholipase.
2. **Natural ripening and climacteric rise:**
   Increase the activity of ripening genes leading to the synthesis of ripening specific mRNA.
   Increase the permeability of plasma membrane resulting entry of some unsaturated gases line Acetylene, propylene within the cells- increased ethylene activity in the cells.
3. **Shoot and root growth:**
   Triple response-
   - Inhibit linear growth of shoot and root
   - Induce lateral and radial growth of stem by cell expansion
   - Induce horizontal orientation of growth of stem against gravity
4. **Flowering and sex expression:**
   - Although ethylene inhibits flowering in many species, it induces flowering in pineapple and its relatives, and it is used commercially in pineapple for synchronization of fruit
   - Flowering of other species, such as mango, is also initiated by ethylene.

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- On plants that have separate male and female flowers (monoecious species), ethylene may change the sex of developing flowers. The promotion of female flower formation in cucumber is one example of this effect.

5. **Breaks Seed and Bud Dormancy:**
   - Ethylene has the ability to break dormancy and initiate germination in certain seeds, such as cereals. In addition to its effect on dormancy, ethylene increases the rate of seed germination of several species. In pea nuts (*Arachis hypogaea*), ethylene production and seed germination are closely correlated.
   - Ethylene can also break bud dormancy, and ethylene treatment is sometimes used to promote bud sprouting in potato and other tubers.
6. **Induces the Formation of Roots and Root Hairs:**
   - Ethylene is capable of inducing adventitious root formation in leaves, stems, flower stems, and even other roots.
   - Ethylene has also been shown to act as a positive regulator of root hair formation in several species.

Commercial Application of Ethylene:

- Ethylene has been commercially exploited in a very big way all over the world for improving the quality or promoting ripening of fruits such as tomatoes, apples, coffee berries and grapes.
- It facilitate the harvesting of cherries, walnuts and cotton by accelerating abscission or fruit dehiscence
- Helps to increase rubber production by prolonging latex flow in rubber trees

- Increasing sugar production in sugarcane
- Synchronizing flowering in pineapple and accelerating senescence of tobacco leaves.

References

1. L.M. Srivastava (2002). Plant Growth and Development: Hormones and Environment. Academic press, San Diego, California, USA. pp. 231-250.
2. L Taiz, E Zeiger (2002). Plant Physiology (3rd end.). Sunderland: Sinauer Associates, pp. 518-538.

Course Name	Growth and Development of Horticultural Crops
Lesson 9	Growth inhibitors and retardants
Course Creator Name	MANOJ KUNDU
University/College Name	Bihar Agricultural University, Bhagalpur
Course Reviewer Name	DR SATESH KUMAR
University/College Name	Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu

Learning Objectives:

- To get basic knowledge about growth inhibitors and growth retardants in details
- To know about the role of growth inhibitors and growth retardants in horticulture

Glossary:

Growth retardant: the substance that slow down the rate of cell division and cell elongation of shoot tissues.

Growth inhibitor: the substance which suppress the growth and development of the plant by inhibiting cell division and cell elongation process.

Leaf abscission: Abscission is a naturally occurring phenomenon which involves the separation of leaves from plants.

Introduction:

- The term growth retardant is defined as the substance that slow down the rate of cell division and cell elongation of shoot tissues and regulate plant physiological process accordingly without any formative effects.
- Example of growth retardants are AMO 1618, Phosphon-D, CCC, Mepiquat chloride and Alar etc. They do not occur naturally in the plant system but play significant role in retardation of stem elongation, preventing cell division.
- Growth inhibitors is defined as the substance which suppress the growth and development of the plant by inhibiting cell division and cell elongation process and other physiological activities in the plant system.
- Different inhibitors are - Phenolic inhibitors (Benzoic acid, Salicylic acid, Coumarin and Chlorogenic acid), synthetic inhibitors (maleic hydrazide and Triiodo benzoic acid) and abscissic acid (ABA).

Role of inhibitors

- Accumulation leads to induce dormancy
- Regulation of flowering, senescence and tuber formation
- Induction of cold hardiness
- Cause abscission and dehiscence of leaves and fruits
- Suppress the formation of a amylase in the barley endosperm
- Interfere with DNA and RNA synthesis
- Modify the nucleic acid and protein synthesis systems.

- Phenolic compounds inhibit stem and root growth
- Phenolics affect almost all the metabolic system
- Inhibit gibberellin activity resulting inhibition of plant growth

Physiological effect of ABA in plant system

1. **Stomatal regulation:**
   - The role of ABA in causing stomata closure in plants undergoing water-stress is now widely recognized. It has been suggested by various workers that in response to the water stress, the permeability of the chloroplast membranes of mesophyll cells to ABA is greatly increased. As a result, the ABA synthesized and stored in mesophyll chloroplasts diffuses outinto the cytoplasm. It then moves from one mesophyll cell to another through plasmodesmata and finally reaches the guard cells where it causes closing of stomata. Fresh biosynthesis of ABA continues in mesophyll chloroplasts during periods of water stress.
   - When waterpotential of the plant is restored (i.e., increased), the movement of ABA into the guard cells isarrested. ABA disappears from the guard cells a little later. The application of exogenousABA causes closing of stomata by inhibiting the ATP-mediated H+/K+ ions exchange pumpsin guard cells.
2. **Leaf abscission:**
   - ABA is known to produce abscission layers at the base of the leaf petiole where deadcells are formed.
   - ABA production increases in senescing leaves once the photosyntheticactivity of the leaves decreases below the compensation point.
3. **Seed and bud dormancy:**
   - Seeds and buds remain dormant in unfavourable seasonal and soil conditions for germination and growth respectively. Presence of ABA in such seeds and buds provides dormancy to these structures. Once favourable conditions are available, ABA gets denatured or overcome by production of growth promoting hormones such as GA or IAA.
4. **Flowering:**
   - ABA does not ordinarily promote growth of flowers in short-day plants.
   - High concentrations of ABA usually inhibit or delay flowering in plants.
   - Both ABA and ethylene appear to act in part through effects on differentially permeable membranes and in part through control of protein synthesis.

5. **Fruit Growth:**
   - Though ripening fruits contain large amount of ABA, yet application of ABA to fruit has little or no effect.
   - However, as an exception, when ABA is applied to ripening grape berries, their ripening is accelerated and their colour changes fast.
   - ABA in the fruit coat does not affect the germination or dormancy of seed.
   - ABA is present in fairly constant amounts throughout the development of seed. However, the aborted fruits contain larger amounts of ABA.

Mode of action of different growth retardants:

S. N.	**Group**	**Name of the retardant**	**Mode of action**
1	*Quaternary ammonium and phosphonium compound*	AMO-1618, Chlormequat chloride or CCC, Mepiquat Chloride	Block the biosynthesis of ent-kaurine from GGDP by inhibiting the activity of coplyl diphosphate synthase which ultimately block the GA biosynthesis
2	*Nitrogen containing heterocyclic compounds*	Ancymidol, Paclobutrazal, Uniconazol	Inhibit the oxidation of ent-kaurine to ent-kaurinic acid by suppressing the activity of P450 monooxygenases which ultimately block the GA biosynthesis
3	*Acylcyclohexanediones*	Prohexadione-Ca, trinexapac-ethyl	Inhibit deoxygenase activity by competing for the binding site for the cosubstrate 2-oxoglutarate which ultimately inhibit the biosynthesis of different GAs from GA-aldehyde

Role of paclobutrazal in fruit culture

- Paclobutrazal @ 5 g tree^{-1} is commonly used for regular flowering and fruiting in mango particularly to those cultivar which are prone to alternate bearing problem. Paclobutrazal inhibit the GA synthesis pathway and reduces the time duration for shoot maturation leading to flowering in 3-4 months old shoots which otherwise need 8-9 months old shoot for flowering.

- Paclobutrazal treated apple tree have more compact crowns and somewhat smaller and darkergreen leaves as compared to untreated one. The amount of shoot growth reduction rangesfrom 10% to of 90%with an average growth reduction being 40-60%.
- Increased concentration of paclobutrazal (1000ppm) suppressed the root length and increased the root diameter of Assam lemon.
- Paclobutrazal applications stimulate flowering 2 months after the application, or 2months earlier than natural flowering and also about 70-150% increased fruit production in different fruit crops.
- Trees treated with paclobutrazal generally have leaves with a rich green color suggesting high chlorophyll content. There are two possible explanations for this response. One isthat the leaves of both treated and untreated trees contain the same number of cells, but because the cells in leaves of treated trees are smaller, the chlorophyll is more concentrated in the reduced cell volume.
- Paclobutrazal treatment, which blocks the production of gibberellins, results in a shunting of the intermediate compounds from gibberellin synthesis to the production of more leaves.
- Treatment with paclobutrazal promotes the production of abscisic acid - cause stomata to close, reducing water loss from leaves through transpiration.

References

1. L.M. Srivastava (2002). Plant Growth and Development: Hormones and Environment. Academic press, San Diego, California, USA. pp. 231-250.
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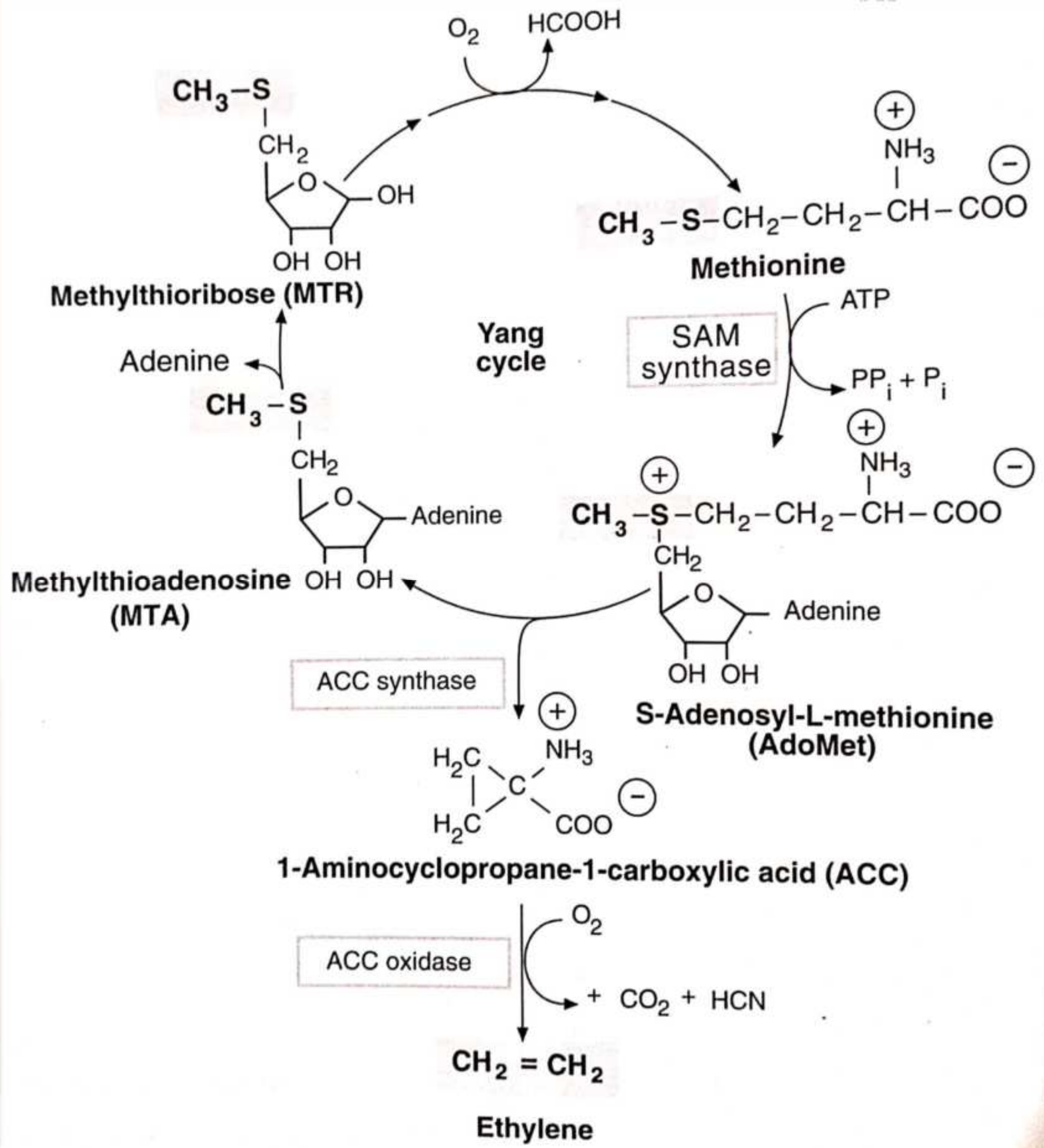

Schematic representation of ethylene biosynthesis (Yang Cycle)

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- However, $KMnO_4$ act as an effective absorbent of ethylene which can reduce the concentration of ethylene in apple storage area from 250 to 10 µl L^{-1}.

Physiological effect of ethylene in plant system

6. **Abscission and senescence:**
    - Causes changes associated with pre-abcission and ageing of leaves, petioles, flowers and fruit by increasing the activity of different cell wall destroying enzymes like phospholipase.
7. **Natural ripening and climacteric rise:**

   Increase the activity of ripening genes leading to the synthesis of ripening specific mRNA.

   Increase the permeability of plasma membrane resulting entry of some unsaturated gases line Acetylene, propylene within the cells- increased ethylene activity in the cells.
8. **Shoot and root growth:**

   Triple response-
   - Inhibit linear growth of shoot and root
   - Induce lateral and radial growth of stem by cell expansion
   - Induce horizontal orientation of growth of stem against gravity
9. **Flowering and sex expression:**
   - Although ethylene inhibits flowering in many species, it induces flowering in pineapple and its relatives, and it is used commercially in pineapple for synchronization of fruit
   - Flowering of other species, such as mango, is also initiated by ethylene.

- On plants that have separate male and female flowers (monoecious species), ethylene may change the sex of developing flowers. The promotion of female flower formation in cucumber is one example of this effect.

10. Breaks Seed and Bud Dormancy:

- Ethylene has the ability to break dormancy and initiate germination in certain seeds, such as cereals. In addition to its effect on dormancy, ethylene increases the rate of seed germination of several species. In pea nuts (*Arachis hypogaea*), ethylene production and seed germination are closely correlated.
- Ethylene can also break bud dormancy, and ethylene treatment is sometimes used to promote bud sprouting in potato and other tubers.

11. Induces the Formation of Roots and Root Hairs:

- Ethylene is capable of inducing adventitious root formation in leaves, stems, flower stems, and even other roots.
- Ethylene has also been shown to act as a positive regulator of root hair formation in several species.

Commercial Application of Ethylene:

- Ethylene has been commercially exploited in a very big way all over the world for improving the quality or promoting ripening of fruits such as tomatoes, apples, coffee berries and grapes.
- It facilitate the harvesting of cherries, walnuts and cotton by accelerating abscission or fruit dehiscence
- Helps to increase rubber production by prolonging latex flow in rubber trees

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- Increasing sugar production in sugarcane
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Course Details	
Course Name	Growth and Development of Horticultural Crops
Lesson	Physiological basis of training and pruning in Horticultural crops

Created by

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Introduction

- **Pruning is defined as the as the art and science of judicious removal of plant parts (undesirable branches, shoots, roots or any other part of a plant) with an objective to obtain good and qualitative yield.**
- **The ultimate aim of pruning is to develop a canopy, which intercepts maximum light interception; hence improves growth, flowering and fruitfulness of the tree with improved size, firmness, soluble solids and other quality attributes of the fruit.**
- **The extent and intensity of pruning on the same tree varies from year to year, depending on the growth of the tree, its bearing intensity and season.**
- **Training is defined as the practice in which tree growth is directed into a desired shape and to build the strong frame work of tree and arrangement of scaffold branches in all directions.**
- **Training is generally done during the initial stage of plant growth before they comes into bearing stage.**
- **The ultimate goal of both pruning and training is to improve light distribution, so that as much of the tree canopy as possible maintains production of high-quality fruit.**

Objective of pruning

- To distribute the fruiting wood in all directions and to maintain a balance between vegetative and reproductive phases (source sink relation).
- To thin out branches to receive more light into the interior of the tree top so that the inner wood also becomes fruitful.
- To improve the quality of fruits in terms of shape, size and colour.
- To regulate the succession of crops and helps to obtain regular bearing.
- To remove diseased, damaged, insect infested and weak shoots.
- To regulate the size and quality of fruit by way of diverting the energy into those parts that is capable of bearing fruits.

Effect of shoot pruning on plant growth and development

1. Effects on plant growth

- **Pruning is a dwarfing process and the more severely a plant is pruned, the greater the degree of dwarfing effect.**

- **Removal of the branch not only removes stored carbohydrate and nitrogen reserves, but also reduces potential leaf surface and growing points as well.**

- **Pruning also reduces root growth and new root growth is delayed until shoot growth in response to pruning occurs.**

- **Shoot growth is dependent upon water and mineral nutrient uptake by the root system, while roots growth depend on the above ground portion of the tree for carbohydrates.**

- **Pruning of either portion of plant parts reduces its capacity to perform its function; thus growth in other parts of the plant is also reduced and energy is redirected to regenerate the missing component. This concept, known as functional equilibrium. It seems to be moderated by plant hormones and growth of the plant is not become normal until the equilibrium balance is re-established.**

- Pruning the above ground portion of the plant during the dormant season increases the supply of cytokinins from the roots. These increased hormone levels are probably responsible for stimulating cell division and ultimately shoot growth which in turn, promotes auxin production in the shoot tips and gibberellin production in the new, unfolding leaves. Normally a terminal bud makes the most growth in an unpruned, upright branch and each subsequent subtending lateral makes progressively less growth. This growth is mainly due to cumulative auxin concentrations produced from each of the buds above resulting a reduced growth in the shoot originating at lower levels.Hence, removal of apical portion results in an increase in the growth of the subtending laterals.

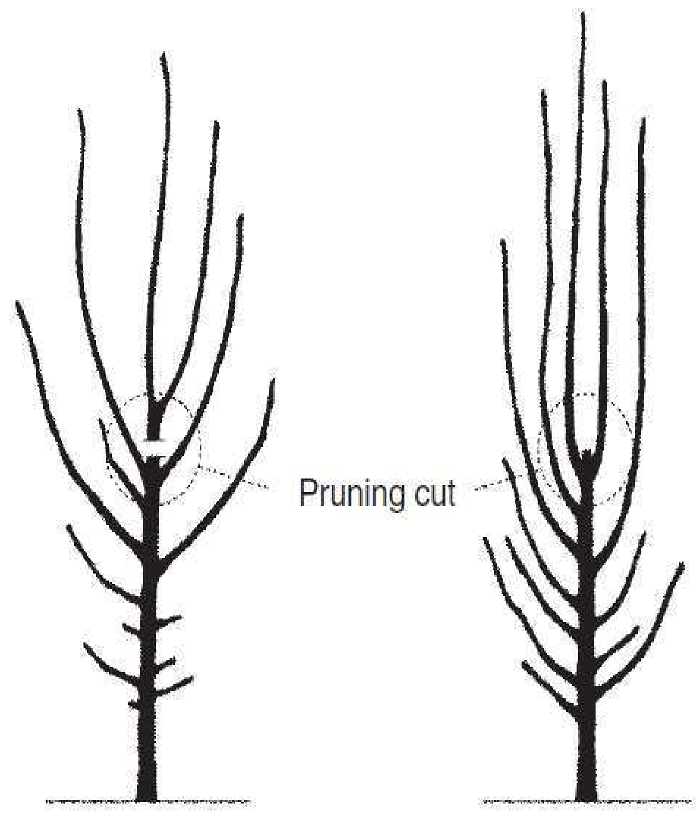

Figure: Natural growth pattern of apple tree (left) and change in growth pattern caused by a heading back (right)

2. Effects on flowering

- **Pruning delays the flowering and fruit bearing of young trees and decreases fruiting in mature trees which is associated with three factors-**
  - **The removal of effective bearing surface**
  - **The stimulation of vegetative growth from growing points**
  - **Direct competition between vigorous shoot growth and fruit set.**
- **Pruning of young trees tends to force growth of long succulent shoots which continue to grow late in the season. Thus, carbohydrates do not accumulate for flower-bud initiation but are used in producing the vigorous vegetative growth.**

3. Effect on fruiting

- **One of the primary reasons for annual pruning is to increase fruit size. The impact on fruit size is not a direct effect of pruning, but results from the reduced number of fruit and improved light conditions in the canopy.**
- **Generally fruit set is higher on pruned trees because the supply of reserves available to remaining blossoms is increased.**

Methods of shoot pruning

1. **Thinning out:**

- When a shoot is removed entirely from the inception (from the point of origin), new shoots are not arises from that place. It is referred as thinning out.
- It is practiced for the removal of shoots arising in unwanted places, water sucker etc. resulting improved light penetration into the canopy; thus increasing flower initiation and fruit setting in lower parts of the canopy.
- It is also practiced to remove unfruitful wood that is upright and vegetative or pendant and weak.

2. **Heading back**

- When only one-third to one-half terminal portions of the branches, having their basal portions intact, are removed, it is referred as heading back.
- When the branches grow tall and vigorously without producing flowers, these shoots are headed back to stimulate the growth of the lateral buds.
- It stimulates more vegetative growth which tends to be vigorous and shades the tree interior resulting in fewer fruiting sites and less flower initiation than thinning out.

3. **De-blossoming:**

- Removal of surplus flowers to enable the tree to produce crops regularly year after year is called deblossoming.
- This is practiced in alternate bearing crops like mango, apple etc. and also to regulate the flowering in those crops which produce flowers more than one time in a year like guava, pomegranate, lemon etc.

Effect of root pruning on plant growth and development

- Root pruning is the practice of trimming the root portion of the tree to alter the growth and development of the plant and also to develop a thick mass of roots or to remove broken or damaged root.
- To reduce tree size and to promote flowering, root pruning is considered as one of the important technique which affect the plant growth and development in the following way-

1. Effects on physiological processes

- Root pruning reduces the net photosynthesis, transpiration, stomatal conductance and leaf water potential of the tree with little effect on concentrations of leaf nutrient elements and no influence on the carbohydrate fractions in the leaves or shoots.
- When roots are removed by pruning, assimilates are redistributed to the root system as evidenced by the increase in small roots in close proximity to the trunk coupled with a reduction in leaf and new shoot growth.

2. Effects on tree growth

- **Root pruning decreases the leaf number per tree, leaf size, total leaf area, shoot growth and decreased dry weight of leaves, shoots and roots.**
- **It also helps to reduce trunk cross-sectional area, shoot length, shoot number significantly which ultimately helps to increase the light penetration significantly in the lower portion of the orchard.**
- **Root pruning results in root regeneration in close proximity to the cuts.**
- **In almost all perennial fruit crops, the effect of root pruning on root distribution is greatest in the top 30 cm of soil, parallel to the location of the root-pruning cut.**

3. Effect on fruit yield and quality

- **In long run, root pruning reduces the biennial bearing pattern in different fruit crops.**
- **It increases yield efficiency (yield per trunk cross-sectional area), fruit colour and soluble solids concentration with reduced fruit size.**
- **It slightly increases fruit firmness but reduce the starch hydrolysis at harvest.**
- **It also helps to reduce pre-harvest fruit drop.**

Objectives of Training

- The main objective of training is to control and regulate shape of trees so that cultural operations of the orchard as well as harvesting can be done easily.
- To build the strong frame work of tree and arrangement of scaffold branches.
- To admit adequate sunlight and air to the centre of the tree and to expose maximum leaf area to the sun.
- To help to have a better crotch angle between scaffold branches of the tree.
- To build the structure of the tree in such heights at which trees are less exposed for sunscald and wind damage
- Training develops a balance between vegetative and reproductive growth of the tree.
- To limit the growth and spread of the tree so that various cultural operations such as spraying and harvesting are performed at minimum cost.

Special horticultural practice to develop the frame work of the plant

1. **Bending**

- **Physically bending a branch of any trees results in the reduction of terminal shoot growth and a redistribution of growth hormones, particularly auxin.**
- **The stress created by bending results in increased ethylene content in the internal air spaces within the branch.**
- **The growth reduction and increase of floral stimulus (ethylene) caused by bending helps to produce greatest number of short, fruitful shoots and the fewest number of undesirable shoots.**
- **Further, the reduced vegetative growth on the bent shoot also prevent the biosynthesis of gibberellins which are antagonistic to flowering. The formation of moderately vigorous lateral shoots on the bent limb creates additional sites for flower formation. These two effects result in increased flowering and earlier fruiting on the bent limbs.**
- **Fruit quality is also improved because of improved light penetration and more fruits hang free instead of rubbing against the branch on more upright limbs.**

- **The degree of bending also influence the growth of the laterals on the bent limb. The more the branch orientation is changed towards the horizon, the greater the number of shoots released towards the branch base because the auxin influence progresses down the branch and buds on the upper side are released from the hormonally induced apical dominance and begin to grow laterally.**

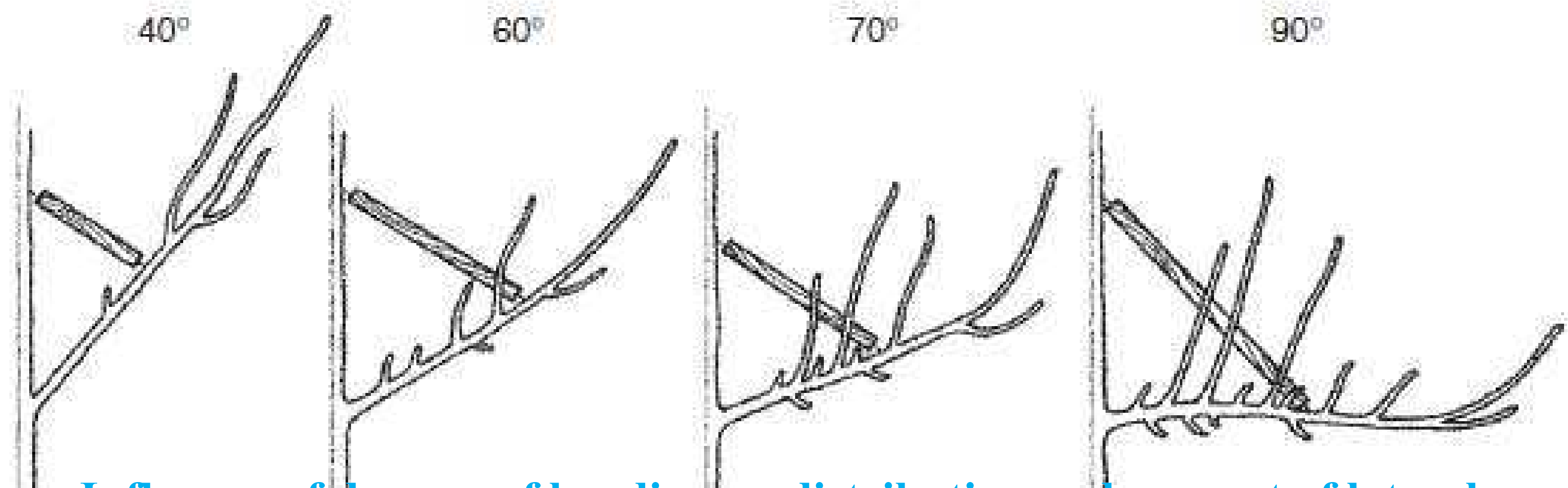

Figure: Influence of degrees of bending on distribution and amount of lateral growth on bent limb of apple

- **However, bending of the branches up to 60º angle is most suitable and recommended practice.**
- **Bending beyond 60º angle may cause excessive lateral formation and heavy crop load. Heavy crop load on the tip brings the branch to a horizontal or below-horizontal position while the vegetative growth on the weeping tip portion nearly ceases and several very vigorous suckers will form from buds on the highest point of the bend shoot which is not desirable.**

2. Phloem interruption

- It is an important technique to alter the growth and development of the plant.

- It is mainly done by scoring and ringing resulting interruption in the downward flow of carbohydrates and hormones through phloem.

- A number of studies showed that phloem interruption reduced terminal growth, trunk cross-sectional area, shoot diameter and number of shoots per plant significantly.

- Scoring and/or ringing interrupt phloem translocation resulting the storage of photosynthates in the portion of the tree above the cut which ultimately accelerate the process of flowering and fruiting with improved fruit size and quality.

3. Notching

- Notching is a phloem-interruption technique, used to stimulate lateral branching from buds that would not normally grow.
- In this technique, removal of 2–3 mm wide strip of bark is done directly above the bud. The cut extends down to the secondary xylem and around about one-third of the circumference of the stem.
- It stimulates the growth of lateral branching by interrupting the downward movement of auxin from the shoot tip.
- Notching is found to be most effective for inducing shoot growth from buds on the top of the branch, less effective for buds on the side and least effective for buds on the underside of the branch.
- Notching is able to overcome bud inhibition imposed by a shoot apex by preventing the movement of auxin to the bud, but it is not able to overcome inhibition due to geotropism.

Course Name	Growth and Development of Horticultural Crops
Lesson 11	Physiological Basis of Flowering
Course Creator Name	MANOJ KUNDU
University/College Name	Bihar Agricultural University, Bhagalpur
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University/College Name	Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu

Learning objectives:

- To get basic knowledge about flowering in fruit crops in details
- To know about the physiology behind the flowering in horticultural crops

Glossary:

Endogenous stimulus: Endogenous stimuli otherwise known as internal triggers are thoughts feelings and sensations inside an individual that cause a certain behaviour.

Proliferate: increase rapidly in numbers; multiply

Photoperiodism: Photoperiodism is the physiological reaction of organisms to the length of night or a dark period.

Floral meristem: The gene regulatory networks that govern the transition of a vegetative shoot apex to reproductive shoot apex.

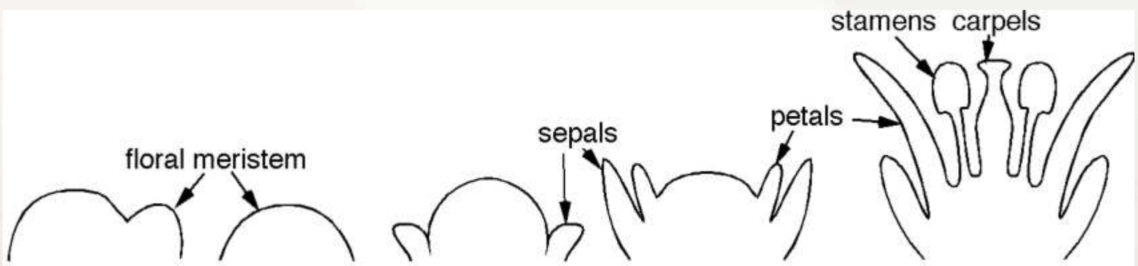
Phytochrome: Phytochromes are a class of photoreceptor in plants, bacteria and fungi used to detect light.

Catabolism: Catabolism (/kəˈtæbəlɪsm/) is the set of metabolic pathways that breaks down molecules into smaller units that are either oxidized to release energy or used in other anabolic reactions.

Introduction:

- The phenomenon of flower formation from reproductive shoot or bud is called as flowering. Floral induction started with the transition phase of vegetative to reproductive phase.
- The initiation of flowering is a multistep process, including the formation of a floral meristem, the establishment of unique organ identities followed by the differentiation of floral structures.

- In response to floral inductive cues, shoot apical meristems that are producing leaves and branches convert to a reproductive fate.
- In some species, this transition results in a floral meristem that forms an individual flower, whereas in others, an inflorescence meristem is produced that in turn forms floral meristems.
- One of the most dramatic differences between a floral and vegetative shoot apical meristem is that the floral meristem is determinate to produces a finite set of organs and then ceases proliferation while the growth of vegetative shoot is indeterminate.
- However, there are a few examples of naturally occurring or experimentally induced systems in which the floral meristem is indeterminate and continues to proliferate organs.



Different stages of floral initiation

A. **Transitional stage:** Have both juvenile and mature tissues and may revert back to juvenile if environmental conditions are optimum for the vegetative growth of the plant. It involves the transition of a vegetative meristem, producing leaves and stems into a floral meristem followed by flowering**.**

B. **Flower Initiation and Development**

- Irreversible change in which bud (meristem) changes from growing vegetative tissues to reproductive tissues.
- Improper conditions can cause flower buds to abort like high temperature, moisture stress etc.
- Flowers can be induced naturally or through the application of PGRs (plant growth regulators)

C. Maturity or reproductive stage

- It is the stage where plants are ready to flower and flowering is the ultimate expression of mature state which is mainly influenced by environment because environment serve as expression changes regulator. Although, in many plants, flowering is independent of environmental conditions.

✓ After the plant has acquired competence to flower, it is able to perceive environmental or endogenous stimulus.

✓ The environmental factors are day length and temperature.

✓ The endogenous factors include carbohydrates (nutrients), hormones, and circadian rhythm.

✓ The interaction of external and internal factors enables plants to synchronize their reproductive development with the environment.

✓ Some plants exhibit an absolute requirement for specific environmental conditions in order to flower. Such floral induction responses are referred as obligate or qualitative responses.

✓ If flowering is promoted by certain environmental conditions but eventually occurs in the subsequent absence of such conditions as well, the flowering response is said to be facultative or quantitative.

✓ There are some plants in which flowering occurs strictly in response to internal developmental factors and do not depend on any particular environmental condition. These are said to exhibit autonomous regulation.

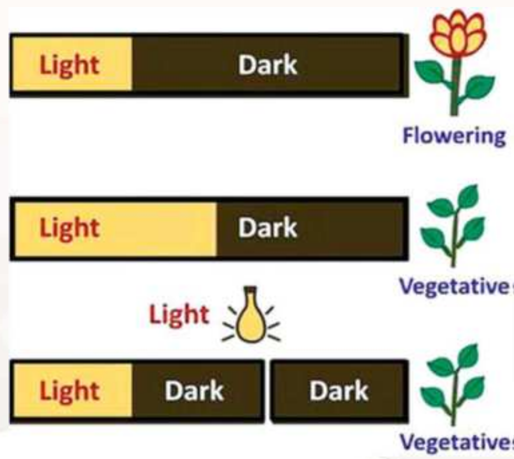
Mechanism of flowering

- Four different genetically regulated pathway are there which plays significant role for flower induction in higher plant. These are-
  - Light-dependent pathway
  - Temperature-dependent pathway
  - Gibberellin-dependent pathway
  - The autonomous pathway
- Plants can rely on one of these pathways but all four pathways can be present

The Light-Dependent Pathway (Photoperiodism)

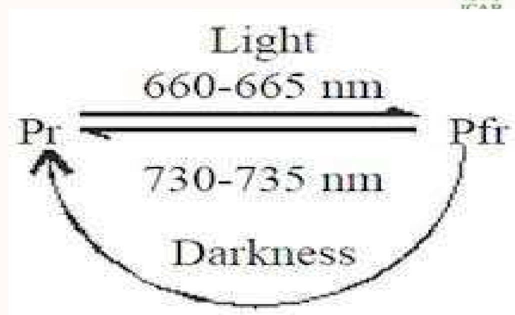
- Photoperiodism can be defined as the developmental responses (flowering) of plants to the relative lengths of light and dark periods.
- Critical day period is the duration of the photoperiod or the dark period that ultimately determines whether the plant has to go through vegetative growth or to produce flowers.
- On the basis of photoperiodic responses, plants are classified in three different groups-
  - **Short day plant (SDP):** The plant can only flower under shorter day length (Day length <12 h) than its critical day length of 24 h cycle. Example- Chrysanthemum, Strawberry, Pineapple, Coffee.

- **Long day plant (LDP):** The plant can only flower under longer day length (14-18 h) than its critical day length of 24 h cycle. Example- Chinese Cabbage, Beet, Passion fruit, Banana, Apple.
- **Day neutral plant (DNP):** Without critical day length, they can flower in any day length of 24h cycle of critical day length, if other conditions are satisfied. Example- Tomato, Cucumber, Egg Plant, Bean, Papaya, Guava, Mango.

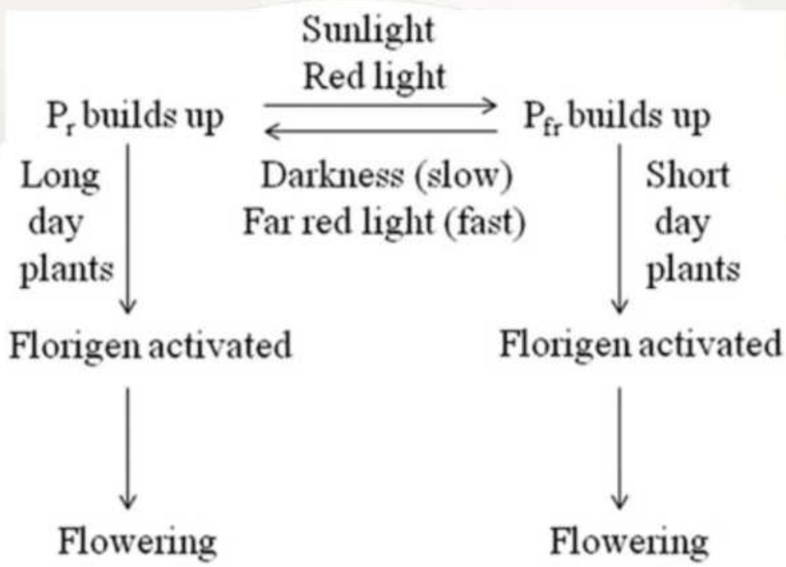


Photoperiodic control of flowering

- Another important light factor for flowering in higher plant is the photoreceptors - Phytochrome and cryptochrome.
- Phytochrome comprises of nuclear encoded proteins which paly vital role in flowering.
- Two forms of phytochrome compound that absorbs lights are phytochrome far red (PFR) and phytochrome red (PR). Both are inter-convertible to each other.



- Pfr (P730-735 nm) promotes flowering in LDP while Pr (P660-665 nm) promotes flowering in SDP plant.
- During long night, Pfr is converted to Pr form and if dark period is interrupted with red light, sufficient Pr form is not formed resulting no flowering in SDP.
- Similarly, during day time, Pr is converted to Pfr form.
- The flowering is interrupted with interruption in dark period however not affected by the duration of day time.



Influence of phytochrome on flowering

Temperature-dependent pathway (Vernalization)

- Vernalization is defined as the method of inducing early flowering in plants by pre-treatment of their seeds or young seedlings at very low temperature.
- In contrast to photoperiodic effect which leads to flower initiation, vernalization prepares the plants for flowering.
- Apical buds are the sites of vernalization. Generally, the stem apex perceives the cold temperature signal. The dividing cells in plants perceive vernalization stimulus.
- Vernalization affects competence of a plant to flower by bringing about stable changes in the pattern of gene expression in the meristem after cold treatment. Such changes are termed as epigenetic changes
- Period of chilling can vary from few days to weeks and from plant to plant, but longer exposure to low temperature will be more effective for early flowering.
- However, the response due to vernalization may decrease by interrupting with heat treatment.
- Vernalin is for the hypothetical active substance, induced through vernalization which in turn stimulates the flowering stimulus florigen causes flowering.

Low Temperature → Vernalin → Florigen

GA dependant pathway

- Gibberellins play important roles during transition of vegetative to reproductive meristem. This includes their role in competence, promotion of bolting and flowering in long-day plants.

- Chailakhyan stated that vernalin hormone may be a precursor of gibberellin. Under long-day conditions, it is converted to gibberellin.
- Another hormone called anthesin is present in long-day plants which along with vernalin, causes flowering in long-day plants.
- In short-day conditions, vernalin is not converted to gibberellin. Hence, flowering does not occur.
- Gibberellin treatment to long-day non-vernalized plants kept under long day leads to flowering as these plants possibly contain anthesin.
- Gibberellin is ineffective in flower induction in short-day plants as they lack anthesin.
- Auxin application induces flowering in pineapple and litchi. In pineapple, the effect of auxin might be due to stimulation of ethylene production.

The autonomous pathway

- Bunning (1958) assumes the presence of endogenous rhythms (Oscillator) which consist of two half cycles- responsible for flowering.
- The first half cycle occurs in day and is called photophilous phase. During this, anabolic process predominates including flowering in plants. The other half cycle is dark and is called skotophilous phase. In this, catabolic process (dehydration of starch) predominates.
- In short day plants, oscillator is close to skotophilous phase, while in long day plants it is close to photophilous phase.
- Now, short day plants have a critical day length of 9 hours. This period falls within the photophilous phase. Light during scotophilous phase will inhibit photo process, initiated during photophase.

- The long day plants have a critical day length of 15 hours and if some light falls in the skotophilous phase, it will induce flowering.

Other factors controlling flowering

1. **Mineral nutrition**
   - Klebs (1918) reported that the ratio of carbohydrate with inorganic nutrient especially N is very important for flowering in higher plants. High C:N ratio promotes flowering.
   - Kraus and Kraybill (US) reported that the flowering on tomato plants was controlled by CHO:N level
     - Low CHO:N ratio – delay flowering and produce less flowers (N high)
     - Low CHO, low N – reduction in vegetative growth, less flowering
     - High CHO:N – precocious flowering with increased number of flowers
2. **Different biotic and abiotic stresses**

   Different types of stress promotes the synthesis of secondary messengers such as salicylic acid (SA) and nitric oxide (NO) which are mainly involved in defence responses resulting early and delayed flowering respectively.

Reference:

1. Kalra, G and Lal, M.A. (2018). Physiology of Flowering. *In:* Plant Physiology, Development and Metabolism (Bhatla, S.C. and Lal, M.A. eds.). Springer

Course Name	Growth and Development of Horticultural Crops
Lesson 12	Physiology of fruit set, growth and development
Course Creator Name	MANOJ KUNDU
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Learning objectives:

- To get basic knowledge about the physiology of fruit setting in details
- To know about the physiology behind fruit growth and development in horticultural crops

Glossary:

- **Fruit:** mature ripen ovary is called fruit.
- **Parthenocarpy**: the development of a fruit without prior fertilization steno-spermocary
- **True fruits**: fruit derived from a single ovary
- **False fruits:** composed of tissues derived from flower parts other than the ovary.
- **Simple fruits**: derived from a single ovary e.g., mango
- **Aggregate fruit** :derived from a single flower having multiple ovaries and all the fruits fused together to form a single fruit e.g., blackberry
- **Multiple fruit or compound fruit**: fruit that develop from the multiple flowers having single ovary in each flower and ultimately all the fruitlets fused together to form a single fruit e.g., pineapple, jackfruit

Introduction:

- Botanically fruit is called as the mature ripen ovary
- In some fruit crops (apple, pear etc.), other floral parts also involved in fruit developmental process.
- Hence, fruit can be defined as the mature ripen ovary with or without accessory parts developed with or without successful pollination and fertilization.

- The event of fruit setting starts with pollination, which involves the transfer of pollen from the anther to the stigma.
- Once pollination has occurred, the pollen tube grows down the style into the ovary until it reaches the embryo sac within the ovule.
- Two male gametes from the pollen tube are inserted into the embryo sac, one of which unites with the female gamete, a process known as fertilization, to produce a zygote which divides to become the embryo while the other one unites with two polar nuclei to produce the endosperm.
- The ovary gives rise to the fruit and the ovule leads to the formation of seed.

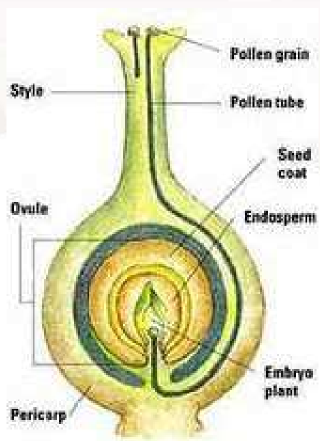


Figure: Fruit development process through pollination and fertilization

Physiology of fruit setting

- Fruit setting may be defined as the rapid growth of the ovary which usually follows pollination and fertilization.
- Both pollination and fertilization must take place to produce viable seeds.

- However, there are cases where fruit setting and further fruit development occurs with or without pollination but without fertilization too resulting the formation of seedless fruit; this process is called parthenocarpy.
- There are two types of parthenocarpy, one is vegetative parthenocarpy, which is characterized by the development of fruit without any pollination and fertilization (e.g., pineapple, banana, common fig etc.). However, in other cases, fruit development takes place only after successful pollination but without fertilization which is called as stimulative parthenocarpy. Here, for fruit setting and subsequent fruit growth, it needs the stimulus from pollen grain (e.g., Black Corinth grape).
- There is another group in which fruit setting takes place only after successful pollination and fertilization. But at the very early stage of fruit growth, the embryo starts to abort resulting the development of fruit without seeds. Such phenomena is commonly known as steno-spermocary. It is observed in mango cultivar Sindhu, all seedless cultivars of grape except Black Corinth grape.

Effect of different plant growth regulators on fruit setting in horticultural crops

- Synthetic auxins such as NAA have been shown to be most effective for fruit setting in such crops having multiple ovules such as strawberry, fig, tomato, rose, eggplant and others. IAA is much less effective for fruit setting than the synthetic auxins, probably because it is unstable in the light and can be broken down by IAA oxidase within the plant or converted to inactive conjugates

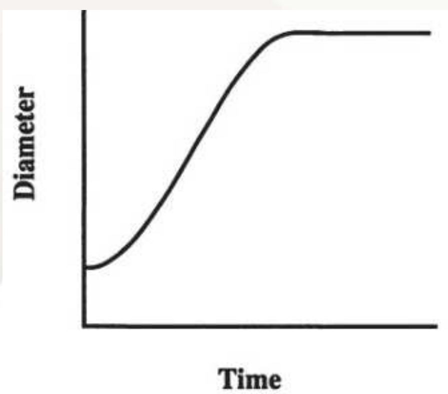
- Gibberellic acid (GA_3) also have the ability to enhance the process of fruit setting in all plants which are responsive to auxins as well as other crops such as blueberries, citrus, grapes, and stone fruits where auxins were shown to be ineffective.
- The induction of parthenocarpy by gibberellins has been reported in a number of fruit crops including grape, peach, apricot, almond and tomato.
- Synthetic cytokinins have also been shown to be effective in increasing fruit set in grapes, figs and muskmelon. It has been suggested that the ability of cytokinins to mobilize assimilates to the area of application is responsible for increased fruit set.
- Abscisic acid and ethylene cause abscission of flowers and young fruits so their effects on fruit set are negative.

Physiology of fruit growth and development

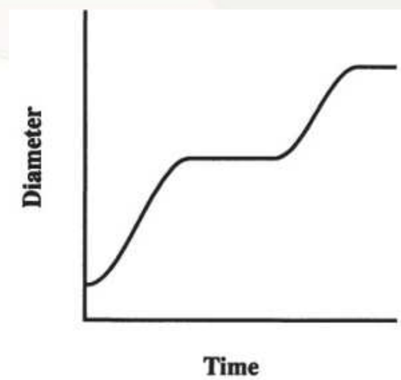
- Fruits undergo dramatic increases in size following anthesis. An example of this is the apple which may increase in volume up to 6,000 times during 20-weeks growth period
- Fruit growth typically follows two distinct growth curves.
- One type is a smooth sigmoid curve which is exhibited by many plants including apples, pears, tomatoes, cucumbers and strawberries.
- However, the second type of growth curve is represented by a double sigmoid which can be viewed as two successive sigmoid curves. Examples of this type of fruit growth are blueberries, grapes, figs and many stone fruits

including cherries, olives and peaches. This type of growth pattern has two periods of rapid growth separated by an intermediate period where little or no growth occurs. During the first stage of rapid growth, the ovary and its contents grow rapidly except the embryo and endosperm. In second phase which appears to be as plateau, is characterized by the growth of the embryo and endosperm, lignification of the endocarp, and a small amount of growth of the ovary wall. While in third or final phase, rapid growth of the mesocarp occurs promoting a rapid increase in fruit size followed by maturation.

- In crop like kiwi fruit, triple sigmoid growth is observed with three successive rapid growth period separated by two intermediated period of little or no growth.



Single sigmoid growth curve



Double sigmoid growth curve

Phases of fruit growth and development

1. **Rapid cell division**
   - Occurs in all growing parts of the fruit.

- Controlled by the developing seeds where the number of fertilized ovules in a fruit is correlated with both the initial cell division rate and the final size of the fruit.
- Cytokinin present in the developing embryos is involved in cell division in surrounding tissues resulting rapid growth of the fruit

2. Cell differentiation

- Differentiation of specific cell types such as sclereids takes place which helps to increase the cell wall thickness as well as the size of the cell.
- Further, the distribution of air spaces in between the cells takes place at this phase resulting increment in fruit size by volume.

3. Cell expansion

- It involves the longitudinal as well as radial expansion of cell.
- The rate and duration of cell expansion varies among fruits and tissues within a fruit.
- Tissues made up of many small cells at maturity continue dividing while tissues composed of large cells have begun to expand.
- Cytokinins helps to expand the cell at this phase. However, gibberellins are also associated with fruit expansion.

4. Seed formation

- After double fertilization, the ovule (containing a zygote) develops into a seed (containing an embryo) and the ovary develops into a fruit enclosing the seed.
- As the embryo develops, the seed store proteins, oils and starch.
- Initially, these nutrients are stored in the endosperm but later on translocated to the cotyledons of the embryo itself.

5. Fruit formation

- Most commonly develop from the ovary wall.
- "True fruits" – fruit derived from a single ovary
- "False fruits" - composed of tissues derived from flower parts other than the ovary.
- Simple fruits - derived from a single ovary. Example- mango
- Aggregate fruit – derived from a single flower having multiple ovaries and all the fruits fused together to form a single fruit. Example- blackberry
- Multiple fruit or compound fruit - fruit that develop from the multiple flowers having single ovary in each flower and ultimately all the futilets fused together to form a single fruit. Example- pineapple, jackfruit

Effect of different plant growth regulators on fruit growth and development of horticultural crops

- The use of plant growth substances to control fruit set, size, shape and maturation has become important in current agriculture because they have the ability to increase fruit size, colour and shape of the fruits, thereby increasing marketability.
- In addition, by hastening or delaying maturation, the grower can utilize peak demands, avoid un-favourable environmental conditions and extend the market period.

The physiological effect of different PGRs on fruit growth and development are as follows-

1. Auxin:

- It play important role for fruit growth and development in different fruit crops.

- Fruit size and shape is closely correlated with seed number and seed distribution pattern within the fruit. Now, endosperm and embryo in the seed produces auxin, which moves outward and stimulates growth of the endosperm and subsequent growth of the fruit.
- The location of the seeds within the fruit has a profound effect on its growth and development. This phenomenon has been extensively studied in strawberries because the achenes presents on the outside of fleshy receptacle are easy to remove. Auxins present in the achenes affects the growth of the strawberry receptacle. It was observed that when achenes were completely removed from the receptacle, growth ceased while leaving several achenes attached to the receptacle, growth occurred directly below the achene.
- The presence of auxin in pollen, its production in the style and ovary accompanying pollen tube growth and fertilization, ultimately stimulates the growth of the ovary leading to rapid fruit growth.

2. **Gibberellins:**
    - Seeds are rich sources of gibberellins; therefore, along with auxin it was suspected that they were somehow involved in fruit growth.
    - The ability of exogenous applications of gibberellins to induce parthenocarpic fruits suggests that they were involved in fruit growth.
    - It has been shown that growth patterns of parthenocarpic fruits produced by exogenous gibberellin application closely paralleled patterns induced under normal conditions in peaches, grapes and other crops.

3. **Cytokinin:**
   - Young developing fruits have rapidly dividing cells and the seeds contained within them have been shown to be rich sources of cytokinins, suggesting that they play an important role in fruit growth.

Limitation of Fruit Setting

1. **Limited pollination**
   - Types of flower
   - Receptive condition
   - Pollinators
2. **Limited nutrients**
   - CHO:N – High CHO:N ratio favour better fruit setting
3. **Abscission of flowers and young fruits**
4. **Light**
5. **Rain or drought during flowering**
   - Rain - reduce cross-pollination
   - Drought – pollen tube grows slow or style wilts
6. **Temperature**
   - Moderate temperature favor fruit set

Environmental conditions affecting fruit growth and development

1. **Water**
   - Deficient water results in slow growth and production of small fruit.
   - Superfluous water causes fruit drop and less sweet, less aromatic fruit.

2. Temperature

- Fruit development is enhanced by greater difference in T between day and night.

3. Light

- Without enough light, fruit is smaller, low sugar contents and poor color.

4. Mineral nutrition

- P, K increase fruit and seed and fruit sugar contents.

Designed and developed under the aegis of NAHEP Component-2 Project "Investments In ICAR Leadership In Agricultural Higher Education"
Division of Computer Applications, ICAR-Indian Agricultural Statistics Research Institute

Course Name	Growth and Development of Horticultural Crops
Lesson 13	Seed development and maturation in horticultural crops
Course Creator Name	MANOJ KUNDU
University/College Name	Bihar Agricultural University, Bhagalpur
Course Reviewer Name	DR SATESH KUMAR
University/College Name	Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu

Learning objectives:

- To get basic knowledge about the physiology of seed development in details
- To know about the regulation of seed development and maturation in horticultural crops

Glossary:

- Pollination: the transfer of pollen to a stigma, ovule, flower, or plant to allow fertilization

Fertilization: the action or process of fertilizing an egg, female animal, or plant, involving the fusion of male an..

Polyembryony: the formation of more than one embryo from a single fertilized ovum or in a single seed.

- **Meiosis:** type of cell division that results in four daughter cells each with half the number of chromosomes
- Apomixis: apomixis is asexual reproduction without fertilization
- Obligate apomicts: Plants that produce only apomictic embryos
- Facultative apomicts: Plantsthat produce both apomictic and sexual embryos

Introduction:

- A seed is a reproductive unit which develops from an ovule, usually after fertilization. It has three distinctive stages: pollination, fertilization and development.
- Seed development is the period between fertilization and maximum fresh weight accumulation, while maturation is the attainment of

maximum physiological stamina, where the seed obtains its capacity to reproduce its generation.

- At physiological maturity, the seed attains its maximum dry weight
- The attainment of seed maturation is understood either based on duration from anthesis or through the physical appearance of fruit /seed.
- Fruit /seed colour often serves as the valuable and easily practicable sign of seed maturation.

Different events of seed development:

1. Fertilization

- After successful pollination, fertilization phase play a critical role in seed development.
- It started with the union of a haploid male nucleus of the pollen grain with a haploid female nucleus within the ovule to form a new diploid embryo.
- Fertilization must be preceded by pollination, the arrival of a pollen grain on the stigma of the female flower in angiosperms or close to the micropyle of the gymnosperm ovule.
- At the time of fertilization a typical angiosperm ovule consists of one or two protective coats - the integuments and a central tissue - the nucellus.
- Often the integuments and the nucellus are clearly differentiated only in the region of the micropyle - the minute pore in the integuments through which, in many species, the pollen tube enters the nucellus.
- The ovule is attached to the wall of the ovary by a stalk - the funicle.
- When the pollen tube reaches to the embryo sac it releases two male gametes. One male gamete unites with one of the nuclei in the embryo

sac (the egg cell) to form a zygote which later develops into the diploid embryo. The second male gamete unites with two other female nuclei (the polar nuclei) to form a triploid cell which later develops into the endosperm, a tissue which acts as a food reserve for the growing embryo.

- This phenomena of successful fertilization of the egg cell and triple fusion with the polar nuclei both are necessary for development of a viable seed.
- The remaining five nuclei of the embryo sac (2 synergids and 3 antipodal cells) play further role in seed development.
- The synergids have special thickenings at the micropylar end. These are together called the filiform apparatus.
- Antipodals are nutritive in function and they nourish the embryo sac. Substances developed by the antipodal cells are helping in growth and development of endosperm.

2. Growth of embryogenic tissues

- The embryo is composed of the embryonic axis and one or more cotyledons. The axis is composed of the embryonic root (radicle), the hypocotyl to which the cotyledons are attached and the shoot apex with the first true leaf primordia (plumule).
- After successful fertilization, the resultant zygote divides to produce several free nuclei, around which cell walls are laid down to form the proembryo.

- Subsequent cell divisions give rise to the embryonal and suspensor cells. These develop to form a single embryo and an elongated suspensor.
- Simple polyembryony occurs when more than one egg is fertilized in the ovule thus each embryo is genetically different, resulting from the fusion of separate eggs and pollen grains.
- In dicot, other than normal fertilization, sometimes embryo may also developed from the cells of embryo sac or surrounding nucellus or integument which does not undergo meiosis resulting the emergence of off spring of same genetic makeup as of female parent. It is commom in *Parthenium*, raspberry, apple, onion, *Poa*, *Solanum nigrum, Lilium, Allium*, *Agave* and *Dioscorea* species.
- Sometimes, this polyembryonic phenomena occurs along with the development of one zygotic embryo through normal fertilization. Such phenomena is known as facultative apomixis. It is commonly observed in citrus except pummelo, citron and tahiti lime and also observed in polyembryonic mango cultivars.
- The embryos of the mature seeds of the dicots possess two cotyledons, whereas there is only one in monocots. Mature gramineous embryos also include a specialized thin tissue that covers the radicle (coleorhiza) and one that is around the plumule and covers the first foliage leaf (coleoptile).

3. Growth of endosperm

- The cells of endosperm are triploid and is derived from the primary endosperm cell that contains the triple fusion nucleus.

- Two main types of endosperm development are - (1) nuclear or noncellular (also called syncytial or coenocytic), where several divisions of the nuclei occur prior to cell wall formation (e.g., apple, wheat, squash); and (2) cellular, where there is no free-nuclear phase, cell walls being formed after the first mitotic division (e.g., magnolia , lobelia). However, rarer is the type of endosperm present in the coconut seed, with a dense cellularized peripheral region and a liquid suspension of free spherical cells.
- Nutrients are drawn from adjacent tissues into the endosperm during its development, and new products are also laid down therein. Thus, the growing embryo becomes enveloped in, or intimately associated with an available food source upon which it can draw during its maturation and subsequent germination/growth stages.

4. Growth of testa (seed coat)

- Development of the seed coat commences after fertilization from the inner and outer layers of the integument, lying to the outside of the ovule; therefore it is of maternal origin.
- Its component tissues are initially undifferentiated, but rapidly undergo programmed changes to produce a structure that is extremely variable among species and even in the same species under different environmental conditions.

Regulation of seed development

1. **Embryo Polarity and Patterning**

- Embryogenesis can be divided into early, mid, and late stages, although these are overlapping to each other.

- Early embryogenesis is regulated by the precise distribution of the plant hormone auxin between the embryo and suspensor, and this is essential for the development of embryo polarity and patterning.
- During the early globular stages (2–16 cells), auxin is concentrated in the embryo and is transported from the suspensor by PIN-FORMED7 (PIN7), one of several PIN transporter proteins mediating efflux of this hormone from cells.
- As the globular stage progresses, the highest concentrations of auxin (auxin maxima) become highly localized, and this determines the apical-basal polarity of the embryo.
- Auxin distribution is also important for cotyledon patterning. After the establishment of apical-basal polarity and the root meristem in the globular-stage embryo, the central and peripheral domains of the apical part of the embryo are then specified during the transition stage; these will later develop into the shoot apical meristem and cotyledons, respectively.
- When the embryo reaches the early-heart stage, the adaxial (closest to the axis) and abaxial (farthest from the axis) sides of the cotyledons are already determined.

2. **ABA Content and Sensitivity to ABA During Development**

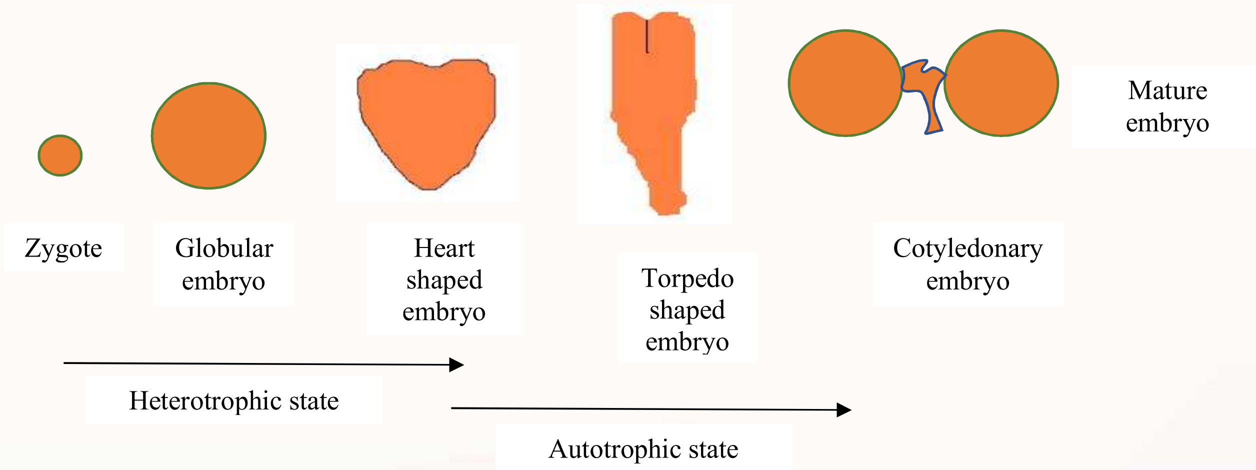
- During seed development and maturation of many horticultural crops, primary dormancy is around mid-development and is often only completed close to full maturation of the seed.
- The onset of primary dormancy frequently coincides with a transient rise in ABA content during seed development.

- In some crops, ABA content increases during the first half of seed development and declines during the maturation phase (e.g., tomato) while in other, two ABA peaks are observed, usually one at around mid-development and one at late maturation.
- The first peak of ABA that accumulates is due to its synthesis in both zygotic and maternal tissues. The maternal ABA (i.e., located in testa and fruit tissues) may play a role in the inhibition of precocious germination and in early developmental processes, whereas the ABA that is synthesized during late maturation originates from zygotic tissues and is related to the induction and maintenance of dormancy. Example apple, pear, peach, plum and other temperate fruits.
- The rise of ABA content coincides with many developmental processes other than dormancy which includes storage protein synthesis, suppression of precocious germination, induction of desiccation tolerance, and synthesis of late embryogenesis abundant proteins.

3. Epigenetic Control of Endosperm Development

- While the embryo is the vital next generation of plant, the major role of the endosperm is to provide nutrition to the embryo during its development and/or following germination until the seedling becomes autotrophic.
- Development of the endosperm is initiated after double fertilization and continues concomitantly with embryo development.

- During the initial stage of embryo growth (upto heart shape stage), endosperm is the only source for supplying nutrients to embryo.



Somatic Embryogenesis and Apomixis

- Somatic embryogenesis is the formation of embryos asexually, i.e., circumventing the necessity for gamete production and fusion.
- Development of embryo, not as a result of meiosis and fertilization but from diploid or haploid egg cells or from cells in embryo sac or surrounding nucellus or integument which does not undergo meiosis and emergence of off spring of same genetic makeup as of female parent is called as apomixes.
- The seedlings which are produced through apomixis are known as apomictic seedlings.
- Plants that produce only apomictic embryos are called as obligate apomicts while other which produce both apomictic and sexual embryos are called as facultative apomicts.

Types of apomixes:

a. **Recurrent apomixis:** Embryo develops from the diploid egg mother cell or from some other diploid cells of the embryo sac without fertilization. It is quite common in *Parthenium*, raspberry, apple, onion, *Poa* etc. In some species, this phenomenon occurs without the stimulus of pollination whereas in others, pollination appears to be necessary for the development of a viable embryo.

b. **Non-recurrent apomixis:** Embryo develops directly from the haploid egg cell or some other haploid cells of embryo sac without fertilization and as a result, the developed embryo is also haploid in nature. It is common in *Solanum nigrum* and *Lilium* species.

c. **Adventitious embryony:** It is also called as nucellar embryony. Here the embryo does not develop from the cells of the embryo sac but from a cell or a group of cells either of nucellus or integuments. Such embryos usually develop outside the embryo sac in addition to the regular embryo. This is quite common in citrus, where normal pollination and fertilization takes place in usual manner and apomictic embryos are develop outside the embryo sac.

d. **Vegetative apomixis:** In this type, vegetative buds or bulbils are produced in the inflorescence in place of flowers. These buds or bulbilis may sprouts into new plants while they are still attached to the mother plants. This is quite common in *Allium*, *Agave*, *Poa* and *Dioscorea*.

Apart from these, different scientists also included polyembryony as one type of apomixis. But it is not a separate type of apomixis. It is the phenomenon in which two or more embryos are produced in a single seed. The condition may results from many reasons. One of the most common reasons being the nucleus develops within the embryo sac, which may lead to the development of more than one embryo. Cleavage of pro-embryo during the early stages of development may the other reason for the development of multiple embryos.

Significance of apomixis:

i. Produce homozygous line
ii. Useful for producing uniform rootstock. Eg. Rootstock of apple like *Malus tiringoides*, *M. hupehensis*, *M. sikkimensis etc*.
iii. Apomictic seedling are quite healthy and highly uniform
iv. Effective for the production of virus free quality planting materials

Course Name	Growth and Development of Horticultural Crops
Lesson 14	Physiology of ripening of fruits
Course Creator Name	MANOJ KUNDU
University/College Name	Bihar Agricultural University, Bhagalpur
Course Reviewer Name	DR SATESH KUMAR
University/College Name	Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu

Learning objectives:

- To get basic knowledge about fruit ripening physiology in details
- To know about the factors affecting fruit ripening process in horticultural crops

Glossary:

- **Ripening:** Ripening is a process in fruits that causes them to become more palatable
- **Carotenoids:** Carotenoids (/kəˈrɒtɪnɔɪd/), also called tetraterpenoids, are yellow, orange, and red organic pigments that are produced by plants and algae, as well as several bacteria, and fungi.
- **Non – climacteric fruits:** Non climacteric fruit produce little or no Ethylene and no large increase in CO_2 production.
- **Climacteric fruits:** The climacteric is a stage of fruit ripening associated with increased ethylene production and a rise in cellular respiration.
- **Temperature quotient:** Q10 is a unitless quantity. It is the factor by which the rate increases when the temperature is raised by ten degrees.

Introduction:

- The growth and developmental stages of fruits and vegetables can be divided into three major phases based on their physiological development *i.e.* growth, maturation and senescence.
- Growth involves cell division, enlargement and differentiation which ultimately giving the produce a particular size, weight, and volume. While maturation usually initiated before the cessation of growth and lasts till the onset of senescence.

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- Growth and maturation are often collectively referred as the development phase of the produce.
- Senescence refers to the stage when anabolic (synthetic) processes almost terminate and catabolic (degradative) processes are initiated and speeded up causing ageing and finally death of tissues.
- However, after the maturation of fruit but before senescence, it go through a particular phase called ripening.
- Ripening is a phase of qualitative change which occurs in the fruits particularly after completion of maturation, during which the fruit becomes acceptable for consumption in terms of taste and flavor.
- It occurs during the last stage of maturation and continue till the first stage of senescence.
- Ripening is a very important event in the life of a plant as it transforms a physiologically mature but inedible (or not preferred to be eaten) plant part into an edible, visually and olfactorily attractive and tasty commodity.
- Ripening is an irreversible event which marks the completion of development phase.
- Generally the growth and maturation of the fruits are completed on the plant itself but ripening and senescence may take place even after detachment of the commodity from the plant *i.e.* ripening and senescence can take place both on and off the plant.

Physico-chemical changes occurs during ripening

The following physiological as well as biochemical changes may take place during ripening of fruits-

- *Changes in fruit skin colour:* Almost all the fruits remain green till maturity. On the onset of ripening, green colour started to convert to light green or orange or yellow or red or any other colours depending on the type of fruit crop. Example – in mango cv. Langra, green colour converted to light green while in cv. Zardalu, it converted to bright yellow colour. In tomato, green colour converted to red colour due to the synthesis of lycopene (carotenoid).
- *Loss of chlorophyll:* The change of colour during ripening in different fruit is mainly due to the degradation of chlorophyll content. Although the chlorophyll degradation is desirable in fruits but not in most of green vegetables.
- *Development of anthocyanin /carotenoids:* During ripening, pigments like anthocyanin or carotenoids start to synthesis in the fruit flesh as well as on the skin of the fruit depending upon the type of fruit crops. Example, in apple, cherry, strawberry and plum- anthocyanin is synthesis on the fruit skin during ripening resulting in the development of red skin colour in those fruits while purple colour in Jamun. However, in mango cv. Zardalu, carotenoid synthesis on the fruit flesh as well as on the fruit skin during ripening resulting bright yellow colour flesh and skin during ripening.
- *Changes in respiration rate:* Usually respiration rate decreases with the advancement of ripening in non – climacteric fruits, while in climacteric fruits, it rises initially and then declines.
- *Changes in ethylene production:* Usually ethylene production rates increase with the advancement in ripening.

- *Softening of the fruit:* Generally the fruits tend to soften with the advancement of ripening due to changes in the composition of cell wall pectic substances.
- *Changes in carbohydrate content:* With the advancement of ripening, starch content of the fruit start to convert into sugars.
- *Organic acids* are converted into other substances.
- *Changes in flavour of fruit:* Different aroma volatiles are also produced during the process of ripening.
- *Development of waxy layers on the fruit skin*: In some fruits like apple, plum etc, waxy layers start to develop on the fruit skin during the onset of ripening.
- *Seed maturity:* In most the fruit crops, the seed at the time of fruit ripening get matured and the colour of the seeds turn brown.
- *Formation of abscission layer:* A layer of abscission start to develop during the late stage of ripening between fruit stalk the branch lets on which the fruit is attached.

Physiology behind ripening:

- A major metabolic process taking place in harvested produce or in any living plant product is respiration.
- Respiration is a process of oxidative breakdown in which stored complex organic materials (carbohydrate, protein, fat) are broken down into simpler molecules such as carbon dioxide and water with the concurrent release of energy and other molecules that can be used by the cells for synthetic reactions.

- Respiration can occur in the presence of oxygen (aerobic respiration) or in the absence of oxygen (anaerobic respiration).

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{energy (686 kcal)}$$

- The rate of respiration of produce is an excellent indicator of the metabolic activity of the tissue and thus is a useful guide to the potential storage life of the produce.
- If the respiration rate of a fruit or vegetable is measured as their O_2 consumed or CO_2 evolved during the course of the development, maturation, ripening and senescent period, a characteristic respiratory pattern is observed.
- The respiratory pattern also impacts the pattern of ethylene evolution. Based on this pattern, fruits can be classified into 'climacteric' and 'non-climacteric'.
- Climacteric fruits are those in which the respiration rate is minimum at maturity and remains constant even after harvest which gradually increase at the beginning of ripening followed by sharp rise to a peak (climacteric peak) and then slowly decline (post climacteric stage).
- Coincident with ripening, the climacteric fruits produce much larger amounts of ethylene than non-climacteric fruits. The respiratory climacteric as well as the complete ripening process may proceed while the fruit is either attached to or detached from the plant.
- Example of climacteric fruits are Apple, Apricot, Avocado, Banana, Blue berry, Breadfruit, Cherimoya, Feijoa, Fig, Jackfruit, Kiwifruit, Mango,

Muskmelon, Nectarine, Papaya, Passion fruit, Peach, Pear, Persimmon, Plantain, Plum, Sapota, Tomato, Watermelon etc.

- Non-climacteric fruits are those that do not exhibit respiratory climacteric (pronounced increase in respiration coincident with ripening forming a peak) and shows a gradual decline in respiration rate with ripening. These fruits ripen on the tree and therefore may be harvested when they become edible.
- Coincident with ripening, the non-climacteric fruits produce much lesser amounts of ethylene than climacteric fruits.
- Example of non-climacteric fruits are Ber (Jujube), Black berry, Cashew apple, Cherry, Cucumber, Brinjal, Grape, Grapefruit, Lemon, Lime, Litchi, Loquat, Olive, Orange, Pepper, Pineapple, Pomegranate, Citrus, Satsuma mandarin, Strawberry, Summer squash, Sweet orange, Tree tomato, Tangerine etc.

Respiration rate

- Rate of consumption of oxygen or evolution of CO_2 from a commodity is called as respiration rate.
- It is an indicator of the metabolic activity of the fruit tissues thus is useful in the determination of potential storage life of produce.
- Immature fruits and vegetables have highest respiration rates which decline steadily towards maturation, ripening and senescence. It can be measured in ml CO_2 $kg^{-1}h^{-1}$.

Table 1. Classification of horticultural crops based on respiration rates:

Category	Respiration rate (ml CO_2 $kg^{-1}h^{-1}$)	Crops (at 5^oC)	Crops (at 15^oC)

Very low	Less than 5	Dried fruits, nuts, dates	May be nuts
Low	5 - 10	Apple, citrus, grape, kiwifruit, garlic, onion, potato (mature).	Potato
Moderate	10 - 20	Apricot, banana, cherry, peach, plum, nectarine, fig, cabbage, carrot, lettuce, pepper, tomato, potato(immature)	Grape, lemon, orange
High	20 - 40	Avocado, cauliflower, limabean, blackberry, raspberry, strawberry.	Apple, cabbage
Very High	40 - 60	Artichoke, snapbeans, green onion, brussels sprouts, cut flowers.	Banana(green), peach, carrot
Extremely High	More than 60	Asparagus, broccoli, mushroom, pea, spinach, sweet corn.	Banana (ripe), lettuce, pea, bean, pear, strawberry.

Table 2.Difference between Climacteric and Non - Climacteric fruits

	Climacteric fruit	Non – Climacteric fruit
1	Fruits exhibit respiratory climacteric (pronounced increase in respiration coincident with ripening forming a peak)	Fruits do not exhibit respiratory climacteric.
2	Coincident with ripening, the fruits produce much larger amounts of ethylene	No such relationship exists in these fruits
3	Fruits may ripen on and off the trees	Fruits ripen on the tree only

4	Example- Apple, Guava, Papaya, Tomato.	Example- Citrus, Cucumber , Grape , Litchi

Factors Affecting fruit respiration and ripening

1. Temperature

- During ripening a number of enzymatic reactions take place inside the fruit and the rate of these reactions depend on temperature and may be described by temperature quotient (Q_{10}).
- Van't Hoff, a Dutch chemist described that the rate of a chemical reaction within the fruit is almost doubles for every 10 ^{0}C rise in temperature.
- In non- climacteric fruits, reduction in temperatures lower down the rate of respiration and hence the rate of deterioration slow down.
- In climacteric fruits, low temperatures can delay the onset of ripening. But in commodities sensitive to chilling injury, reduction of temperatures below 10 ^{0}C or more precisely 7 ^{0}C for long durations may damage the produce.
- There is an inverse relationship between storage life and respiration rate. Higher the respiration rates and lesser will be the storage life and vice versa. However, there is a direct relationship between temperature and respiration rates up to a temperature range of 30 – 40 ^{0}C depending upon the commodity, i.e. higher the temperatures, higher will be respiration rates and lesser will be storage life.

2. Atmospheric composition:

- The concentration of oxygen in the atmosphere surrounding the commodity is very important factor governing the respiration rates and thus ripening.
- The modern storage structures *i.e.* controlled atmosphere, modified atmosphere and hypobaric storage are also dependent on the composition of gas and pressure in the surrounding atmosphere of the commodity.
- Increased concentration of oxygen with lower level of CO_2 in the atmosphere accelerate the process of respiration and thus ripening of the fruit. However, the reverse condition (low level of oxygen with increased CO_2 concentration) inhibits the ripening process.

3. Effect of Ethylene:

- Ethylene is one gas which is produced during the ripening of fruits and is released into the storage atmosphere from the ripen fruits. Presence of ethylene also initiates unwanted ripening in unripe fruits.
- All fruits produce small quantities of ethylene during ripening but climacteric fruits produce much larger amounts of ethylene than non – climacteric fruits.
- Internal ethylene concentration of climacteric fruits varies largely but the non- climacteric fruit experiences little change during ripening.

Table 3.Effect of Applied Ethylene on Climacteric and Non – Climacteric Fruits

Climacteric fruits	Non – Climacteric fruits
Ethylene applied @ 0.1 – 1 µL/Litre for one day is sufficient to hasten full ripening in climacteric fruits.	Applied ethylene @ 0.1 – 1 µL/Litre for one day merely increases the respiration and does not hasten full ripening.
The magnitude of climacteric rise is independent of applied concentration i.e. 0.1 as well as 1 or 10 µL/Litre for one day would result in almost equally good response.	The magnitude of climacteric rise would depend on the applied concentration. 10 or 1000 µL/Litre for one day would result in more sharp rise as compared to 0.1 – 1 µL/Litre for one day.
Rise in respiration in response to applied ethylene occurs only once.	Rise in respiration in response to applied ethylene may occur more than once.

Table 4.Classification of Horticultural crops Based on Ethylene Production Rates

Category	Ethylene evolution rate (µL ethylene $kg^{-1}h^{-1}$)	Crops (at 20^oC)
Very low	Less than 0.1	Artichoke, Asparagus, Cauliflower, Cherry, Citrus, Grape, Ber, Strawberry, Pomegranate, Leafy and root vegetables, Cut flowers.

Low	0.1- 1	Blueberry, Cranberry, Cucumber, Brinjal, Okra, Olive, Pepper, Persimmon, Pineapple, Pumpkin, Lemon, Lime, Orange, Raspberry, Watermelon.
Moderate	1 - 10	Banana, Fig, Guava, Mango, Tomato, Plantain.
High	10 - 100	Apple, Apricot, Avocado, Cantaloupe, Feijoa, Kiwi fruit, Nectarine, Papaya, Peach, Pear, Plum.
Very High	More than 100	Apple, Nectarine, Cherimoya, Passion fruit, Sapota.

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Course Name	Growth and Development of Horticultural Crops
Lesson 15	Postharvest Physiology and Biochemistry of Fruits and Vegetables
Course Creator Name	MANOJ KUNDU
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Course Reviewer Name	DR SATESH KUMAR
University/College Name	Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu

Learning objectives:

- To get basic knowledge about physiological and biochemical changes of fruit and vegetables under storage conditions in details.
- To know about the physiological disorders of fruit and vegetables under storage conditions.

Glossary:

Hypoxia: Hypoxia is a condition in which the plant or a region of the plant is deprived of adequate oxygen supply at the tissue level.

Anoxia: Anoxia is a condition characterized by an absence of oxygen supply to an organ or a tissue. Anoxia is an extreme form of hypoxia

Fermentation: Fermentation is a metabolic process that produces chemical changes in organic substrates through the action of enzymes

Organoleptic: organoleptic: [adjective] being, affecting, or relating to qualities (such as taste, color, odor, and feel) of a substance (such as a food or drug) that stimulate the sense organs.

Senescence: Senescence is the gradual deterioration of functional characteristics in living organisms.

Freeze injury: Freezing injury is the term usually applied to injury caused by freezing

chilling injury:

Chilling injury: It is a form of cold damage (with similar symptoms to freezing injury) that occurs to certain species when exposed to non-freezing temperatures.

Introduction

- Storage can be define as keeping the commodity fresh or processed in safe condition with minimum of deteriorative changes for later use.
- The main goal of storing perishable horticultural commodities is to delay ripening and senescence and maintain organoleptic quality parameters with the benefits of prolonging commercial and shelf-life.
- Storage of perishable horticultural commodities is also done to reduce the decay incidence and severity.
- The storage of any fresh produce depends on a number of factors, the most important represented by the specific physiological and metabolic responses to the imposed stress that in turn, determine the overall results in terms of produce quality and consumer acceptance.

Reason of deterioration during storage

1. **Physical changes**
    - Damage caused by insect, rodents, animals etc.
    - Weight loss and shriveling
    - Bruising during handling
2. **Physiological changes**
    - Physiological disorders including freezing injury, chilling injury etc.
    - Increased ethylene evolution
    - Higher respiration rate
3. **Biochemical changes**
    - Loss of carbohydrates and vitamins
    - Development of off flavor

- Changes in skin colour

4. **Microbial incidence**

- Postharvest diseases caused by pathogens resulting faster rotting, fermentation etc.

Goal of storage

- Slow down biochemical activities within the produce i.e. respiration rate, ethylene evolution etc.
- Reduce product drying and moisture loss (shriveling)
- Reduce growth of microorganisms and pathogenic damage
- Avoid the occurrence of physiological disorders including freezing injury, chilling injury, heat injury, storage disorders etc.
- Reduce physical damage caused by insect, rodents, animals etc.

Storage conditions

1. **Temperature**

- According to Van't Hoff Quotient (Q_{10}), the rate of deteriorative reactions within the produce doubles for each 10 ºC rise in temperature. Hence, the storage temperature should be optimum.
- Higher temperate cause increase in respiration and lower may cause chilling or freezing injury too.

2. **Relative humidity (RH)**

- Relative humidity under storage should be in optimum level depending upon the produce.
- Lower humidity level may cause shrinkage and weight loss.
- Usually for most of the fruit and vegetable crops, RH levels of 85-95%is optimum except some produce like onion, garlic, potato etc.

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where RH level of 65-75% are required as higher RH in these produce may cause rotting.

3. **Atmospheric gaseous composition**
    - Composition of gases affects the storage life of any produce in a particular set of temperature and humidity.
    - More the available oxygen higher shall be the respiration rates; however, absence of oxygen may initiate anaerobic respiration, leading to the formation of alcohol within the produce.
    - Presence of ethylene in the storage atmosphere also favours respiration which may differ in climacteric and non-climacteric fruits.

Physiological responses of fruits and vegetables under storage conditions

- Low-oxygen-based storage techniques (controlled and modified atmosphere conditions) are a means to preserve quality parameters and the shelf-life of specific agricultural commodities, in particular some perishable fruits and vegetables.
- The effects of these storage protocols on the physiology of horticultural crops are many, involving changes in primary and secondary metabolism and also depends on several factors.

1. **Effects of low oxygen levels on fruit metabolism and composition**
    - Lack of oxygen causes a reduction in respiratory efficiency and, as a consequence, in energy production. Therefore, under hypoxia/anoxia, ATP synthesis is mostly provided by glycolysis coupled with NAD^+ regenerative pathways, including ethanolic

fermentation and alanine production. Hence, under low oxygen level, ethanol and alanine accumulation increases within the produce.

- Increased ethanol accumulation leads to off-flavors of the produce as well as the onset of different physiological disorders.
- Further, amino acid metabolism is also affected by low-oxygen stress.
- The concentration of many different molecules belonging to this class, such as alanine, aspartate, γ-aminobutyric acid (GABA), proline, serine, and threonine, has been often found to be modulated by oxygen level during fruit storage.
- Sugar metabolism is modulated under storage condition. Glucose, galactose, and melibiose concentrations show increasing trends when hypoxic conditions are applied.
- Galactose in fruit tissue is mainly bound to the side chains of cell-wall polysaccharides and its level increases as a result of cell wall breakdown.
- Other sugars, such as arabinose, melibiose, raffinose, and sucrose, as well as many sugar alcohols, are known as osmoprotectants and stress markers in plants. Their increase under stress conditions serves also as a carbohydrate reserve of disaccharides, which could be important in protecting tissues from prolonged stress periods and energy losses.
- Firmness loss mainly relates to disassemble the middle lamella and cell wall by specific enzymes, such as β-galactosidase, β-xylosidase,

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α-arabinofuranosidase, pectate lyase, endoglucanase (EGase), or pectin methyl esterase. Controlled and modified atmosphere conditions down-regulate the expression of some genes coding for such enzymes, allowing a good maintenance of firmness levels, with the best effects obtained under the lowest oxygen concentrations.

2. Influence of oxygen level on fruit aroma profile

- Controlled and modified atmosphere conditions affect the accumulation pattern of volatile organic compounds (VOCs), which have a great impact on fruit aroma and flavor, and are considered one of the most important quality parameters influencing consumer acceptance.
- Ethyl esters production is reported to be enhanced under low-oxygen storage in different fruit species with increased accumulation of fermentative products within the produce. However, a slight increase or decrease in the level of alcohol and esters (ethyl esters) does not really influence the final aroma.
- In addition to esters, other chemical classes of aroma volatiles are produced during normal ripening of climacteric and non-climacteric fruits, such as aldehydes, alcohols, lactones, terpenoids, ketones, and volatile acids, and they can also be modulated by the applied storage conditions, characterizing altogether the stored fruit aroma.

3. Incidence of physiological disorders under storage

- These are caused by improper climatic conditions during handling or nutritional deficiencies or imbalance.

- When a freshly harvested horticultural commodity is exposed to undesirable temperatures, it may result in post-harvest physiological disorders which are as follows-

A. Freezing injury:

- ✓ When the produce is stored below its freezing temperature, this injury occurs.
- ✓ Generally this temperature is 0 ºC or even less in some fruits.
- ✓ The common symptoms of this injury are the formation of ice crystals inside the fruit, browning of damaged area etc.

B. Chilling injury

- ✓ This type of injury occurs in subtropical or tropical fruit crops.
- ✓ Chilling injury occurs when a commodity is stored above freezing point but below its optimum storage temperature. Example – peel of banana when kept in refrigerator turn black after some times.
- ✓ The common symptoms of this injury are surface and internal discolouration, pitting, water soaked areas, uneven ripening or failure of ripening, undesirable off flavour development, high incidence of surface moulds and decay.

C. Heat injury

- ✓ This injury occurs when the commodity is exposed to direct sunlight or excessive high temperature.
- ✓ The common symptoms of this injury are bleaching, surface burning or scalding, uneven ripening, softening, desiccation and weight loss.

D. Bitter pit

- ✓ It is common in apple and occurs due to the deficiency of calcium in the fruit.
- ✓ The common symptoms of this injury is bitterness of the fruit flesh although the fruit looks normal from outside.
- ✓ Pre-harvest spray of calcium is recommended to control this disorder.

E. Blossom end rot

- ✓ It is common in tomato, pepper, water melon etc. and also occurs due to the deficiency of calcium.
- ✓ The common symptoms of this injury is that the fruit starts rotting from blossom end and cause losses.
- ✓ Pre-harvest spray of calcium is recommended to control this disorder.

F. Superficial scald

- ✓ It is common during cold storage of apple and occurs due to oxidation products of alpha farnesene that occur when the natural antioxidants are degraded or inactivated during cold storage.
- ✓ The common symptoms of this injury is the development of scald (slight sunken skin discolouration) on the fruit surface.
- ✓ Addition of synthetic antioxidants effectively control this disorder. Postharvest dip in diphenylamine (0.1-0.25%) or 1,2-dihydro, 6- ethoxy, 2,2,4- trimethyl quinolone (ethoxyquin) @ 02.-0.5% is effective to control this disorder.

4. **Incidence of post-harvest diseases**

   - The incidence of post-harvest decays are most commonly caused only after improper handling of the produce during harvesting, field handling, transportation and storage.
   - Pathogens like *Alternaria, Botrytis, Phomopsis, Rhizopus, Penicillium* etc. only invade the bruised or damaged produce but cannot penetrate healthy fruit skin; however, *Colletotricum* can even penetrate the healthy fruit skin.

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Course Name	Growth and Development of Horticultural Crops
Lesson 16	Seed and bud dormancy in horticultural crops
Course Creator Name	MANOJ KUNDU
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Learning objectives:

- To get basic knowledge about seed and bud dormancy in horticultural crops in detail
- To know about the methods to overcome seed and bud dormancy of horticultural crops

Glossary:

Dormancy: Dormancy is a period in an organism's life cycle when growth, development, and physical activity are temporarily stopped..

Stratification: a process of pre-treating seeds that helps the seed "break dormancy" and initiate the germination process.

Scarification: involves weakening, opening, or otherwise altering the seed coat mechanically, thermally, and chemically to encourage germination.

Chilling requirement: minimum period of cold weather after which a fruit-bearing tree will blossom.

Inhibitors: a substance that reduces or suppresses the activity of another substance (such as an enzyme)

Endocarp: the innermost layer of the pericarp which surrounds a seed in a fruit. It may be membranous (as in apples) or woody (as in the stone of a peach or cherry).

Introduction

- All the viable seeds have the capacity to germinate if placed under suitable conditions, necessary for germination.
- But some seeds fail to germinate for sometimes even if placed under the favourable condition for germination.

- This may be due to some internal factors or due to specific requirement for some environmental factors.
- During this period, the growth of the seeds remains suspended and they are said to be in rest stage or dormant stage and this phenomenon is called as dormancy of seeds.
- Seed dormancy can be define as the phenomenon of failure of a viable seed to germinate even under favourable environmental condition such as light, temperature, aeration etc.

Significance of Seed Dormancy

1. From an ecological perspective, dormancy is an important survival mechanism that favours propagation and dissemination of seeds to establish plant populations.
2. Dormancy allows the seeds to remain in suspended animation without any harm during drought, cold or high summer temperature.
3. The dormant seeds can remain alive in the soil for several years. They provide a continuous source of new plants even when all the mature plants of the area have died down due to landslides, earth quake, floods, epidemics or continuous drought.
4. It helps the seed to get dispersed over long distances through unfavourable environment or inhospitable area.
5. Dormancy induced by the inhibitors present in the seed coats is highly useful to desert plants. The seeds germinate only after a good rainfall which dissolves away the inhibitors. The rainfall ensures the seed a proper supply of water during its germination.
6. It follows storage of seeds for later use by animals and man.

Different types of seed dormancy

Basically it is of two types-

A) Primary dormancy: It induced during seed development; hence the seeds remain in dormant condition when dispersed from the mother plant.

B) Secondary dormancy: It induced by unfavourable environmental conditions following shedding of mature seeds from the parent plant. Secondary dormancy can be induced by unfavourable conditions for germination such as adverse temperatures, illumination or oxygen. Types of secondary dormancy includes:

i) Thermo-dormancy: It is caused by prolonged exposure of imbibed seeds to unfavourable temperatures for germination, generally high temperatures.

ii) Skoto-dormancy: It is induced in seeds (require light for germination) when they are imbibed in the dark for extended periods of time.

iii) Photo-dormancy: It occurs in seeds (require dark condition for germination) when they are exposed to an excess of light.

- Secondary dormancy is not only induced in non-dormant seeds, but also in seeds that already have some form of primary dormancy. For example, a lettuce seed that requires light to germinate is said to be photosensitive and when imbibed in the dark, it will not germinate until light is provided. However, if dark imbibition is extended for a period of time, skoto-dormancy can be induced and the seed will not germinate even if it is placed under optimum light conditions.

Primary dormancy can again be classified into the following ways-

A. Seed coat dormancy

1. Physical dormancy

- Here the seed coats are impermeable to water and gases.
- Crops of Leguminosae, convolvulaceae, malvaceae, chenopodiaceae and solanaceae has this type of dormancy.
- Here the embryo is generally quiescent (non-dormant) and the cause of dormancy is the structure of the outer cell layer which becomes impermeable to water and gases.
- Macrosclereid cells, a mucilaginous outer cell layer, or a hardened endocarp are three reasons that seed coats become impermeable to water and gases.
- Such seed coats develop during the last stages of seed development.

2. **Mechanical dormancy**

- Seed coats are too hard to allow the embryo to expand during germination.
- Causes includesstructure of seed coats or remaining fruit.
- Such type of dormancy is occurs in walnut, pecan nut etc.

3. **Chemical dormancy**

- Presence of chemical inhibitors (phenols, ABA, caumarin) in the outer coverings of many fruits and seeds is the main factor for chemical dormancy.
- This occurs in fleshy fruits, hulls and capsules of many dry fruits. Examples are apples, citrus, grapes, desert plants.
- Very often this kind of dormancy disappears with dry storage.
- This kind of dormancy may also be present in other tissues surrounding the embryo such as the endosperm.

B. Morphological dormancy

- In this case, embryo is not fully developed at time of ripening and they remain in rudimentary condition. Hence, they need additional embryo growth even after the seed is separated from the plant.
- This type of dormancy mainly observed in several herbaceous flower, seed such as Ranunculus, poppy; temperate zone species such as holly, snowberry; tropical plants such as date palm.

C. Endogenous dormancy:

- Here the dormancy is controlled internally within the living tissues of the seed. It may be of two types-

i. **Physiological dormancy:** Most of the temperate fruits (apple, pear, peach, plum, cherry), vegetables and flowering annuals have physiological seed dormancy lasting from 1-6 months, which disappear on storage. The seeds of these species have physiologically immature embryo and they do not germinate even under favourable conditions.

ii. **Embryo dormancy:** Here the dormancy is due to dormancy of the embryo which over winter in soil and germinate in spring under natural condition.

D.Epicotyl dormancy

- Seeds of some species have different stratification requirement for the growth of their radicles, hypocotyls and epicotyls and this type of dormancy is called as epicotyls dormancy.
- On the basis of chilling requirement for epicotyls, different plant species are divided into two sub groups. In one group, seed germinate initially during warm period of 1-3 months and produce roots and hypocotyls but these require 1-3 months chilling for epicotyls to germinate as in lily and peony. In second group, it requires a certain amount of chilling period to after ripen the embryo

followed by a warm period for the roots to grow and again a chilling period to stimulate shoot growth as in Trillium.

E. Double dormancy

- In certain plant species, seeds have dormancy due to hard seed coats and dormant embryos. This is called as double dormancy.
- For proper germination, both the blocking conditions must be modified to allow water to penetrate the embryo and after ripening of the embryos.
- This type of dormancy is found in trees and shrubs producing seeds with hard seed coats, grown primarily in cold winter area.
- To overcome the problem of double dormancy, the seeds are first treated in a way to soften the seed coat and then cold stratification treatment is given to them.

Phases of seed dormancy

The period of seed dormancy follows four different phases-

1. Induction phase:

- Here the dormancy is induced by various environmental factors.
- Among different environmental factors, temperature and light at the time of seed development and maturation are the first to induce the dormancy phase in many seeds.
- For instance, hot and dry weather during seed maturation helps in the development of hard seed coat in clover seeds. However, the seeds have soften coats if they mature and ripen during rainy season.
- Besides, the balance of promoter (Auxin, gibberellins, cytokinin) and inhibitors (ABA) also play important role to induce dormancy in the seed. It is induced if the level of inhibitors is more in the seed than the level of promoters.

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2. Maintenance phase:

- In this phase, the promoter-inhibitors balance has shift towards inhibitors resulting stop of different metabolic activities within the seed.
- This phase can be shorten or lengthened artificially through exogenous application of growth promoters or inhibitors.
- Pre-treatment of seeds with promoter (GA_3) at 40-50 ºC for 2-3 hours may shorten the rest period to some extent.

3. Trigger phase:

- Here the promoter-inhibitors balance shift towards promoters by the environmental triggers
- Stratification, scarification, exposure of seeds to light and leaching of inhibitors are some treatments which may help to overcome the dormancy in many seeds.

4. Germination phase:

- During this phase, the seeds germinate under favourable environmental conditions.
- Water is absorbed by seeds through imbibition which helps to activate the protoplasm.
- The metabolic block created during maintenance phase is removed and the metabolic activity of the seeds increased due to the increase of enzymatic and hormonal activities which ultimately initiate the germination process of the seed.

Methods to Overcome Seed Dormancy

- The methods to overcome dormancy are better understood once the mechanisms of dormancy are known.

- For instance, if the cause of dormancy is an impermeable seed coat that impedes seed water uptake, removing the seed coat or reducing its permeability should break dormancy.
- When dormancy is caused by an underdeveloped embryo, additional time for embryo growth should overcome dormancy.
- Finally, when dormancy is imposed by a physiological mechanism, actions that decrease the amount of or sensitivity to dormancy-inducing compounds (e.g., ABA), along with actions that increase the amount of or sensitivity to dormancy-breaking compounds (e.g., GA) should break dormancy.

The effective methods to overcome seed dormancy are as follows-

1. **Softening seed coat and other seed coverings:** This helps in better absorption of water and gases, which ultimately leads to better germination of the seeds. This can be achieved by the process called scarification. It is the process of breaking, scratching, mechanically altering or softening the seed covering to make it permeable to water and gases. Different forms of scarification are as follows-

I. Mechanical scarification:

- It is simple and effective means of scarification.
- It involves the scratching or injuring the hard seed coat by rubbing with sand paper or against any rough surface.

II. Acid scarification:

- It involves the treatment of dry seeds with concentrated sulphuric acid (H_2SO_4) or HCl in the ratio of one part of seed to two parts of acid.
- The amount of seed treated at any time should be restricted to not more than 10 kg to avoid uncontrollable heating.

- The containers should be of glass, earthenware or wood, non- metal or plastic.
- The mixture should be stirred cautiously at intervals during the treatment to produce uniform results.
- The time may vary from 15 minutes to 6 hours depending upon the species.
- With thick-coated seeds that require long periods, the process of scarification may be judged by drawing out samples at intervals and checking the thickness of the seed coat.
- When it becomes paper thin, the treatment should be terminated immediately.
- At the end of the treatment period, the acid is poured off and the seeds are washed with running tap water for 10-15 min to remove the acid.
- The treated seeds may place in large amount of water with small amount of baking soda to neutralize the adhering acid.
- Thereafter, the treated seeds can either be planted immediately when wet or dried and stored for later planting.

III. Hot water scarification:

- Drop the seeds into 4-5 times their volume of hot water with temperature ranging from 77 to 100^{o}C.
- The heat source is immediately removed, and the seeds soaked in the gradually cooking water for 12 to 24 hours.
- Following this the swollen seeds may be separated from the swollen seeds by suitable screens. The seed should be sown immediately after hot water treatment.

IV. Warm moist scarification:

- The seeds are placed in moist warm medium for many months to soften the seed coat and other seed coverings through microbial activity.
- This treatment is highly beneficial in seeds having double seed dormancy.
- The hard seeds are planted in summer or early fall when the soil temperature is still higher, that usually facilitates germination. For instance the stone fruit including cherry, plum, apricot, peaches etc show increased germination if planted early enough in the summer or fall to provide one to two months of warm temperature prior to the onset of chilling.

V. Harvesting immature fruits:

- In certain plant, seeds are extracted pre-maturely to avoid the development of hard seed coats. Such seeds should be sown immediately after extraction.

2. Stratification: It is a method of handling dormant seed in which the imbibed seeds are subjected to a period of chilling to after ripen the embryo in alternate layers of sand or soil for a specific period. It is also known as moist chilling.It can be achieved by the following methods-

I.Refrigerated stratification:

- In this practice, dry seeds are 1st soaked in warm water for 12-24 hrs. After soaking, seeds are usually placed in a convenient size box in alternate layers of previously prepared medium containing well washed sand, peat moss or vermiculite.
- The boxes are placed in the refrigerator at a temperature of 4-7^{o}C. At higher temperature seeds sprout prematurity and low temperature delays

sprouting. The time for keeping the seed in refrigerator depends on the kind of seed. Usually it takes 1-4 months time.

- However, during the process care should be taken to examine the boxes periodically and if the seeds are dry, the medium should be re-moistened immediately.

II. Outdoor stratification:

- If refrigerated storage facilities are not available, outdoor stratification may be done either by storing seeds in open field conditions in deep pits or in raised beds enclosed on wooden frames.
- However it is likely that seeds are destroyed in outdoors by excessive rains, freezing, drying, or by rodents. Seeds are placed in alternate layers of sand to provide and low temperature and proper aeration in the stratification pit. The top is covered with Sphagnum moss to maintain moisture level. The pit or tray is irrigated at regular intervals to maintain appropriate moisture status.

III. Outdoor planting:

- Seeds of different species require cold treatment for after ripening of the embryos.
- Such seeds may be planted directly in the seedbeds, when the natural environmental conditions are favourable for them.
- The seeds should be sown in such a way that they may get proper moisture and make use of all other natural conditions, particularly the winter chilling period.
- The seeds, in general germinate quickly during spring when the soil temperature begin to raise.

3. Leaching of inhibitors:

It is established fact that some inhibitors and phenolic compounds are present in seed coverings of many species, which inhibit germination. Therefore, soaking of seeds in the running water for 12-24 hours or placing them in water for few hours help in leaching off the inhibitors and phenolic compounds, which help in easy germination.

4. Pre-chilling:

In seeds of certain plant species, dormancy can be overcome by pre-chilling treatment. In this treatment, the imbibed or soaked seeds are kept at a temperature of 5-10^{0}C for 5-7 days before sowing. After that seed can be sown in the field immediately.

5. Pre-drying:

This is also a useful practice in some seeds to overcome seed dormancy. In this treatment, the dry seeds are subjected to a temperature of 37-40^{0}C for 5-7 days prior to sowing. After this, seed can be sown in the field.

6. Hormonal treatment:

GA_3@ 200-500 ppm is commercially used to break dormancy. However, soaking of seeds with kinetin (cytokinin) @ 100 ppm solution for 3-5 min is also effective to overcome dormancy in many seeds.

7. Treatment with chemicals:

Some compounds other than hormones are also used to break dormancy but their role is not clear.

- Thiourea is one example known to stimulate germination in some kinds of dormant seeds. The seeds are soaked in 0.5 – 3 per cent solution of thiourea for 3-5 minutes. Afterwards seeds are rinsed with water and are sown in the field.

- Similarly, potassium nitrate (0.1-2%), hydrogen peroxide (5%) and sodium hypochlorite also stimulate seed germination in many plant species.

8. Seed priming:

Seed priming refers to the procedures followed to overcome dormancy in freshly harvested fruits. Most widely used seed priming procedures are osmo-conditioning, infusion and fluid drilling.

- In osmo-conditioning, the seeds are placed in shallow layer in a container having 20-30 per cent solution of polyethylene glycol (PEG). The seeds are then incubated at 15-20^{0}C for 7-21 days, depending upon seed size and plant species. Different hormones and fungicides can also be added in PEG solution to protect the seeds from pathogens. After it, the seeds are washed and dried at 25°C and are stored until use.
- In infusion, the hormones, fungicides or insecticides and antidotes are infused into dormant seeds through organic solutions. In this process the seeds are placed in acetone or dichloromethane solution containing chemicals to be used for 1-4 hours.Afterwards, the solvent is allowed to evaporate and seeds are dried slowly in vacuum desiccators for 1-2 hours. The seeds absorb the infused chemical directly into the embryo when soaked in water.
- In fluid drilling, the seeds are suspended in a special type of gel before sowing. Now-a- days different types of gels are available in the market but sodium alginate, guar gum and synthetic clay are most widely used in fluid drilling.

Bud dormancy

- Perennial crops like shrubs, tree have to go through different season in a year.

- The onset of winter is always an unfevourable season for the growth and even survival of the plant become difficult.
- Though leaves perceive changes in the photoperiodic effect of the day, it is the buds that act as the site of perception for inducing dormancy which starts only after the falling of leaves.
- Bud dormancy can be define as the phase of development of the bud that allows the tree to survive unfavorable weather condition during winter and after successful completion of chilling requirement, the bud start to grow again.

Different stages of bud dormancy

- Lang *et al.* (1987) classified various stages of bud dormancy as para-dormancy, endo- dormancy and eco-dormancy.
- Para-dormancy occurs in the mid to late summer when buds do not grow because inhibitors produced in the leaves and terminal buds inhibit bud growth.
- Endo-dormancy or deep dormancy occurs in winter when the dormancy causing factors (ABA) resides within the bud in higher concentration. During this phase of dormancy the trees will not grow even under ideal growing conditions.
- Eco-dormancy occurs in late winter and spring when dormancy is imposed by temperature or other unfavorable conditions for growth of the bud as well as the entire plant. However, the growth may resume if the plants are exposed to suitable temperatures and day lengths.

Factors responsible for bud dormancy:

1. **Hormonal balance in the bud or the tree**

- Auxins, gibberellins, cytokinins and abscisic acid (ABA) is involved in breaking and imposing dormancy in the bud.

- ABA is termed as 'dormin' or dormancy inducer and is the most important inhibitor preventing growth.
- On the other hand, cytokinin triggers metabolic activities that are geared for growth including DNA, RNA and protein synthesis, increase in the energy metabolism and decrease the pathway important for resting tissues. These ultimately resume the plants to grow satisfactorily by breaking the bud dormancy.
- Further, GA_3 has antagonistic role against ABA. Hence, when the concentration of GA_3 start to increase within the bud, it starts to counteract the effect of ABA within the dormant bud which in turn helps to break the dormancy of the bud.

2. **State of water within the bud during dormancy**

- The conditions such as short day length and low temperature that induces dormancy also increased the level of bound water within the bud. Water is gradually bound during the dormant period and rapidly converted to free water when resumption of growth is started.
- As the water remain in bound form within the bud during dormancy, no significant enlargement of leaf or flower primordia is observed at this stage. However, towards the end of endo-dormant period when about two-thirds of the water is frees, an appreciable enlargement of leaf or flower primordia occurs without any visible sign of bud break.

3. **Anabolic potential of the bud**

- Bud dormancy occurs also due to the loss of potential competition of the bud with other plant tissues and the dormancy release is considered as an improved competing bud power with its neighboring tissues.

- A gradual development of communication block between the bud and the adjacent tissues occurs during the transition phase of dormancy.
- By reversing the competing power of different tissues, the bud may overcome the blocks of its development.
- The internal bud cell pH raises when the dormancy is over and is higher than that of the stem and receptacle cells while the reverse is true during dormancy phase.
- The raise in pH occurs due to increased plasma lemma ATPase activities in the cell membrane and proton pumping (a measure of active metabolic activities).

Methods to overcome bud dormancy:

1. In natural course, with the onset of spring and long photoperiods, the dormant buds become active and start to produce new flushes.
2. In temperate regions the buds formed in autumn remain dormant until next spring due to severe colds. This dormancy of buds can be broken by gibberellin treatment.
3. In potatoes also, there is a dormant period after harvest, but the application of gibberellin sprouts the eyes vigorously. However, potato tubers exposed to ethylene also helps to break the dormancy of the buds resulting early sprouting of the eyes.
4. Cytokinin analogs particularly thidiazuron (TDZ) is widely used to overcome the bud dormancy.
5. The other chemicals which substitute the chilling requirement are also effective to break the dormancy of the bud such as dinitro-o-cresol (DNOC- oil), hydrogen cyanamide etc.

6. Besides, KNO_3 is also known to compensate the lack of chilling effect partly. Application of KNO_3 also trigger the cytokinin production in the root of the tree which ultimately helps to break the dormancy of eco-dormant bud.