**Discovery of ethylene**

A unique feature about discovery of ethylene as plant growth hormone is that experimenters first knew ethylene as exogenous chemical affecting plant growth and thereafter only gradually and over a period of over half a century it become evident that it is infact a natural plant growth hormone.

The discovery of ethylene as a plant growth regulator may indirectly be traced back to 19th century when street lights were used to be lighted with illuminating coal gas. It had been a common observation at that time that the trees in the vicinity of the street lamps defoliated more extensively than other trees. Even ancient Chinese knew that their harvested fruits would ripen much faster in burning incense.

However, the credit for first establishing the fact that ethylene affects plant growth goes to a Russian physiologist Dimitry N. Neljubow who in 1901 identified ethylene in laboratory air from illuminating coal gas which caused typical symptoms in etiolated pea seedlings grown in dark in the lab viz., i) inhibition of stem elongation, ii) stimulation of radial swelling of stems and iii) horizontal growth of stems with respect to gravity. These symptoms were later termed as triple response and were not observed in etiolated pea seedlings grown in normal air free from coal gas.

The first indication that ethylene might be a natural product of plant tissues came through as annual report by H.M.Cousins in 1910 to Jamaican Agriculture Department wherein he mentioned that bananas should not be stored with oranges in ships because some emanations from oranges caused bananas to ripen prematurely. But it was R. Gane (1934) who clearly established that ethylene is actually a natural product of ripening fruits and is responsible for faster ripening process.

Meanwhile, several other experiments found evidence of ethylene being produced not only by ripening fruits but also by flowers, seeds, leaves and even roots and having profound regulatory activity in plants. But, their proposals to consider ethylene as natural plant hormone met with strong criticism by other well known phygiologists of that time especially Went and Thimann (1937) were rejected.

For further almost two and half decades, the importance of ethylene as natural plant hormone remained subdued. It was only after the advent of gas chromatography (GC) and its use in ethylene research, that importance of ethylene as important hormonal regulator of physiological processes was realised. Soon, this was followed by an avalanche of experimental research work on ethylene and finally ethylene emerged as accepted natural plant growth hormone.

**Physiological roles of ethylene**

1. **Fruit ripening**

One of the most pronounced effects of ethylene is in ripening of fruits and therefore, ethylene is also known as fruit ripening hormone.

Different types of fruits react differently with exogenous application of ethylene. In climacteric fruits such as apples, bananas, tomatoes etc., exposoure of mature fruits to ethylene result in respiration climacteric (marked increase in respiration during initiation of ripening) followed by additional production of ethylene leading to hastening of ripening process. Additional production of ethylene by ripening fruits is autocatalytic. But, in non-climacteric fruits such as citrus fruits and grapes, ethylene treatment does not cause respiration climacteric and additional ethylene production and the ripening process remains unaffected.

However, minimum threshold level of endogenous ethylene is essential for all types of fruits for ripening. This has been confirmed by experiments with transgenic tomatoes in which ethylene production was completely blocked by making expression of antisense version of ACC synthase or ACC-oxidase. Ripening process was completely checked in these transgenic tomatoes which could be restored only by exogenous application of ethylene. In never ripe mutant of tomato also, ripening process is completely blocked due to mutation in ethylene receptor making it unable to bind with ethylene and preventing the latter to exert its hormonal effect.

1. **Plumular Hook Formation**

In etiolated dicot seedlings, the plumular tip (i.e., shoot apex) is usually bent like a hook. This hook shape is advantageous to seedling for penetration through the soil, protecting the tender apical growing point from being injured.

The plumular hook formation and its maintenance in etiolate (dark grown) seedling are due to formation of ethylene in that region which causes asymmetric or unequal growth on the two sides of plumular tip. Ethylene causes more rapid elongation of outer side of plumular tip than on its inner side. When the seedling is exposed to white light, formation of ethylene decreases, the inner side of the hook also elongates rapidly equalising the growth on two sides and the hook opens.

Red light is more effective in opening of plumular hook. This effect is reversed by exposing the seedling to far-red light. This red/far-red reversibility is inductive of the role of the pigment phytochrome in it.

When etiolated seedlings are exposed to light in presence of ethylene, the plumular hook fails to open. On the other hand, if seedlings are grown in dark along with ethylene absorbant such as KMnO4, the plumular hook opens.

It is believed that asymmetric growth on two sides of plumular tip resulting in hook formation and its maintenance in etiolated dicot seedlings is probably due to an ethylene dependent auxin gradient similar to that which develops during phototrophic curvature.

1. **Triple response**

Ethylene causes triple response of etiolated seedling such as in pea which consists of

1. Inhibition of stem elongation
2. Stimulation of radial swelling of stems and
3. Horizontal growth of stems with respect to gravity
4. **Formation of adventitious roots and root hairs**

Ethylene induces formation of adventitious roots in plants from different plant parts such as leaf, stem, peduncle and even other roots. In many plants especially *Arabidopsis*, ethylene treatment promotes initiation of root hairs.

1. **Inhibition of root growth**

Ethylene is known to inhibit linear growth of roots of dicotyledonous plants.

1. **Leaf epinasty**

When upper side of the petiole of the leaf grows faster than the lower side, the leaf curves downward. This is called as epinasty. Ethylene causes leaf epinasty in tomato and other dicot plants such as potato, pea and sunflower. Young leaves are more sensitive than the older leaves. However, monocots do not exhibit this response.

Higher concentrations of auxin, stress conditions such as salt stress, water logging and pathogen infection also induce leaf epinasty indirectly through increased ethylene formation. In tomato and other plants, water logging creates anaerobic condition around the roots resulting in accumulation of ACC in roots. ACC is then translocated to shoots along with transpiration stream where it is converted into ethylene in presence of oxygen and induces leaf epinasty.

1. **Flowering**

Ethylene is known to inhibit flowering in plants. However, in pineapple and its allies and also mango, it induces flowering. Ethylene is used commercially to synchronize flowering and fruit set in pineapple.

1. **Sex expression**

In monoecious species especially some cucurbits like cucumber, pumpkin, squash and melon, ethylene strongly promotes formation of female flowers thereby suppressing the number of male flowers considerably.

1. **Senescence**

Ethylene enhances senescence of leaves and flowers in plants. In senescence, concentration of endogenous ethylene increases with decrease in concentration of cytokinins and it is now generally held that a balance between these two phytohormones controls senescence.

Freshly cut carnation flowers when held in water in conical flask, loose colour of their peatls and whiter within a few days. But, if the cut carnations are held in conical flask containing silver thiosulphate solution, they remain fresh for many weeks. This is because silver thiosulphate is potent inhibitor of ethylene action. Role of ethylene in enhancing senescence has now been confirmed by studies with transgenic plants also.

1. **Abscission of leaves**

Ethylene promotes abscission of leaves in plants. Older leaves are more sensitive than the younger ones. Fumigating the wild type birch tree with 50 ppm ethylene results in rapid defoliation of the tree within few days. Contrary to this, transgenic birch tree with a mutated version of Arabidopsis ethylene receptor ETR-1 does not respond to ethylene treatment and therefore, does not defoliate.

The relative concentration of auxin on two sides of the abscission layer has regulatory influence on the production of ethylene that stimulates leaf abscission. At the time of abscission, concentration of auxin in laminar region decreases with simultaneous increase in ethylene production. This also increase sensitivity of cells of abscission zone to ethylene which now synthesize cell wall loosening and cells separation ultimately leading to leaf abscission.

1. **Breaking dormancy of seeds and buds**

Ethylene is known to break dormancy and initiate germination of seeds in barley and other cereals. Seed dormancy is also overcome in strawberry, apple and other plants by treatment with ethylene. Non-dormant varieties of seeds produce more ethylene than those of dormant varieties.

In many plants, rate of seed germination is increased by ethylene than and close correlation has been found between ethylene formation and seed germination in peanuts. In many plants, dormancy of buds can also be broken by ethylene treatment. Sometimes, potato tubers are exposed to ethylene in order to sprout the dormant buds.

**Biosynthesis of Ethylene**

Ethylene is known to be synthesized in plant tissue from the amino acid methionine. A non-protein amino acid, 1-amino cyclopropane-1-carboxylic acid (ACC) is an important intermediate and also immediate precursor of ethylene biosynthesis. The two carbons of ethylene molecule derived from carbon no.3 and 4 of methionine. Whole process of ethylene biosynthesis is three steps and is aerobic.

1. First step: in the first step, an adenosine group (i.e. adenine+ ribose) is transferred to methionine by ATP to form S-adenosylmethionine (SAM). This reaction is catalysed by the enzyme SAM-synthetase (methionine adenosyl transferase).
2. Second step: in the second step, SAM is cleaved to form 1-aminocyclopropane-1- carboxylic acid (ACC) and 5’-methylthioadenosine (MTA) by the enzyme ACC-synthase.

* Synthesis of ACC is rate limiting step in ethylene biosynthesis in plant tissues.
* Exogenously supplied ACC greatly enhances production of ethylene in plant tissues.

1. Third step: in the third step of ethylene biosynthesis, ACC is oxidised by the enzyme ACC-oxidase to from ethylene. Two molecules, one each of HCN and H2O are eliminated.

* ACC oxidase activity can be rate limiting step in ethylene biosynthesis in plant tissues which show high rate of ethylene production such as ripening fruit
* The enzyme ACC oxidase requires ferrous iron and ascorbate as cofactors
* ACC can be conjugated to give N-malonyl ACC and thus, may play an important role in regulation of ethylene biosysthesis.

