

The Fruit

The word "Fruit" derives from the Latin word "fructus" meaning to enjoy, produce. A fruit is the product of determinate growth from an angiospermous flower or inflorescence. From botanical standpoint a fruit can, be defined as a matured ovary. Or it defines fruit as "the edible product of a plant or tree, consisting of the seed and its envelope, especially the latter when juicy and pulpy".

The other defined fruits as "the tissues which support the ovules and whose development is dependent on the events occurring in these ovules". Fruit evolved as vehicles for production and dispersal of seeds. The concept of a fruit as a sweet and fleshy object for eating is really quite recent in evolutionary terms.

Fruit growth dynamic:

Fruit can increase in mass or volume by 100 fold or more from fertilization to maturity, and such changes commonly follow a sigmoid. Interpretation of such growth curves are complex because a single variable (mass, length, volume) is commonly applied. To an object that contains several organs and different tissue types, each developing at their own rate and in accordance with their own program.

In fruits like late maturing peaches and other stone fruits double sigmoid growth curve. It is primarily just an outcome of the development patterns of fruit over daily (or smaller) time steps to their size or development state at the beginning of a time state.

Here, growth takes place in three distinct stages:

In stage (I): ovary, nucellus and integuments of the seed grow rapidly, but the embryo and endosperm grow little.

In stage (II): embryo and endosperm grow rapidly, but ovary does not increase much in size again.

At stage (III): a surge of ovary growth begins and continues to fruit ripening.

Fruit development:

Fruit development is comprised of a series of complex physiological, biochemical and genetic processes. Fruit development can be divided into four major phases, viz., fruit set, rapid cell division, cell enlargement, and maturation and ripening.

Fruit set:

Fruit set: is the transition from non-growing ovaries to rapidly developing fruits. It normally requires the full completion of fertilization, although in some plants fertilization can be bypassed leading to the formation of a seedless fruit, a process referred to as parthenocarpy.

Models for regulating fruit set:

Sugar signaling model and multi hormonal model, which regulate the fruit set process. In sugar signaling model two sets of conditions are considered. Under optimal conditions, phloem unloaded sucrose is hydrolyzed by invertase (INV) in ovaries and ovules. The resultant glucose functions as a signal to repress programmed cell death (PCD) genes and to promote cell division, which together lead to seed and fruit set.

Starch reserve may be remobilized to supplement glucose production, particularly under mild stress conditions. Under severe stress, phloem import of sucrose is blocked, which in turn decreases invertase (INV) activity. This, together with depletion of starch reserve, reduces glucose levels that activate the programmed cell death (PCD), pathway and inhibit cell division, consequently,

seed and fruit abort. In multi hormonal model, a set of hormones are responsible for fruit set to occur.

According to this model, pollination and fertilization result in increased levels of both auxin and gibberellins (GA), which triggers fruit growth through stimulation of cell division and expansion.

Auxin can stimulate fruit set either directly or via inducing (GA) biosynthesis. Each hormone seems to play a specific role given that auxin application results in a high number of pericarp cells, whereas (GA) treatment results in fewer but larger pericarp cells.

Natural fruit set seems to require both hormones given that only Parthenocarpic fruits induced by concomitant auxin and (GA) treatment is similar to pollination- induced seeded fruits.

Putative involvement of ethylene and abscisic acid (ABA) in regulating fruit formation has been mainly suggested by transcriptomic studies. In particular, during the transition from anthesis to post-anthesis, ethylene- related genes, along with those related to auxin, account for most of the changes among all phytohormones-related genes, thus indicating that ethylene must play an active, but yet not understood, role in fruit set.

Exogenous application of cytokinins can induce Parthenocarpic fruit yet the underlying model of action remains unknown genes involved in fruit set and development. There are several genes involved in the process of fruit set and subsequent development. More studies have been done in this regard in the crop Arabidopsis.

Fruit cell division and cell expansion:

Fruit growth through cell division and expansion is controlled by hormones. Differential hormone concentration occurs in seed and surrounding tissue with developing seed influencing its environment. Multiple studies have shown that increases in auxin, cytokinins, gibberellin, and brass in asteroid at fruit set, and

an involvement of auxin, gibberellin, and brassinosteroid at fruit growth. For fruit maturation there is an inhibition of auxin transport from the seed and increase in (ABA). This triggers the ripening/senescence program which leads to an increase in (ABA) and/or ethylene biosynthesis and response in the surrounding tissue.

Division of fruit cell is critical for determining the final size of the fruit.

There are differences in cell number at harvest between different cultivars of *Pyrus pyriboule* and no differences were observed at pollination.

Despite complexities of fruit growth and development, there are some overall consistencies in patterns of cell division and enlargement, as well as tissue differentiation and fruit enlargement.

During the first (1– 4) weeks, flesh volume increases rapidly and embryo volume remains small. Growth at this time is mainly the result of cell division. In kiwifruit all tissues of the mature fruit (exocarp, outer and inner pericarp and central core) are already discernable in the ovary before anthesis and pollination. Each layer grows to a different extent and at different rates, so that the relative contribution of each to the total fruit volume varies with time. Cell division ceases first in the exocarp and last in the innermost regions of the central core.

Correlation between seed and fruit development:

A positive correlation between the number of seeds in the fruit and final fruit size is noticed. Seeds serve as source of hormones for cell division and cell division phase is more critical than subsequent cell expansion in determining final fruit size. Fruit size in Braeburn apple depends closely on the number of viable seeds per fruit (up to a normal maximum of 10 per fruit), emphasizing the strong influence that seed development has on fruit growth.

Fruit maturation:

Fruit maturity is a developmental point where the fruit has reached the competence to ripen, but has yet to start the ripening process. Several changes were noticed in maturing blueberry fruit. They considered five stages of fruit development, viz., pad, cup, green, pink and blue.

Ripening:

Ripening is a complex process involving changes to the metabolic and physiological traits of a fruit. Several major changes take place as fruits ripen, and taken collectively they characterize ripening processes.

They include:

- Change in colour.
- Flesh softening and textural change.
- Changes in carbohydrate composition, resulting in sugar accumulation and increased sweetness.
- Accumulation of organic acids with associated development of flavour.
- Formation of aroma volatiles.
- The major rise in ethylene production may take place before, just after or close to the respiratory peak.
- Such fruit are classed as "climacteric", with apple, avocado, banana, fig, mango, papaya, pear and tomato being classic examples.
- As with the respiratory rise, the levels of ethylene produced vary widely between species.
- Climacteric fruit ripen after harvest, and need not remain on the tree or vine. A second category of fruit, exemplified by blueberry, cherry, citrus, cucumber, grape, pineapple and strawberry do not show such sharp changes.

- Respiration rate either remains almost unchanged or shows a steady decline until senescence intervenes, with little or no increase in ethylene production; these are called "non-climacteric" fruit and fruit ripen only if they remain attached to the parent plant.

Ethylene biosynthesis:

Ethylene biosynthesis is the key event of ripening. Ethylene production is closely associated with fruit ripening in many species, and is the plant hormone that regulates and coordinates the different aspects of the ripening process; color development, aroma production and texture are all under the control of ethylene.

Ripening phenomenon of fruit influenced by ethylene is governed by ACS gene expression. Ethylene response factors (ERF) acting on ethylene synthesis to initiate the transition from a system 1 to a system 2 mode of ethylene synthesis regulate the expression of the different ACS genes. It may also be regulated by very high concentration of (IAA).

Color change:

One of the ethylene induced event is color change. Color changes occur due to degradation and chlorophyll molecules. It may lead to unmasking the already present carotenoid and anthocyanin pigments. At the same time synthesis of carotenoid and anthocyanin pigments is also an influencing factor of color change. Chlorophyll degradation generally occurs in the following way:

Degradation of chlorophyll due to chlorophyllase enzyme

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Splitting of chlorophyll into phytol chain and porphyrin

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Loss of Mg⁺⁺ion and conversion of porphyrin into phaeophytin

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Change in tetrapyrrolic chain and it becomes biliverdin

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Oxidation or saturation of double bonds

Fruit softening:

Fruit softening in ripening is the result of alterations to various pectin & hemicellulose polysaccharide wall components, and changes to the bonding between some polymers.

In a study in kiwi fruit following changes were noticed which led to fruit softening:

- Solubilization of pectin.
- The cell wall swells and shows an increased affinity for water.
- Loss of galactose from pectin (especially of a galactan).
- De-esterification of some pectin.
- De-polymerization of the hemicellulose polysaccharide xyloglucan associated with reduction in cell wall strength.
- De-polymerization of pectin associated with dissolution of middle lamella and reduced intercellular adhesion.

Starch degradation:

Hydrolysis of starch to sugar is a characteristic event of fruit ripening. Starch degrading enzymes are:

α – Amylase

β – Amylase

Phosphorylase

α – 1, 6 – glucosidase

Changes in the level of sugars:

During maturation and ripening, sugars accumulate, mainly due to sugar import or from starch degradation. Changes in the level of organic acids. During maturation and ripening, sugars accumulate, whereas organic acids that accumulated in young fruits strongly decrease. (Citric acid, malic acid and fumaric acid) are the major organic acids found in the fruits.

In a study Batista-Silva et al., (2018) found that citrate content increases with stages of ripening in both climacteric and non-climacteric fruits. However, reduction in fumarate and malate were observed in tomato as well as capsicum.

Changes in aroma compounds:

Development of characteristic fruit aroma is influenced by ethylene. Fruit aroma is determined by a complex mixture of a large number of volatile compounds including alcohols, aldehydes, and esters. During fruit development, especially at ripening, there are many changes of these metabolites caused by their synthesis, transport or degradation.

Bound aldehydes, alcohols, terpenoids, esters and phenols gradually decrease during ripening due to the hydrolyses to their free form. Free aroma compounds of ripened red fruits are hexanal, 2-heptanone, ethyl hexanoate, 4-terpineol, geranial and methyl eugenol.

Regulation of ripening by calcium:

Plenty of studies have shown that calcium plays an important role in the storage and preservation of fruits. Role of calcium in delaying senescence can be summarized as –Maintaining the fruit cell wall structure and function maintaining the cell membrane structure and function. The effects on fruit respiration and ethylene synthesis. Regulating activities of enzymes and metabolism of substances related to Senescence.