

REVIEW PAPER

Physiological and biochemical basis of fruit development and ripening - a review

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ABSTRACT Fruits and vegetables are the natural source of vitamins, minerals and nutrients that play an important role in the human diet. Despite of tremendous increase in production and productivity, their per-capita availability for world population is a great challenge ahead due to constant postharvest losses occurring in perishable horticultural produce. These postharvest losses especially in terms of quality and nutritional composition could be controlled to a greater extent with better knowledge regarding their postharvest physiology. The ultimate physiological condition of the fresh produce determines their fitness for end use, including storability and acceptability for primary or secondary processing. Hence, it is indispensable to understand the physiological responses of perishable commodities to the storage conditions in direct relation to the intended end use. Physical, physiological and biochemical changes occurring during fruit ripening seem to modify their internal quality in terms of firmness, colour, starch content, organic acids and flavouring compounds. Thus, the knowledge on physiological profile of perishable fruits and vegetables could act as a powerful tool for their optimized commercial utilization.

KEYWORDS Postharvest physiology, ethylene, fruits and vegetables, horticulture, climacteric, non-climacteric

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INTRODUCTION

Fruits and vegetables play an important role in the human nutrition, especially as sources of vitamins (vitamin C, vitamin A, vitamin B6, thiamin, niacin), minerals, and dietary fibre. They also possess various bioactive components which have been associated with reduction of certain chronic diseases such as cancer, heart ailments, stroke, and other life style disorders. Though India stands next to China as second largest producer of fruits and vegetables, there are considerable losses after harvesting. Both qualitative and quantitative losses occur in the horticultural crops since harvest till consumption by the end user. The magnitude of postharvest losses in fresh fruits and vegetables is estimated to be around 5 - 25 % in developed countries and 20 - 50 % in developing countries, depending upon the commodity (Verma and Joshi 2000). Quality losses especially of vitamin C could be substantial and aggravated by the mechanical damages, extended storage, high temperature, low RH and chilling injury of the sensitive commodities. Fresh fruits and vegetables are the living entities subjected to uninterrupted changes since harvest. Although certain changes are desirable, most of them are undesirable from the standpoint of consumer. Postharvest changes in fresh produce cannot be stopped, but they can be slowed within certain bounds. Senescence is the ultimate stage resulting in breakdown and death of cells through a series of irreversible events. In order to reduce these losses, we must understand the physiological behaviour and changes occurring in the harvested fruits and vegetables during handling, transportation and storage.

FRUIT GROWTH AND DEVELOPMENT

A typical fruit develops from the ovary after pollination and fertilization. During fruit development the cells in the ovary wall undergo a continuous series

of divisions and expansion, which gives the fruit its final size before the onset of ripening (Stikic et al. 2015). The S-shaped growth curve is also known as 'sigmoid curve' which mainly depicts four phases of growth viz. initial slow growth (*lag* phase), the rapid growth period (*log* phase) where maximum growth is seen in a short span of time and, the *diminishing* phase where growth is slow and *steady/ stationary* phase where it stops finally (Paul et al. 2012). Three different kinds of growth curves were being identified in different fruit crops such as single sigmoidal growth curve (Apple, Mango, Banana, Citrus, Avocado, Pomegranate, Seeded Pear, subtropical Peach, Bael, Date, Pineapple, Tomato, Melon and Strawberry), double sigmoid growth curve (Grape, Seedless banana, Papaya, Guava, Sapota, Plum, Olive, Ber, Raspberry, Blueberry, Stone fruit) and triple sigmoid growth curve (kiwifruit) (Reid et al. 1982, Kim et al.2012).

In general, the fruit developmental stages are classified broadly into three phases viz., Phase 1: Ovary development, Fertilization, and Fruit set, Phase 2: Cell division, Seed formation, and Early embryo development and Phase 3: Cell expansion and Embryo maturation. During the early phases of fruit development, the carpel differentiates into epicarp, pericarp, mesocarp and endocarp (Fig 1). Fruit growth was distinguished into four distinct phases (Gillaspay et al. 1993). Phase I, floral meristem differentiates into ovary, phase II, cell division follows fertilization for few days. In phase III, Fruit reaches its ultimate size with increased cell volume resulting from cell expansion, and in phase IV, the fruits reach their final phase and the process of ripening starts. Among all these growth stages, phase III is the longest phase of fruit growth and development. However, in certain cases like avocado, the pericarp cell division continues until shortly before ripening (Stikic et al. 2015).

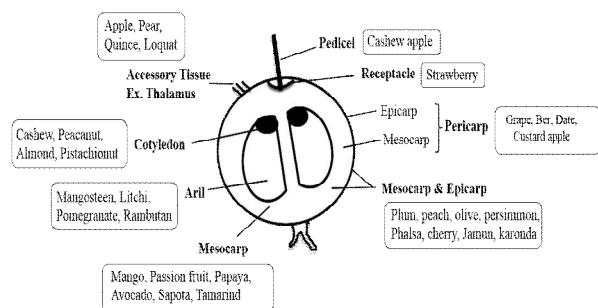


Fig 1 Illustration depicting the tissue of origin of edible part in various fruits

Certain fruits develop without the need for pollination and fertilization which are seedless in nature and the process is technically termed as parthenocarpy (Spena and Rotino 2001). Thus,

parthenocarpy is considered as one of the effective way of producing fruits under such adverse environmental conditions. Three types of parthenocarpy has been reported in horticulture crops viz. *Vegetative*: In which no pollination or other stimulation is necessary for fruit set eg Banana, fig, Cactus Pear and pineapple(Weiss et al.1993, Ortiz and Vuylsteke 1995), *Stimulative*: seedless fruits produced only after pollination or other stimulation eg Litchi, black corianth variety of grape, breadfruit and *Stenospermocarpy*: seedless fruits produced as a result of fertilization but with early abortion of the embryo eg grape, Sindhu variety of mango (Gustafson 1942).

MATURITY INDICES

Maturity is the stage at which the commodity has reached a maximum growth and development. Harvesting of crops at proper maturity is the most important aspect in maintaining the quality of the produce for getting optimum market value. Most of the fruits attain peak edible quality at full ripe stage, however they are typically harvested at mature stage to reduce the chances of mechanical injury during postharvest handling and storage (Mishra and Gamage 2007). Crops picked prematurely might lack flavour and may not ripen properly, while those picked too late might be fibrous or overripe (Kitinoja and Kader 2002). Horticulture commodities could be classified majorly into two categories based on the coincidence of physiological maturity with the commercial horticultural maturity. (1) Horticulture maturity is classified into (i) Physiologically immature fruit-vegetables, viz. green bell pepper, green chili pepper, cucumber, summer (soft-rind) squash, chayote, lima beans, snap beans, sweet pea, edible-pod pea, okra, eggplant, and sweet corn, and (ii) physiologically mature fruit-vegetables, viz. tomato, red peppers, muskmelons (cantaloupe, casaba, crenshaw, honeydew, persian), watermelon, pumpkin, and winter (hard-rind) squash. (2) Physiological maturity is the stage at which fruit attains maximum growth and development (mango, banana, sapota, citrus, and apple). In the first category of commodities, the optimum edible quality is attained prior to complete maturity and further delay in harvesting results in poor quality followed by faster deterioration rate. While in the second category, most of the fruits reach best edible quality when ripened completely over the plant and, except tomato, all are unable to ripe after detachment from the mother plant (El-Ramady et al. 2015). Maturity indices vary with the type/kind, cultivars of the produce, and intended use in processing. The maturity indices standardized for various horticultural crops are based on various subjective and objective methods was shown in (Table 1).

Table 1 Maturity indices and their processing requirements for different horticultural crops

Crop	Harvesting Index	Description	Specifications for Processing
Aonla	Seed colour	Change of seed colour from creamy white to brown black.	Lower content of fibre is most suitable for candy and jam, lower level of phenolics for syrup preparation, low moisture, and high TSS with Vitamin for Drying
Apple	DFFB	140–150 days from the bloom	Sauce and canned products (maximum shear press values of 3.1–3.3 kN for slices, minimum SS of 10 % for sauce), High TSS (12.5 %) for apple cider making
	T stage	The angle between stalk and receptacle should be 90°	
	Starch content	Starch staining 60 % and Starch-Iodine index should be 4.5-5.5	
Apricot	Colour change	¾ of the area of the fruit should have yellowish green or ½ yellow	Canning (full flavour) and Drying (full flavour and ripening)
Avocado	Oil content	min. oil content should be 8 %	The good quantity and quality oil is obtained when harvested at 8 % oil content
Avocado	Harvest date, Oil content	Harvest date, oil content and dry matter (oil content of 8 %), understanding consumer preferences for texture and taste	Less seeds and skin thickness
Bael	Colour change	Change in skull colour from dark green to yellowish green.	Raw or mature green fruits are suitable for making preserve. Ripe fruits suitable for making Jam, toffee and powder, ready to serve nectar and squash
Banana	Pulp to peel ratio and Shape	Pulp-to-peel ratio of 1.35–1.4, or disappearances of angularity, colour	Banana puree (complete disappearance of angularity and full flavour, and flesh appears translucent)
Broccoli and cauliflower	Shape	Compact bud cluster	White or slightly off white compact and smooth heads are required for freezing
Cabbage	Solidity	The heads become solid upon maturity	Sauerkraut (mild flavoured, sweet, solid white head, sugar 2 %, ascorbic acid 30–60 mg/100 g)
Carrot	Firmness	Crispy and long enough	Canning (tender texture) Juicing (juice yield and TSS 6 °B)
Citrus	Juice content	Navel orange (30 %), Grape fruit (35 %), Lemons (25 %), Mandarins (33 %) and clementine's (40 %)	The drying of juicy sacs is a major problem. To get good amount of juice we need to harvest at right sage.
Cucumber	Size and tenderness	Immature stage near to full size before seeds enlarge, approx. 50-60 day after planting	Pickles (ripe with sugar content of 1.5 %–2.5 %)
Custard apple	Creaming	The space between two locules increases and colour changes to creamy white	Fruits should be free from gritty cells for juice making
Date palm	Kimri/Gandora, Khalal/ Doka	<i>Gandora</i> : Hard and Green, 5-9 weeks, apple green colour	The date is a berry with a single seed that varies in size from 9 to 30 % of the fruit weight, a smaller seed or pit and thicker flesh are preferred. Total sugars represent about 50 % (fresh wt basis) or 75 % (dry wt basis)
	Rutab / Dang	<i>Doka</i> : Fully grown but hard in texture, 10-14 th week, Turns from green to yellow	
	Tamr/ Pind	<i>Dang</i> : Softening starts from tip, 18 th week, Translucent	
		<i>Pind</i> : Fully ripened and dehydrated, 19 th week, dark brown	
Fig	Wilting of neck	The peduncle of fruit dries and fruit starts bending down	Fruits with no or minimal peel defects were selected for drying
Grapes	TSS (Total Soluble Solids)	14 %–17.5 % Soluble Solids, or Brix/acid ratio of 20 or higher	White wine fermentation (pH 3.1–3.3, TA 0.7–0.9, Brix 19–22 °B), red wine fermentation (pH 3.3–3.6, TA 0.6–0.8, Brix 21–23.5 °B), Raisin making (Brix 24 °B)
Guava	Mature-green stage, specific gravity 1.01-1.02, TSS 12-14 %	Colour is a good indicator of ripeness stage, Firmness and extent of gritty texture due to the presence of stone cells (sclereids), Flesh colour depends on cultivar and can be white, yellow, pink, or red	Freedom from defects, insects, and decay. Amount of seeds in the flesh (the fewer the better)
Litchi	TSS, colour	Bright red colour and fruit size (minimum 25 mm diameter). Tubercles become flat, and shells become smooth.	Total TSS : acid ratio of 30-40
Mango	Colour, specific gravity	Change of peel colour from green to yellow, The optimum specific gravity for mango harvesting 1.02	Canning (full flavour and total sugar/soluble solids ratio close to 1)
Okra	Size	Desirable size and tips snap off easily	Canning (small, young, and tender)
Olives	Colour	Straw yellow to cherry red	Pickling (slightly less mature, size, colour), Phenolic content should be less than 2 % (w/w) in olive flesh
Onion	Drying of leaves	Tops beginning to dry	Drying (high solids content)

Orange	TSS:Acid Ratio		Minimum juice content of 30 %–35 %, frozen juice concentrate (12.5–19.5 SS/A)
Papaya	Change of skin colour from dark-green to light-green with some yellow at the blossom end.	Papayas picked 1/4 to full yellow taste better than those picked mature - green to 1/4 yellow because they do not increase in sweetness after harvest.	Uniformity of size and colour, firmness, freedom from defects such as sunburn, skin abrasions, pitting, insect injury, and blotchy colouration, freedom from decay. Papayas are usually harvested at colour break to 1/4 yellow for export or at 1/2 to 3/4 yellow for local markets. A minimum soluble solids of 11.5 % is required
Pear	TSS and Colour	13 % SS and yellowish-green colour	Canning (full flavour and firmness measured to 66.7–75.6 N)
Peas	Tenderometer	Well-filled pods that snap easily	Canning (13.4 % AIS, tenderometer reading of 115–125), Freezing (13.4 % AIS, tenderometer reading of 95–105) Drying (9 %–11 % AIS, Tenderometer reading of 85–95)
Pineapple	Flattening of eyes with slight hollowness at the centre	A minimum soluble solids content of 12-14 % and a maximum acidity of 1 % will assure minimum flavour acceptability by most consumers.	Uniformity of size and shape, firmness Freedom from sunburn, sunscald, cracks, bruising, internal breakdown, endogenous brown spot, gummosis, and insect damage. Tops (crown leaves): green colour, medium length, and straightness. Range of soluble solids = 11-18 %, titratable acidity (mainly citric acid) = 0.5-1.6 %, and ascorbic acid = 20-65 mg/100g fresh weight, depending on cultivar and ripeness stage
Pomegranate	Colour of fruit and juice	External red colour (depending on cultivar), Red colour of juice, Acidity of juice below 1.85 %	Freedom from growth cracks, cuts, bruises, and decay. Skin colour and smoothness. Flavour depends on sugar/acid ratio which varies among cultivars. A suitable solids content above 17 % is desirable. Tannin content below 0.25 % is desirable.
Potato	Drying of leaves and Specific gravity	Tops beginning to dry	Chips (dry matter of 21 %–24 %, specific gravity (1.075), 1.5 % sugar) French fries (specific gravity of 1.08–1.12, 0.3 % reducing sugar), frozen chips (total solids 20–22 %, 0.2 %) Canning (whole tubers of 19–38 mm size, specific gravity of 1.08) Dehydrated diced potatoes (specific gravity of 1.1) Starch manufacture (minimum of 15 % starch)
Rambutan	Spinterns colour change	The over matured fruits show change in spinterns colour to brown	Used for preparation of juice
Sapota	Skin colour, Fruit weight,	Skin colour change from light-brown with a tinge of green to light-brown to dark-brown. Weight of fruit 65-70 g, flesh yellow streak when scratched with finger nail, specific gravity 1.025-1.057.	Appearance: size, shape (oval), colour, freedom from defects, and freedom from decay. Firmness (firm-ripe sapotes are preferred). Flavour is related to soluble solids content (13 -26 %) and acidity (0.2-0.3 %).
Strawberry	Colour Change	> 2/3 of fruit surface has pink or red colour	Freezing (firmness equivalent to 10–15 N force)
Sweet corn	Grain sap	Milky sap oozing upon pressing	Canning (slightly immature kernels), baby corn
Tomato	Firmness	Seeds slip upon cutting the fruit	Most processed products (SSC 5 %),
Watermelon	Dull sound, Ground spot, Brix test		Uniformity of size and shape, free from pest and disease damage with TSS 10° Brix most suitable for juice making
Wood apple	Bumping back	The immature fruits bumps back while mature wont when thrown on ground	TSS 16.2 % and Acidity 3.2 % for preparation of jam and jelly

Note: SS-soluble solids, SS/A-soluble solids : acid ratio, TA-titratable acidity, N-newtons, SSC- soluble solid content, kN- kilo Newton, °b- Brix

POSTHARVEST PHYSIOLOGY AND FRUIT RIPENING

Postharvest physiology refers to all the functions and processes occurring in the fruits after harvest. It deals with the changes occurring in the produce once they are detached from the plant, how such alterations are accelerated or controlled during postharvest handling, and their effect on ultimate fruit quality during storage, distribution, and processing. Fresh fruits and vegetables are the living entities with highly perishable nature. Though many alterations occur in colour, composition, and texture, rate of respiration is the most common indicator of their metabolic activity. Various physical, physiological and biochemical

changes occur during fruit ripening which include both anabolic as well as catabolic processes.

Ripening of climacteric and non-climacteric fruits

Fruit ripening has attained substantial attention recently because of the various vivid changes occurring in the metabolic processes before and after harvest. For studying the ripening biology of climacteric and non-climacteric fruits, scientists used tomato as the model climacteric fruit and strawberry as the model non-climacteric fruit (Osorio et al. 2013). Climacteric fruits display a large increase in CO₂ and C₂H₄ production rates coincident with ripening, while non-climacteric fruits show no considerable change in their CO₂ and C₂H₄ production rates during ripening

(Paul et al. 2012). Therefore, fruits and vegetables have been classified as climacteric or non-climacteric based on their respiratory and ethylene evolution patterns (Table 2). The artificial application of ethylene to climacteric and non-climacteric fruits showed respiratory raise in both (Yamane et al. 2007) but rise in endogenous ethylene production occurred only in climacteric fruits (Fig 2). Plum cultivars are known to exhibit variation in their climacteric behaviour during ripening. The cultivars Black Amber (highly climacteric), Amber Jewel (moderately climacteric) and Angeleno (suppressed-climacteric) are harvested at commercial maturity and allowed them to ripe at 21 ± 1 °C for 8 days. Ripening of climacteric fruits is also enhanced by application of ethylene and its analogues under artificial conditions. At present, the categorization of commodities into climacteric and non-climacteric is done based on the respiration rate and ethylene production (Abeles et al. 1992). The climacteric commodities express dramatic increase in their rate of respiration during the onset of ripening which is termed as climacteric rise.

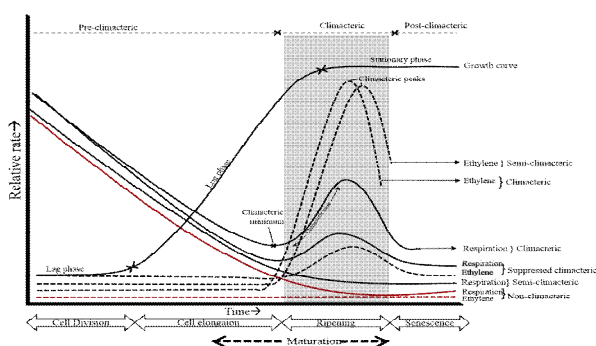


Fig 2 Patterns of growth, respiration and ethylene production during development, maturation, ripening and senescence of different types of fruits

The Climacteric fruits can ripen either on the tree or off the tree because, the increased ethylene synthesis occur in both the cases which increase the rate of respiration leading to breakdown of complex organic molecules into simpler compounds that lead to tissue softening and induction of ripening. But in case of non-climacteric fruits, ripening is slow or non-existent if they are detached from the plant (even if the fruit has completed its growth in size) because the ethylene production will not occur after harvest which in turn shuts respiratory raise and ripening. Generally, concentrations of less than $1 \mu\text{l l}^{-1}$ saturate all the ethylene receptors (Burg and Burg 1962). The climacteric fruits respond very well to external application of ethylene for ripening (mango, banana, tomato) while non-climacteric fruits doesn't ripe in response to external ethylene treatment, except for the degradation of chlorophyll in certain fruits such as citrus and pineapples, which is technically termed as

'degreening' (Noichinda 2000). Ripening in climacteric fruits is predominantly controlled by ethylene, whilst in non-climacteric commodities, ripening is chiefly regulated by other hormones such as abscisic acid. The ripening behaviour of different kiwifruit (*Actinidia*) species is typical. The common ripening-related changes viz. starch-sugar conversion, colour development and pulp softening occurs in the apparent absence of ethylene production (Stage-I) whilst stage-II entails autocatalytic ethylene production and is linked with flavour volatile development and further softening of fruit (McAtee et al. 2015).

CLASSIFICATION OF FRUITS

Climacteric fruits

Physiologically mature climacteric fruits exhibit a logarithmic raise in endogenous ethylene level and respiration rate during ripening. This is also called as postharvest ripening or both on tree and off tree ripening fruits. Ethylene (endogenous/exogenous) is known to mediate the expression of certain specific ripening related genes and associated transcription factors relating to primary and secondary metabolism. It also triggers remodeling of climacteric fruit cell wall and its softening during ripening for attainment of appropriate edible quality. Exposure of climacteric fruit to structural analogues of ethylene such as propylene could induce autocatalytic production of endogenous ethylene and serves as a secondary standard for differentiating climacteric and non-climacteric fruits (Burg and Burg 1962a). Plum cvs. Santa Rosa, July Santa Rosa, Gulf ruby, Beauty and Joanna Red were reported to be in the climacteric group (Minas et al. 2015). Avocado is considered as a distinctive typical climacteric fruit wherein its fruits fail to ripe until detached from their parent tree. The fruits of many crops undergo ripening upon harvest but more slowly or not at all if left on the tree (Paul et al. 2012). In case of avocado, the fruit will not undergo ripening till it is detached from the mother plant. This is due to supply of certain unknown chemicals that inhibit the ACC Synthase enzyme activity when fruit is attached to plant. This type of behaviour is noticed in case of Fuerte avocado fruit (Burg and Burg 1962). Once after removal from the tree the sharp rise in ethylene and respiration were observed. Avocado fruits could be held successfully over the tree for several months after attainment of physiological maturity, often referred to as on-tree storage as they differ from most other fruits and their ripening is triggered only after picking (Schroeder 1953). The resistance of avocado fruit to ripening is lost after 1-2 days of harvest and they tend to ripe successfully. However, the ripening time since harvest is inversely proportional to the on-tree storage period.

Table 2 Classification of fruits and vegetables into climacteric and non-climacteric groups

Climacteric Crops	Scientific Name	Non-climacteric Crops	Scientific Name
Acerola	<i>Malpighia emarginata</i>	Aonla	<i>Phyllanthus emblica</i>
Apple	<i>Malus domestica</i> Borkh	Asian pear	<i>Pyrus serotina</i> Rehder
Apricot	<i>Prunus armeniaca</i> L.	Cactus pear	<i>Opuntia amyclaea</i> T.
Araza	<i>Eugenia stipitata</i>	Bayberry	<i>Myrica rubra</i>
Avocado	<i>Persea americana</i> Mill.	Ber (Chinese)	<i>Ziziphus jujuba</i>
Banana	<i>Musa paradisiaca</i> L.	Blackberry	<i>Rubus ulmifolius</i>
Babaco	<i>Carica heilbornii</i>	Brinjal	<i>Solanum malongena</i>
Bael	<i>Aegle marmelos</i>	Cocoa	<i>Theobroma cacao</i>
Bilimbi	<i>Averrhoa bilimbi</i>	Capsicum	<i>Capsicum annuum</i> L.
Biriba	<i>Rollinia deliciosa</i>	Carambola	<i>Averrhoa carambola</i> L.
Blueberry	<i>Vaccinium delicosum</i>	Cashew apple	<i>Anacardium occidentale</i>
Breadfruit	<i>Artocarpus altilis</i>	Cherry	<i>Prunus avium</i> L.
Broccoli	<i>Brassica oleracea</i> var. <i>italica</i>	Coconut	<i>Cocos nucifera</i>
Custard Apple	<i>Annona squamosa</i>	Cranberry	<i>Vaccinium macrocarpon</i>
Durian	<i>Durio zibethinus</i> Murr.	Cucumber	<i>Cucumis sativus</i> L.
Feijoa	<i>Feijoa sellowiana</i> Berg.	Date	<i>Phoenix dactylifera</i>
Fig	<i>Ficus carica</i> L.	Grape	<i>Vitis vinifera</i> L.
Ber (Indian)	<i>Ziziphus mauritiana</i>	Grape fruit	<i>Citrus grandis</i> Osbeck
Jackfruit	<i>Artocarpus heterophyllus</i>	Litchi	<i>Litchi sinensis</i> Sonn
Kiwifruit	<i>Actinidia deliciosa</i> planc	Karonda	<i>Carissa carandas</i>
Mamey Apple	<i>Mammea americana</i>	Okra	<i>Abelmoschus esculentus</i>
Mango	<i>Mangifera indica</i> L.	Olive	<i>Olea europaea</i> L.
Mangosteen	<i>Garcinia mangostana</i>	Pea	<i>Pisum sativum</i>
Muskmelon	<i>Cucumis melo</i>	Pineapple	<i>Ananas comosus</i> Merr.
Nectarine	<i>Prunus persica</i>	Pomegranate	<i>Punica granatum</i> L.
Papaya	<i>Carica papaya</i> L.	Prickly pear	<i>Opuntia ficus-indica</i>
Passion fruit	<i>Passiflora edulis</i> Sims	Pumpkin	<i>Cucurbita moschata</i>
Peach	<i>Prunus persica</i> Batsch	Rambutan	<i>Nephelium lappaceum</i> L.
Pear	<i>Pyrus communis</i> L.	Raspberry	<i>Rubus idaeus</i> L.
Persimmon	<i>Diospyros kaki</i> Thunb.	Rose apple	<i>Spondias purpurea</i>
Plantain	<i>Musa Eumusa</i>	Snap bean	<i>Phaseolus vulgaris</i>
Phalsa	<i>Grewia asiatica</i>	Star fruit	<i>Fraxinum jamun</i>
Physalis/ cape gooseberry	<i>Physalis peruviana</i> L.	Strawberry	<i>Fragaria</i> sp.
Plum	<i>Prunus domestica</i> L.	Summer squash	<i>Cucurbita pepo</i>
Quince	<i>Cydonia oblonga</i>	Tamarillo / Tree tomato	<i>Cyphomandra betacea</i>
Sapota	<i>Achras sapota</i>	Watermelon	<i>Citrullus lanatus</i>
Tomato	<i>Solanum lycopersicum</i>	Wax apple	<i>Syzygium samarangense</i>

Non-climacteric fruits

Non-climacteric fruits generally exhibit low CO₂ and C₂H₄ production rates during ripening (Paul et al. 2012). Non-climacteric commodities produce no ethylene and softening occurs very slowly. This is also called as maturation-ripening or “On-tree” ripening fruit. In contrast to their climacteric counter parts, most of the non-climacteric fruits could ripen fully only when remained attached to their mother plant, and once detached, they could produce only basal concentrations of ethylene (system I), while respiration declines with storage at ambient temperatures (Lelievre et al. 1997).

Suppressed climacteric fruits

In these kind of fruits, very low amount of ethylene production is noticed compared to their climacteric counterparts, which might be due to their impaired ability in conversion of ACC to ethylene. Such fruits fail to develop climacteric results due to their inability to perceive ethylene and/or to develop fresh receptors. Fruits with this phenotype generate ethylene only in the final stages of ripening. However, the ethylene levels

are low compared to normal climacteric types and they exhibit a reduced respiratory climacteric. This system was observed in certain cultivars of plum, apple, kiwifruit and pear. Responding to exogenous ethylene or propylene, the slow-softening and detectable amounts of ethylene is produced in suppressed-climacteric cultivars of plum. The cultivars of plums which are reported for this type of property are late Santa Rosa, Casselman, Roysu Shiro, RubyRed and Angeleno.

Semi-climacteric fruits

The pepper is commercially harvested at mature green stage. In addition to its indeterminate growth habit, pepper pods have characteristics indicative of both climacteric and non-climacteric fruits (Gross et al., 1986, Biles et al. 1993, Villavicencio et al. 1999). It is therefore designated as semi-climacteric. The higher ethylene production with the onset of ripening but the lower CO₂ production has been observed in hot peppers (Biles et al. 1993). Mature-green ‘Cherry Bomb’ peppers tend to produce higher amounts of CO₂ than

fruit at any other maturity stage (Gross et al. 1986). This shows that the respiration rate was high during mature green stage while ethylene production is higher during red-ripe stage and in vice versa they are absent. No increase in respiration rate was observed at the time of colour change. Examples include Cayenne pepper (*Capsicum annuum* L), Guava, Plum, Ber, Fig, Olive, Muskmelon etc.

PHYSICAL CHANGES DURING RIPENING

Fruit firmness/ texture

The major components of fruit cell wall include pectin and cellulose along with small amounts of hemicellulose and non-cellulosic polysaccharides. The breakdown and solubilization of pectic substance takes place during fruit ripening. Softening of fruits and vegetables after harvesting is ascribed to enzymatic degradation, solubilization and esterification of the pectic substances. Pectic substance provides mechanical strength to the cells and maintain their physical structure. In middle lamella, the pectin is tightly cross linked with calcium salts that are interlinked during early stages of cell growth. Middle lamella are very much sensitive to heat and their dissolution results in the parting of plant cells. De-esterified pectins in the middle lamella are associated with Ca^{2+} ions, and their elimination results in separation of cells (Prasanna et al. 2007). During ripening, the insoluble protopectin gets converted into highly soluble polyuronides which results in textural softening of the fruits during ripening. Thus, the tightly bound high molecular weight parent pectin is degraded into softening of fruit is caused by the conversion of protopectin, the insoluble, high molecular weight parent pectin into soluble pectins bound loosely to the cell walls (Gowda and Huddar 2001). During softening, the neutral sugars *viz.* galactose and arabinose (major components of neutral protein) as well as the acidic pectin (rhamnogalacturonan) were lost from the cell wall. The key enzymes involved in the fruit softening process are protopectinase, Pectin Methylesterase, Polygalacturonase, cellulase and β -Galactosidase. All these enzymes are sequentially involved in the degradation of pectic substance present in the middle lamella of cell wall (Fig 3).

The changes in polysaccharide architecture of peach during ripening corresponds to the onset of ethylene climacteric and results in a very slow decline of firmness (softening) initially, followed by a rapid and dramatic decrease ('melting') of firmness in the later stages. In some cases it is beneficial but, in certain cases it is ethylene which detrimentally effects the texture by promoting unwanted softening in cucumbers and peppers, or toughening in asparagus, and sweet potatoes (Saltveit 1999).

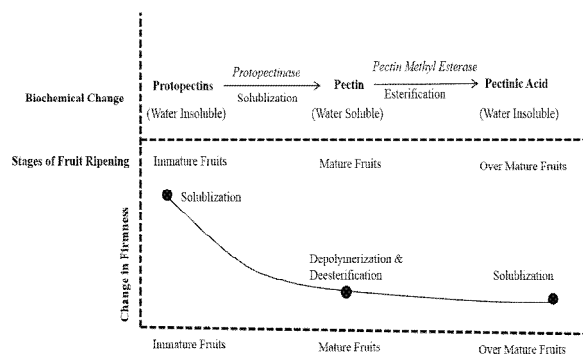


Fig 3 Textural and biochemical changes during fruit development and ripening

Pectins and other polysaccharides are broken down during softening which predisposes them to mechanical injuries. Increased lignin content is responsible for toughening of asparagus spears and root vegetables (Kader 1985). The decrease infirmness during ripening with ethylene treatment was found to be beneficial especially for climacteric fruits and vegetables such as apricots, avocados, melons, pears and tomatoes, but prolonged exposure would result in over softening as the fruits progress into senescence stage. Excessive flesh softening and maceration in watermelon within 3 days of exposure to $5 \text{ ml L}^{-1} \text{ C}_2\text{H}_4$ at 18°C was observed by Risse and Hatton (1982). There is significant difference in tissue softening and loss of firmness in ethylene treated fruits compared to control and its effect on the subjective quality of banana fruit was studied by Salveit (1999).

Colour

The loss of green colour in fruits and vegetables is usually noticed when they start ripening. Colour change is one of the most common harvesting index practically utilized in many fruits and vegetables. With the onset of maturity, the colour of fruits and vegetables changes due to the accumulation of various pigments *viz.* β -carotene (mango, nectarine, peach, plum, citron, loquat, apricot, Mexican lime, carrot), anthocyanin - light red to blue (apple, strawberry, plum, grape, pomegranate, blackberry, raspberry, blueberry, onion, rose), lycopene (tomato, watermelon, papaya, pink fleshed guava, Arka Kiran, grape fruit, Ruby Red, pumello, red carrot, lutein (carrot -Pusa Kulfi, marigold), xanthophyll (papaya), and violaxanthin (Chandler pummelo and orange). The loss of green colour during maturation and ripening is mainly due to degradation of chlorophyll molecules which is mediated by chlorophyllase enzyme, pH changes (leakage of organic acids from vacuoles), oxidative stress and synthesis of secondary metabolites, such as carotenoids, anthocyanins and other pigments that mask the expression of chlorophyll pigment (Wills et al. 1998). Chlorophyll molecule is hydrolyzed to chlorophyllide and phytol by the action of enzyme

chlorophyllase, followed by a replacement of Mg atom with hydrogen resulting in the formation of brownish pheophorbide (Kanayama and Kochetov 2015). The most common maturity index in fruits and vegetables is the loss of green colour with few exceptions *viz.* avocado, kiwifruit, granny smith apple, feijoa. Finally the pheophorbide is converted into colourless compounds such as chlorins and purpurins (Fig 4).

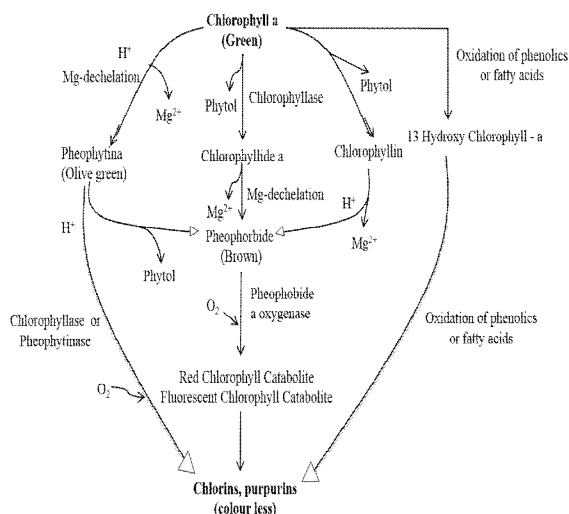


Fig 4 Chlorophyll degradation pathway showing formation of colourless products

PHYSIOLOGICAL CHANGES DURING RIPENING

Respiration rate

Respiration is the process of breakdown of stored organic reserves (carbohydrate, proteins and fats) into simpler molecules with release of energy in the form of ATP (Fonseca et al. 2002). This reaction alters the composition of respiratory substrates *viz.* carbohydrates, proteins, lipids, and organic acids. The type of substrate used for respiration could be identified from its respiratory quotient (RQ), which is defined as the ratio of CO₂ produced to O₂ consumed. The RQ values for vary for different kinds of substrates *viz.* carbohydrates (RQ =1), organic acids (RQ >1), and lipids (RQ <1). Higher RQ values indicate the occurrence of anaerobic respiration. The respiration is basically an exothermic reaction which contributes for raise of commodity temperature.

During respiration, major part (about 57 %) of the energy is dissipated in the form of heat, which is popularly known as vital heat or heat of respiration, which contributes to an increase in the temperature of the commodity further. Three distinct phases are identified in the respiratory pathway: (i) Hydrolysis-breakdown of polysaccharides into simple sugars, (ii)

Glycolysis-oxidation of sugars into pyruvic acid, and (iii) Citric acid cycle-aerobic transformation of pyruvate and other organic acids into carbon dioxide, water, and energy and mitochondrial electron transport chain (Haard 1995, Wills et al. 1998).

The rate of respiration varies with commodity, and their stage of maturity. Generally, the rate of respiration possesses inverse relationship with the shelf-life of the fresh produce (Saltveit 1999). With progressive senescence, the stored food material gets exhausted by respiration for providing energy and maintaining living status of the commodities. This loss results in reduced energy value, loss of flavour, quality, and salable dry weight, which is especially important for commodities destined for dehydration. The rate of respiration mainly affected by temperature, atmospheric composition, and mechanical damage (Siddiq 2012). Respiration is the major process responsible for deterioration of fresh produce and the respiratory metabolic processes doubles for every 10°C raise in temperature (Fagundes et al. 2013). The rate of respiration could be significantly reduced by altering the oxygen and/or carbon dioxide content around the fruit which ultimately increases their storage life. However, the positive effects vary with type of commodity, and their tolerance to minimum oxygen concentration at which they could tolerate without undergoing fermentative reactions or anaerobic respiration. Conversely, mechanical damages occurred during harvesting and postharvest handling could raise their rate of respiration and other metabolic reactions, hastening the deterioration process. In addition to these, fruit maturity, moisture stress, light, growth hormones, pathogens and synthetic chemicals also influence the rate of respiration to certain extent (Saltveit 1999, Siddiq 2012).

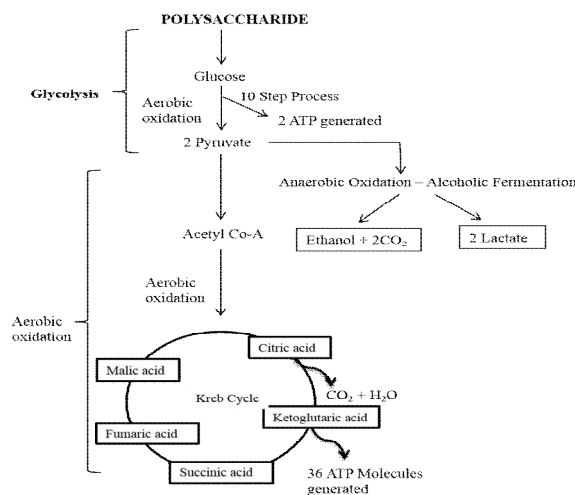


Fig 5 Biochemistry of respiration in fruits and vegetables

The respiratory process is majorly classified into two types, namely aerobic respiration and anaerobic respiration. The stored carbohydrates are catabolized by the process called glycolysis. The glycolytic pathway is often referred to as the Embden-Meyerhof pathway in honor of their discovery. During Glycolysis, 10 enzyme catalyzed process takes place in cytosol of cells releasing 2 ATP molecules. In this process, hexose sugars are oxidised to pyruvic acid (pyruvate) in presence of many enzymes and cofactors, NAD⁺, ADP and Phosphate, with release of some energy. Glycolysis is common for both types of respiration *i.e.* aerobic and anaerobic (**Fig 5**). During aerobic respiration, oxygen is not directly used in glycolysis but it's essential for oxidation of NADH. Glycolysis occurs in the cytosol while oxidation of NADH occurs on the mitochondrial cristae. This system is more often found in commercial horticulture crops for giving energy, which involves the oxidative breakdown of certain organic substances stored in the tissues. A common substrate for respiration is glucose and, it is completely oxidized to form CO₂, H₂O and releases energy in the form of ATP.



However, when there is lack of oxygen, fruits temporarily generate energy using anaerobic respiration wherein partial breakdown of glucose occurs producing ethyl alcohol and carbon dioxide along with two molecules of ATP which is not as efficient as aerobic process.

Ethylene production

Ethylene is a naturally occurring gaseous plant growth substance with copious effects on the growth, development and storage life of various horticultural crops. The beneficial effects of ethylene in fruits and vegetables includes ripening of fruit, pigmentation, chlorophyll degradation and yellowing, seed germination, adventitious rooting, respiration, phenylpropanoid metabolism, flower induction in bromeliads, promotion of abscission and senescence (Saltveit 1999). Ethylene has been shown to be produced from methionine *via* a pathway that includes the intermediate SAM (*S*-adenosyl-L-methionine or *S*-AdoMeT) and ACC (1-aminocyclopropane-1-carboxylic acid). SAM is the immediate precursor for ethylene biosynthesis (Yang and Hoffman 1984, Blecker and Kende 2000). Though methionine acts as essential building block for cellular protein synthesis, about 80 per cent of it gets converted to SAM by SAM synthetase at the expense of ATP utilization. SAM is the major methyl donor used as a substrate for many biochemical pathways, including polyamines and ethylene biosynthesis in plants. According to Yang cycle (**Fig 6A**), the foremost step occurring during ethylene biosynthesis is the conversion of SAM to ACC

by ACC synthase. In addition to ACC, ACC synthase also produces 5-methylthioadenosine (MTA) in this reaction, which gets converted to methionine through a modified methionine cycle and this recovering pathway conserves the methyl group for continuous cyclic ethylene production without the need for a larger pool of methionine. This takes care of conserving the sulfur group of methionine and ultimately ACC gets oxidized by ACC oxidase to form ethylene, CO₂, and cyanide. The toxic cyanide accumulated during continuous cycles of ethylene biosynthesis gets detoxified to β-cyanoalanine by β-cyanoalanine synthase to prevent phytotoxicity.

After ethylene synthesis, the produced ethylene enters into EBS (Ethylene Binding Site) section where the specific receptor binds to ethylene for further action to takes place. EBS is located in endoplasmic reticulum (ER) of cell, where ethylene binds to specific receptors. There are five well known ethylene receptors *viz.* Ethylene Receptor-1 (ETR-1), Ethylene Receptor-2 (ETR-2), Ethylene Insensitive-4 (EIN-4), Ethylene Response Sensor-1 (ERS-1), Ethylene Response Sensor-2 (ERS-2). These receptor proteins bind to ethylene with the help of “Copper” (Cu) cofactor, which is indispensable for their activity and is supplied by Responsive To-Antagonist-1 (RAN-1) located in the golgi complex. The RAN-1 integrates Cu into hydrophobic ends of receptors, without which the receptor couldn't turn off (bind). The ethylene produced through yangs cycle gets bound to the receptor in ER region, which in turn sends signal to Constitutive Triple Response - 1 (CTR-1). The succeeding processes takes place with activation of kinase enzyme and without phosphorylation resulting ultimately in various downstream responses that alter the ripening and physiology of fruits and vegetables. In the absence of ethylene, the reverse process occurs exactly compared with the presence of ethylene. A similar process is observed even with mutant receptors (**Fig 6B**). The receiver domain provides ‘Phosphate’ to a protein called CTR-1 *i.e.* (Rapidly Accelerated Fibrosarcoma) RAF like kinase similar to (mitogen-activated protein kinase) MAPK system. CTR-1 activates EIN-2, which turns on the EIN-3 family of transcription factor, ultimately inducing the expression of (Ethylene Responsive Factor) ERF-1. This activation leads to large scale modifications in the gene expression and finally alters the physiology of fruit ripening and senescence (Chen et al. 2005).

BIOCHEMICAL CHANGES DURING RIPENING Starch

Based on the type of fruit and its place of ripening (on/off the plant), their inner sugar levels tend to raise, attributing to their importation from the parent plant or mobilization of starch within the fruit. As the fruit

maturity progresses, the starch reserves get hydrolysed into sugars (glucose, fructose or sucrose) and this is considered as a distinctive event during fruit ripening. Further the complex sugars *viz.* sucrose are broken down into simple sugars *viz.* glucose and fructose with the catalytic action of enzyme *invertase*. In certain crops like potato and peas, the starch-sugar conversion is an important critical issue. In pea, the higher sucrose content is noticed in fresh immature stage, and gets converted into starch with the attainment of maturity. Changes in carbohydrates include starch to sugar conversion (undesirable in potatoes, cassava but desirable in other fruits), sugar-to-starch conversion (undesirable in peas and sweet corn, desirable in potatoes, cassava), and breakdown of complex starch molecules to simple sugars, CO₂ and water through the process of respiration (Kader 1985). Fruit starch reserves can be an important contributor to the sugar content of some ripe fruits (Souleyre et al. 2004). Starch content decreases progressively throughout the post climacteric ripening stages in banana fruit which is accompanied by progressive increase in soluble sugars.

In many fruits, the breakdown of starch to glucose, fructose or sucrose, is a characteristic ripening event. A series of enzymes are involved in the degradation of starch and formation of its by products with release of energy. The enzyme *α-amylase* hydrolyses the *α*-(1-4) linkages of amylose at random to produce a mixture of glucose and maltose. The *β-amylase* acts on starch and release maltose as a major product. Later the maltose is converted into glucose in the presence of *α-glucosidase* enzyme through the process of hydrolysis. Alternately, the maltose could be directly hydrolysed to form glucose-1-P with the action of *maltose phosphorylase* enzyme (Fig 7) and this could be converted to glucose-6-phosphate with the action of *phosphoglucomutase* (Seymour et al. 2012). Whole this set of reactions takes place in the plastids of chloroplast when the fruits are at immature stage and rich in starch. The end products of starch degradation in chloroplast are either glucose or glucose-1-phosphate. However, further utilization of the breakdown products of starch occur largely in the cytoplasm. The glucose-6-P is converted into triose-P and enters cytoplasm for further breakdown. However, the exact mechanism behind the movement of starch degradation products in the envelope of fruit cells was not clear, but this could be either as six-carbon sugar phosphates (glucose-6-phosphate or fructose-6-phosphate) or more likely as triose phosphates, as in leaf tissue (Douce and Day 1985, Seymour 2012). In the cytoplasm, the products of starch breakdown are either utilized in glycolytic respiration, or converted back to glucose phosphate and fructose for the synthesis of sucrose. Then it forms sucrose with the help of sucrose synthase enzyme. Sucrose phosphate synthase has been reported in grape berries and other fruits for increasing sweetness (Downton and Hawker 1973). The breakdown of sucrose is probably mediated by the action of *invertase*, which is most widely found in fruits and vegetables and their activity increases during ripening (Fig 7).

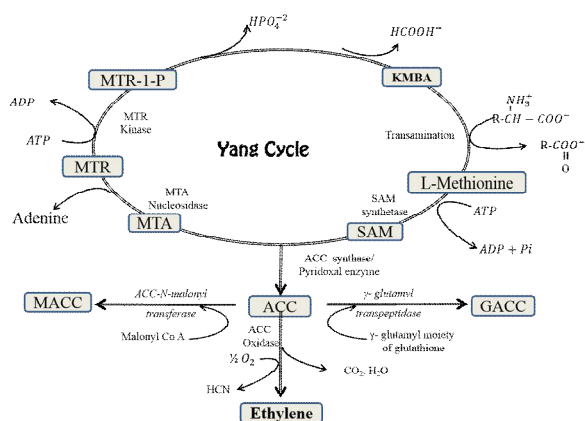


Fig 6A Cyclic biosynthesis of ethylene in fruits and vegetables

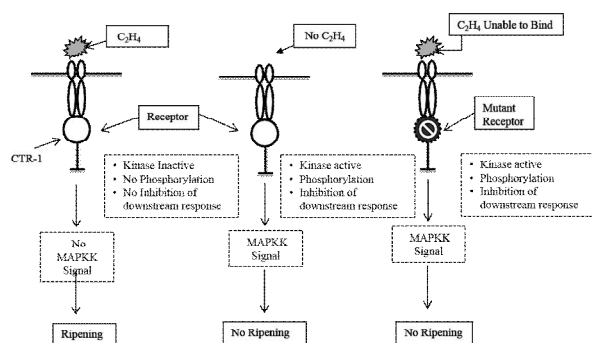


Fig 6B Mode of action of ethylene for ripening of fruits and vegetables

Organic acids

Organic acids play a vital role in the growth, and development of fruits in addition to enhancement of their defense action against several postharvest diseases. Generally fruits are acidic in nature and vegetables are alkaline in nature (with exception of tomato, and rhubarb), as fruits contain greater amounts of organic acids. The total acid content among fruits vary from 0.2 to 0.8 per cent approximately in pear juice and lime, respectively. The major organic acids profoundly found in fruits include citric acid (mango, guava, pineapple, citrus except sweet lime, pear, tomato), malic acid (apple, banana, cherry, watermelon), tartaric acid (grape, tamarind), quinic acid (kiwifruit, blueberry) and ellagic acid (strawberry, jamun), respectively (Bigelow 1917, Gallander 1974).

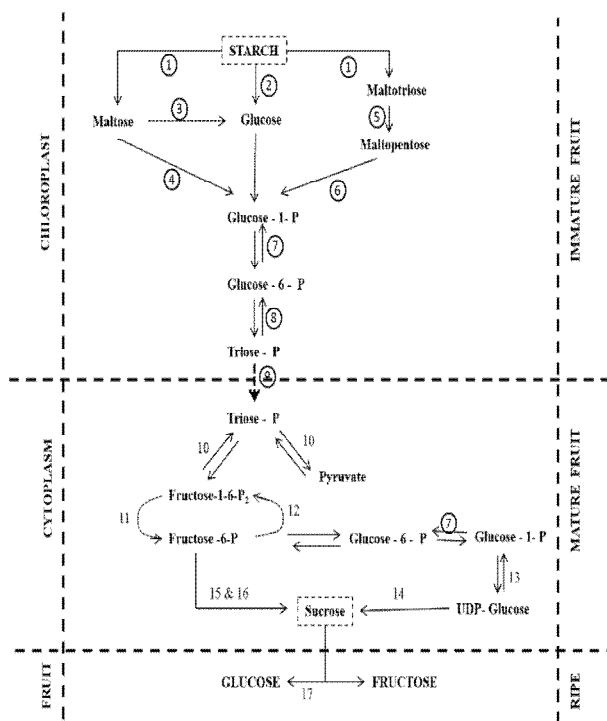


Fig 7 Starch degradation pathway in fruits and vegetables

1. β -amylase; 2. α -amylase; 3. α -glucosidase; 4. maltose phosphorylase; 5. D-enzyme; 6. phosphorylase; 7. phosphoglucomutase; 8. gluconeogenesis; 9. triosephosphate; 10. glycolysis; 11. Fructose bisphosphatase; 12. Phosphofructophosphotransferase; 13. UDP-glucose pyrophosphorylase; 14. Sucrose synthase; 15 and 16. Sucrose phosphate synthetase and Sucrose phosphate phosphatase; 17. Invertase

After reaching maturity, the organic acid content of fruits decline gradually towards the fruit ripening phase except in banana and pineapple where the acid content remains high even after ripening. This common decrease of acidity during ripening/ storage of most fruits might be due to increase in their membrane permeability allowing acids to be stored in the respiring cells resulting in the formation of respective acid salts coupled with a drop in the amount of organic acid translocated from the leaves. The fall in organic acid content after fruit maturity might be due to their reduced acid synthesizing ability, sugar translocation and dilution effect with increase in fruit volume.

Flavour/aroma compounds

The flavour consists of basically three components viz. aroma, taste and mouth feel. Though fruit tastes contributed by the intricate amalgamation of sugars, organic acids, phenolics and volatile compounds, the distinctive flavour of any specific commodity is attributed to a particular flavouring volatile. The major flavouring compounds identified are esters, alcohols, aldehydes, acids and ketones. In apple and orange, at least 230 and 330 different compounds have been identified, respectively. The volatiles are small molecular weight (<250 Dalton) compounds found naturally in fruits and vegetables. The normal range of aroma compounds in fruits and vegetables is 10 mg/100 gm. Minimum threshold concentration at which an odour compound (ethyl-2-methyl butyrate) from an apple is detected by our nose is 0.01 $\mu\text{g}/100\text{gm}$ of fruit (Wills et al. 2007).

Table 3 Respiration rate and ethylene production rates of horticulture crops at 5°C and 20°C, respectively

Class	Respiration Rate (mg CO ₂ /kg/hr)		Ethylene Production Rate ($\mu\text{g}/\text{kg}/\text{hr}$)	
	Range	Commodities	Range	Commodities
Very low	<5	Dates, dried fruits and vegetables, Almonds Brazil nuts, Cashew nut, Chestnuts, Hazelnuts, Hickory nuts, Macadamia nuts Pecan, Pine nuts, Pistachios, Shea nuts, Walnuts	<0.1	Artichoke, asparagus, cauliflower, cherry, citrus fruits, grape, jujube, strawberry, pomegranate, leafy vegetables, root vegetables, potato, most cut flowers
Low	5-10	Apple, beet, celery, citrus fruits, cranberry, garlic, grape, honeydew melon, kiwifruit, onion, papaya, persimmon, pineapple, pomegranate, potato (mature), pumpkin, sweet potato, watermelon, winter squash Apricot, banana, blueberry, cabbage, cantaloupe, carrot (topped), celeriac, cherry, cucumber, fig, gooseberry,	0.1 - 1	Blackberry, blueberry, casaba melon, cranberry, cucumber, eggplant, okra, olive, pepper (sweet and chili), persimmon, pineapple, pumpkin, raspberry, Tamarillo, watermelon Banana, mango, guava, plantain, Mangosteen, litchi, breadfruit, sugar
Moderate	10-20	lettuce (head), mango, nectarine, olive, peach, pear, plum, potato (immature), radish (topped), summer squash, tomato Avocado, blackberry, carrot (with tops),	1 - 10	apple, Honeydew melon, durian, Rambutan, Tomato, Fig
High	20-40	Cauliflower, leek, lettuce (leaf), lima bean, radish (with tops), raspberry, strawberry Artichoke, bean sprouts, broccoli, Brussels sprouts, cherimoya, cut flowers, endive, green onions, kale, okra, passion fruit, snap bean, watercress	10 - 100	Apple, apricot, avocado, cantaloupe, feijoa, kiwifruit (ripe), nectarine, papaya, peach, pear, plum, atemoya
Very high	40-60	Asparagus, mushroom, parsley, peas, spinach, sweet corn	>100	Cherimoya, passion fruit, Sapota, Soursop, Mammee apple

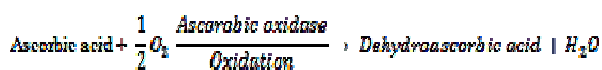
Adapted and modified from Siddiq (2012)

The grassy flavour is due to Hexanal, Pungent, penetrating odour of fruits and vegetables is due to presence of acetaldehyde and Ethyl alcohol like flavour in pineapple cv. jaldoop is due to ethyl acetate. Several authors reported the major flavouring compounds in various fruit crops viz. Apple ripe (Ethyl 2-methylbutyrate) and green (Hexanal, 2-hexenal), Pear (Butyl ethanoate), Banana, green (2-hexenal), ripe (Eugenol) and overripe (Isopentanol), Grape fruit (Nootakaton), Lemon (citral), mango (Ocimene, myrcene and dimethylstyrene), Papaya (Methyl butanoate), Strawberry (Furaneol), Raspberry (1-(π -hydroxyphenyl)-3-butanone), Cucumber (2,6-nonadienal), Mushroom (1-octen-3-ol, lenthionine) and Potato (Ethyl pyrazine, dimethyl pyrazine) and grape (Methyl salicylate – muscat and Methyl anthranilate – foxy), respectively (Deck and Chang 1965, Salunkhe et al. 1976, Schieberle et al. 1990, Atwell and James 1999, Rosillo et al. 1999, Dixon and Hewett 2000, Verma and Joshi 2000, Jayanty et al. 2002, Furusawa et al. 2005, Espina et al. 2013).

Ascorbic acid/ vitamin C

L-ascorbic acid (Vitamin C) is the naturally occurring ascorbic acid in fruits. Ascorbic acid has important antioxidant and metabolic functions in plants and animals in the form of vitamin C. A gradual rise in ascorbic acid content with fruit growth has been observed and the levels decline with the advancement of maturity and onset of fruit ripening and postharvest handling, especially in pear, sweet potatoes, potato, asparagus and okra. However, in certain crops viz. pome, stone and berry fruits the ascorbic acid content was found to be low at the time of harvest. The increase in vitamin C content during the ripening is due to increase in the synthesis of some metabolic intermediates that promote synthesis of precursors for vitamin C. The decrease in vitamin C during the later stages of ripening might be due to its oxidation to dehydroascorbic acid (Wills et al. 2007). The upsurge in ascorbic acid content during ripening of certain fruits could be due to increased lipid peroxidation, since fruit ripening is considered as an oxidative phenomenon necessitating the turnover of active oxygen species (Jimenez et al. 2002).

Ascorbic acid is oxidized to dehydroascorbic acid with the help of ascorbic acid oxidase enzyme. The levels of both the contents are determined in order to know the total amount of vitamin C in vegetables. Dehydroascorbic acid is the first oxidation product of ascorbic acid which is formed by enzymatic and non-enzymatic oxidation (Shimada and Ko 2008).



Phenols and flavonoids

Phenols and flavonoids are one of the most vital bioactive compounds, the composition and content of which defines the quality and flavour characteristics of fruits and vegetables. Maturity had a considerable effect on entire phenolic, anthocyanins and antioxidant content of fruits and vegetables. During ripening there is a gradual change in certain secondary metabolites with the commencement of phenolic pathways. The newly synthesized phenolic compounds play a crucial role in the fruit pigmentation, as well as its pathogen resistance (Ghasemzadeh and Ghasemzadeh 2011). The content accumulation in fruit and vegetables is largely affected by genotype, cultural practice, pre-harvest environmental conditions, degree of maturity at harvest, storage conditions and processing techniques (Shahidi and Nacz 2003). The phenolic content of most fruits declines from early growth stages till attainment of physiological maturity. During maturation and development, the phenolic compounds undergo a sequence of intricate metabolic processes, resulting in compositional changes of the plant and plant derived foods (Prasanna et al. 2007). In recent times, they have received greater attention due to their inherent antioxidant capacities with remarkable health benefits in prevention of various oxidative stress associated diseases, viz. cancer, cardiovascular diseases etc. (Dai and Mumper 2010, Reis Giada 2013).

Flavonoids are present in various horticultural commodities in the form of conjugates *i.e.* glycosylated or esterified forms (Liu 2004). Certain characteristic flavonoid compounds present in fruits and vegetables (Tiwari et al. 2013, El-Ramady et al. 2015) viz., anthocyanin (apple, pomegranate, litchi, blueberries, plum, cherry, raspberries cranberries, longan berries strawberries, purple onion, purple brinjal), lycopene (tomatoes, watermelon, pink grapefruits, apricot, and pink guavas), Quercetin (apples, green and black tea, onions, red grapes, broccoli and cherries) and beta carotene (Carrots, sweet potatoes, winter squash, pumpkin, papaya, mango, oranges, broccoli, spinach and lettuce).

CONCLUSION

Marketing of fresh produce is driven mainly by their quality and round the year availability. For improved growth of this sector, we need to adopt a wide range of technologies to enable extending the shelf-life while preserving the final product quality. In order to control the final quality of fresh produce, a broad knowledge base especially of the postharvest physiology dealing with all essential changes occurring between harvest and final consumer utilization is obligatory. Though, pre-harvest events affect

subsequent postharvest behaviour to certain extent, the genetic makeup of the commodity determines its response to growth and storage environments. The prime objective of studying postharvest physiology is to ensure all the desirable changes to be occurred immediately prior to fruit purchase or in the hands of a consumer before consumption.

In the process of evolution, fruits have developed bright colours during ripening for attracting the scattering agent's *viz.* birds, grazing animals and primates. However, they are becoming particularly important as a visible indicator of maturity and ripeness. Since, the colours are not an universal maturity indicator for all the fruits, there is a great need to standardize other maturity indices based on their physical, physiological or biochemical composition. Next to colour, consumers depend on the fruit aroma to judge their maturity which has a strong influence over its capacity to produce specific set of volatiles and certain fruits could be harvested only when their volatiles production begins. Astonishingly, very meagre information is available regarding biosynthetic pathways or control processes regulating these flavour volatile production and even less is known about the terpenoids contributing to the total flavour profile.

Ethylene metabolism was under keen focus of metabolic exploration into fruit behaviour while it is being used commercially as a ripening trigger with various climacteric fruits *viz.* banana, avocado and early-season kiwifruit to ensure their optimum ripeness before consumption. Exposure of climacteric commodities to exogenous ethylene results in rapid ripening with autocatalytic production of ethylene even after removal of external source of ethylene while in non-climacteric commodities. This results in rapid chlorophyll degradation coupled with significant increase in respiration. Of late molecular tools were deployed for exploring new ways of controlling fruit ripening since three decades.

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