

Fruit Growth & Development & Post Harvest Physiology



Acknowledgment : Australian Society of Plant Scientists: New Zealand Society of Plant Biologists New Zealand Institute of Agriculture and Horticultural Science

ASPEE COLLEGE OF HORTICULTURE & FORESTRY

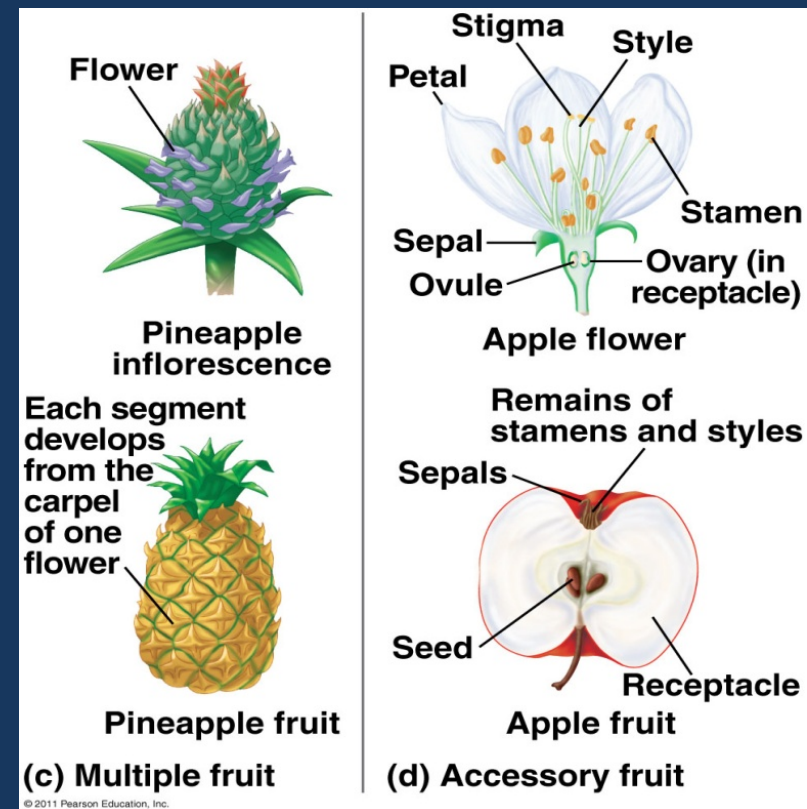
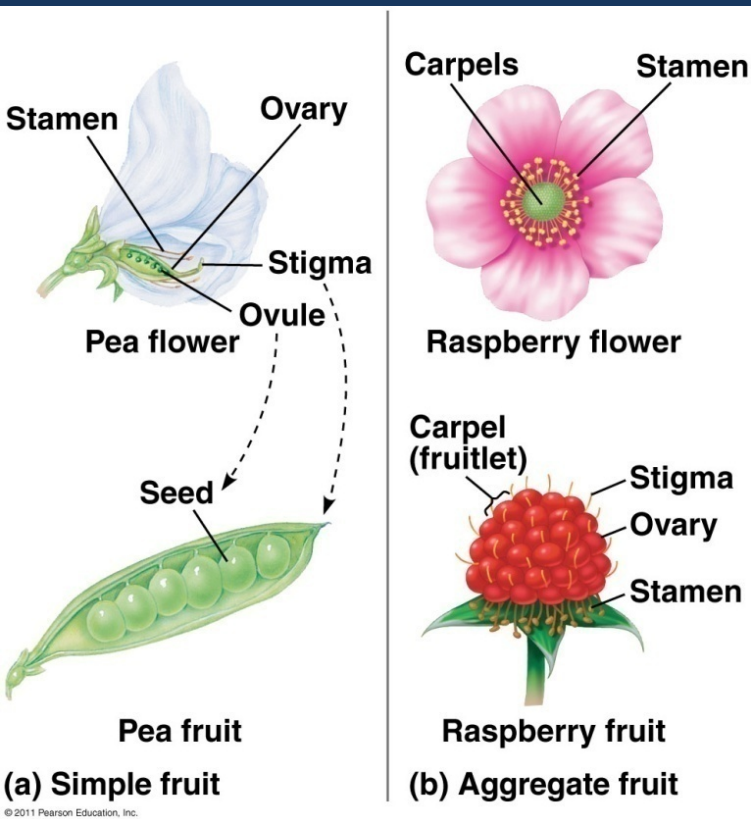
“Whence it is probable, that the use of these leaves, (which are placed, just where the fruit joins the tree) is to bring nourishment to the fruit. And accordingly, I observe ... That all peach leaves are pretty large before the blossom goes off; And that in apples and pears the leaves are one third or half grown, before the blossom blows: So provident is nature in making timely provision for nourishing the yet embryo fruit ...”

(Stephen Hales, 1727)



Origin of fruit tissues

In morphological terms, fruits are structures that develop from fertilized or stimulated ovules, plus associated floral parts that originate from the parent plant.



- ✓ An exocarp will develop a cuticle and may exhibit a variety of morphological features such as coarse hairs (kiwifruit) or fine hairs (peach). The exocarp plus cuticle restricts gas exchange, and determines the general appearance of ripening fruit. Most cuticles are highly impermeable to gases, so that water vapour, O₂ and CO₂ diffuse mainly via either stomata or lenticels or by mass flow through cavities at the calyx and stem ends of fruit.
- ✓ Mesocarp tissues usually represent the fleshy part of a fruit, and commonly hold chloroplasts and starch grains. In fleshy fruit such as berries (e.g. tomato, kiwifruit and grape) this tissue typically comprises large parenchyma cells and contains the main vascular network.
- ✓ Endocarps are less common, but typically develop as a dense hard case around a seed, as in peach, apricot

Fruit set and Fruit Growth

Early events

Pollination

Pollen tube growth

Gibberellins and auxins are involved in the pollination stimulus, and subsequent hormone production by the fertilised ovary is critical to stimulating fruit development



Poor pollination (left) compared with normal pollination (right) influences seed number and hence kiwifruit development. A fully pollinated fruit carries at least a 1000 seeds spread more or less evenly lengthwise, and in about 35 locules around its circumference. Faulty pollination causes big disparities in seed number per locule (from around 30 to near zero). There is a corresponding change in relative development of adjacent tissues.



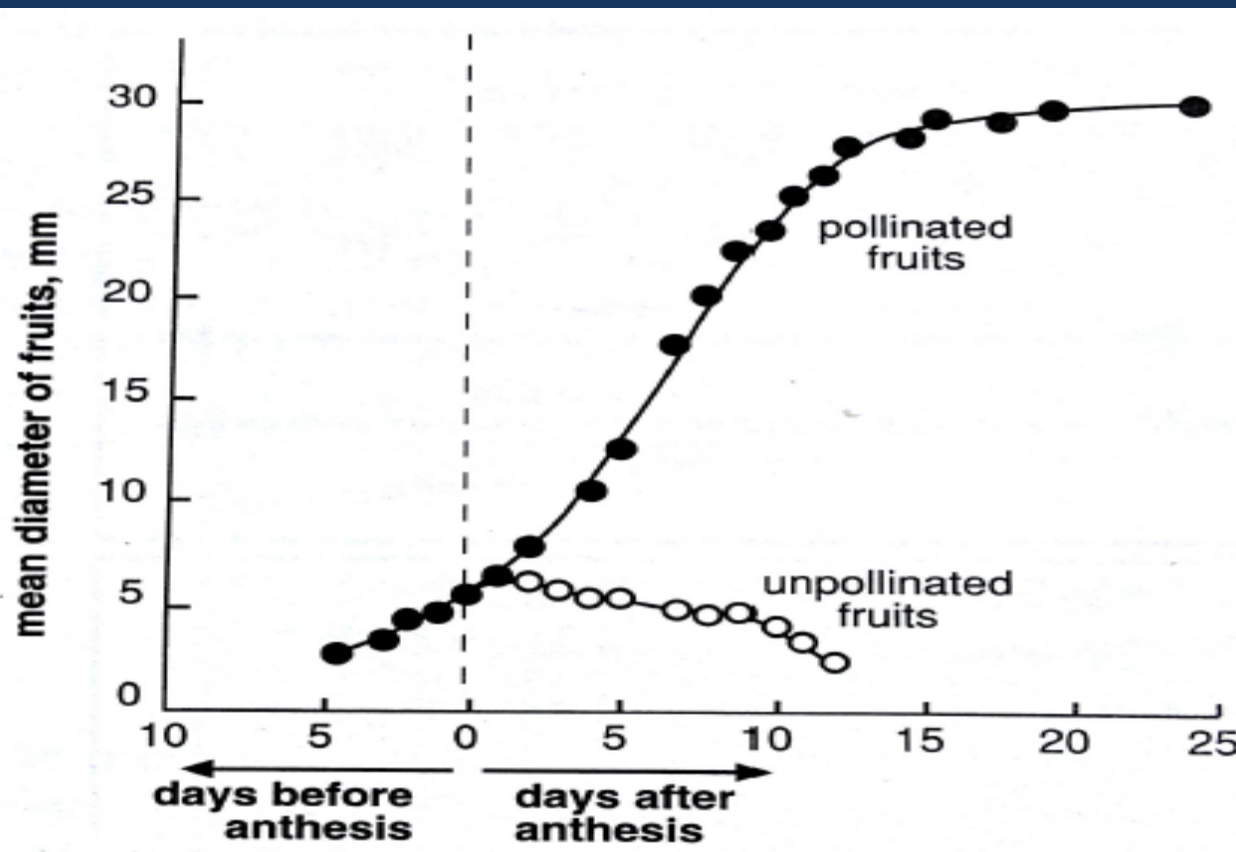
A grape is a 'berry', so that fruits on sultana grape vines are stenopermocarptic berries. Pollination and fertilisation were successful, but embryos so formed soon aborted. Pericarp tissues none the less continued their development to produce the familiar item of commerce about 100 d later. A range of stages in that development is shown here. Upper-row fruit illustrate stages in preveraison development where fruit are small, hard, green and accumulating organic acid. Postveraison fruit (lower row) are translucent, soft textured, enlarging rapidly and accumulating sugar.

Scale bar = 5 mm.

Pollination and “Fruit set”

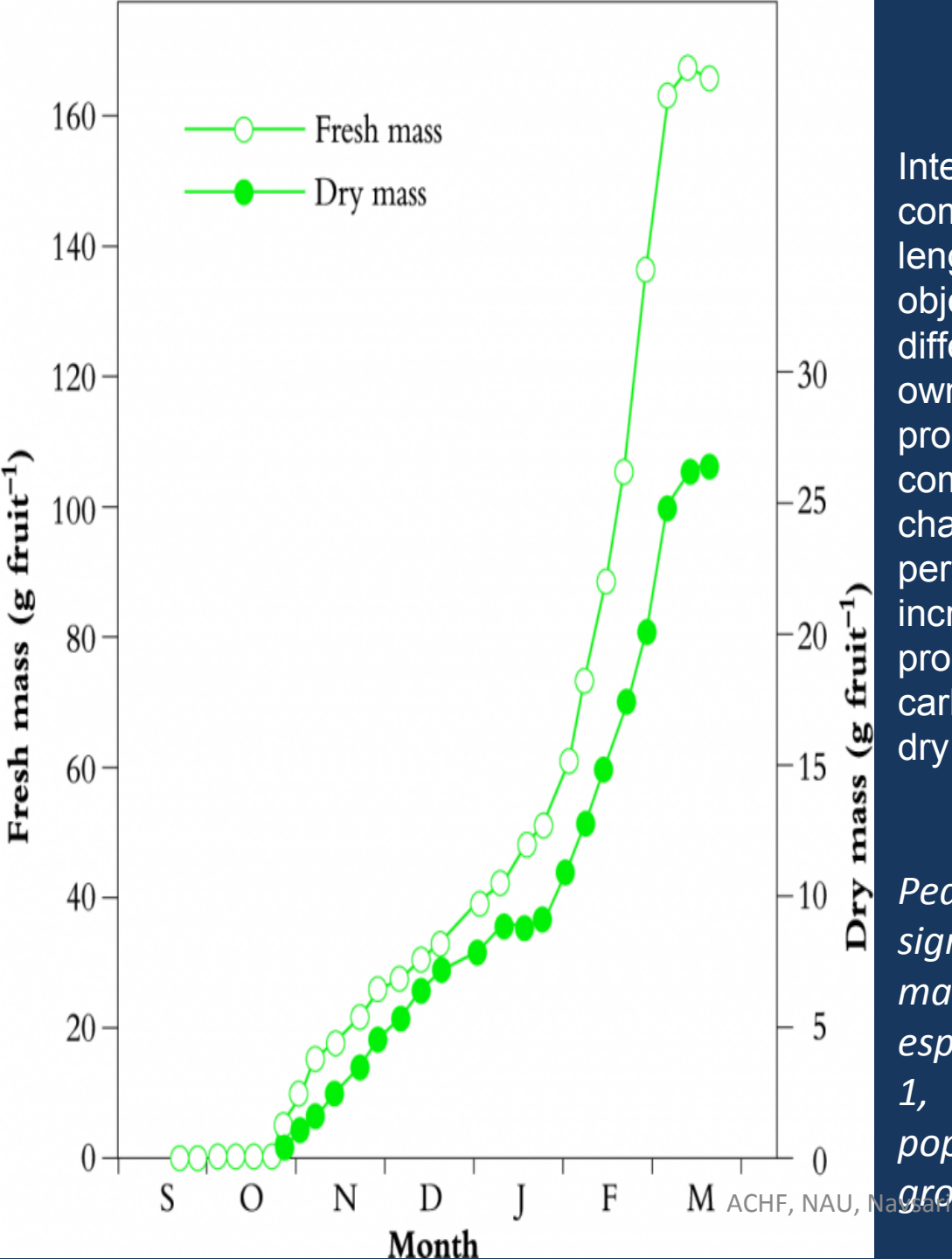
Growth of the ovary by cell division and cell expansion continue to sexual maturity of the flower, but then stop at the time of anthesis or shortly before pollination. The decision to resume growth is taken only if pollination occurs.

For fruit set to occur pollination is necessary, but fertilization is not.



Growth curves of ovary of *Cucumis anguria*. Pollinated ovary shows a typical sigmoid growth curve whereas, unpollinated ovaries shrivel and ultimately drop off.

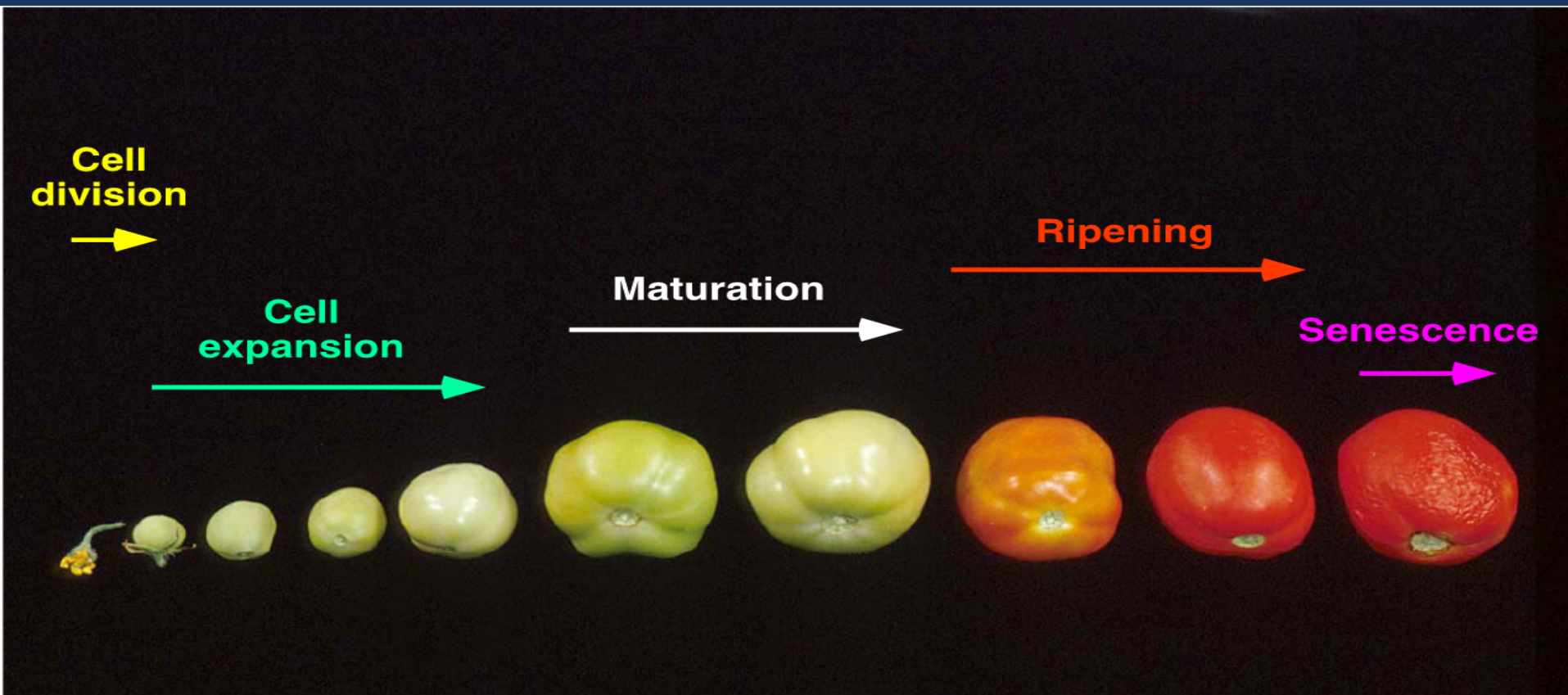
Dynamics of fruit growth



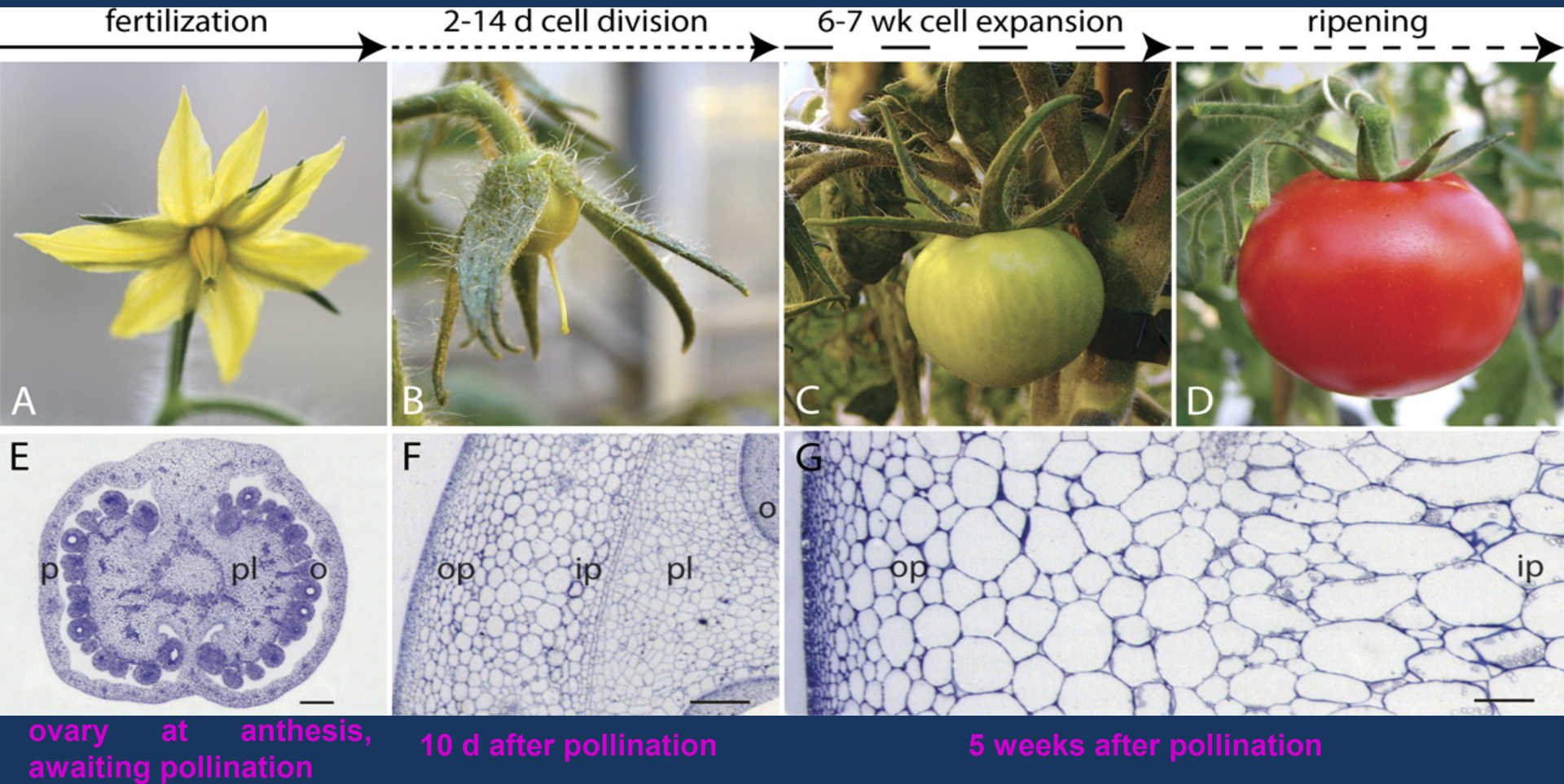
Interpretation of fruit sigmoid growth curves is complex because a single variable (mass, length, volume) is commonly applied to an object that contains several organs and different tissue types, each developing at their own rate and in accordance with their own programme. Moreover, at a cellular level, comparative levels of division and expansion change with ontogeny, while shifts in airspace percentage also play a part in volume increases. Added to this, changes in storage products (oil, starch and sugar) and structural carbohydrate (endocarp thickening) influence dry matter content

Peach growth is biphasic, showing a double sigmoidal pattern in terms of both fresh mass and dry mass. Pericarp cell division is especially active during early stages of phase 1, while enlargement of an existing population of cells is largely responsible for growth during phase 2.

Fruit development can be divided into a series of stages, as shown here for tomato. Early in development fruit are enlarging rapidly and are small, hard, green and accumulating organic acids. The seeds become mature prior to ripening. During ripening fruit become soft textured, and accumulate soluble sugars, pigments and aroma volatiles. Eventually fruit will become over-ripe, cell structures will deteriorate and the fruit will become susceptible to pathogens.



Overview of tomato fruit development.



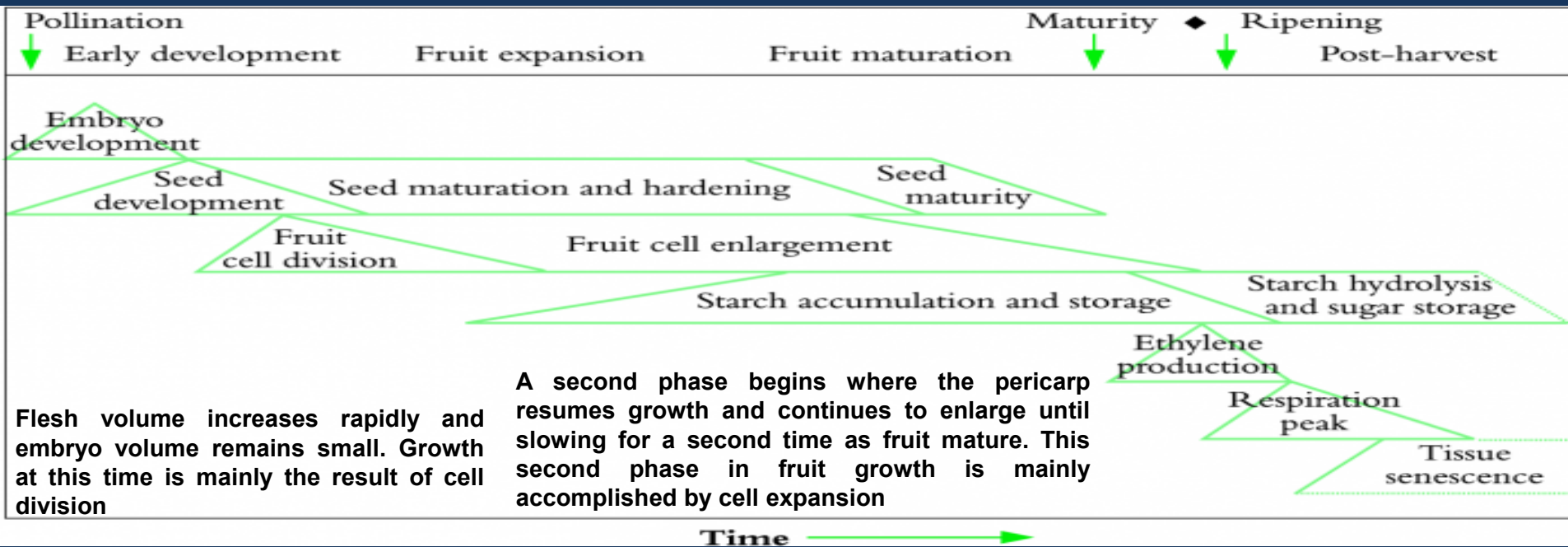
The first stage is fruit set, the initiation of fruit growth after the flower has been successfully pollinated and fertilized. After fertilization, cell division takes place, which lasts up to 14 d. This period is followed by 6–7 weeks (wk) of mainly cell expansion, during which the volume of the fruit rapidly increases. Once the fruit has reached its final size it starts to ripen

P, pericarp; op, outer pericarp; ip, inner pericarp; pl, placenta; o, ovules

ACHF, NAU, Navsari

de Jong M et al. J. Exp. Bot. 2009;60:1523-1532

Cell division and enlargement:

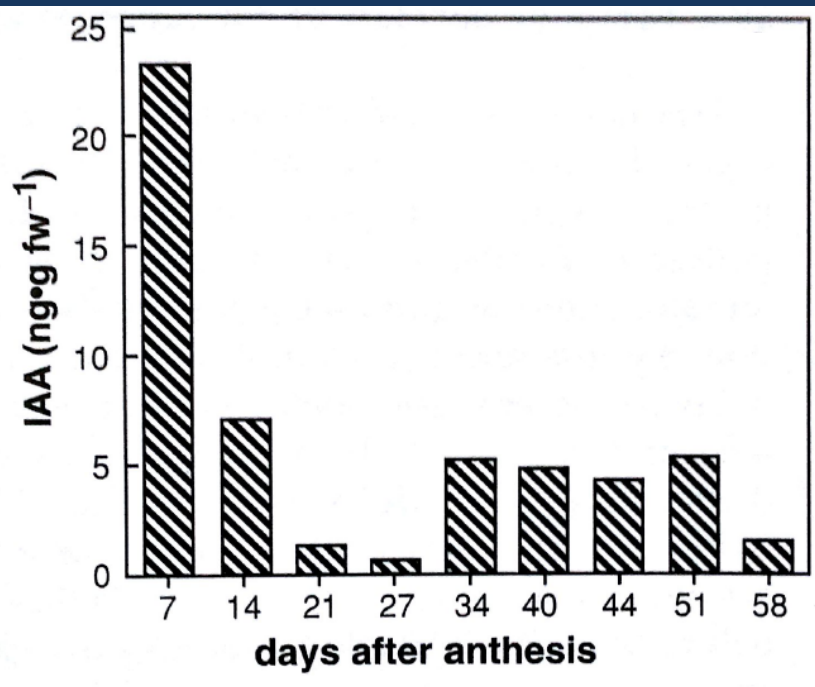


In many commercial fruit (e.g. apple, kiwifruit, tomato and peach), cell division may cease a few weeks after anthesis, and fruit growth slows down, reflected as an inflection in the growth curve, and signalling an end to the first sigmoid phase.

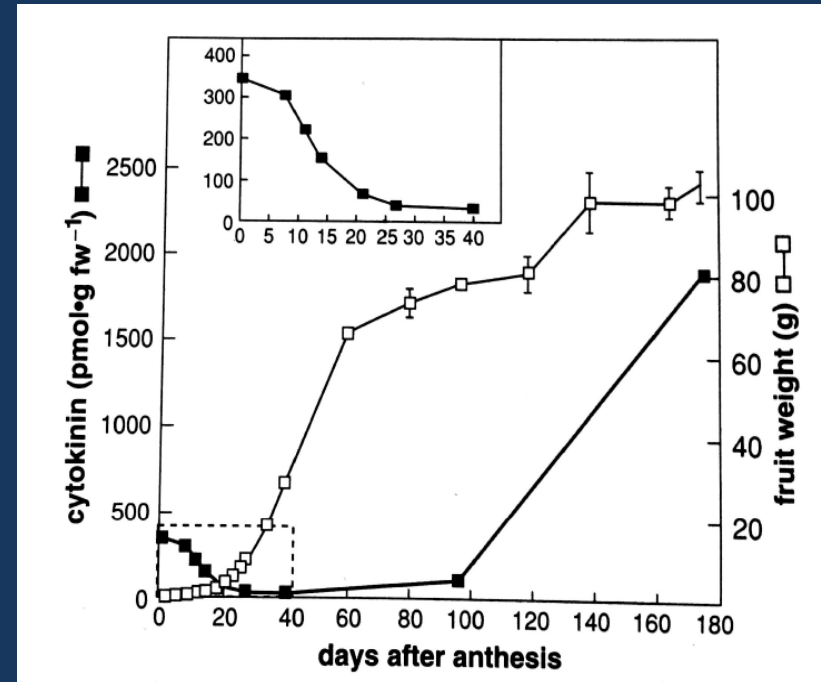
In broad terms, embryo differentiation and seed development are already well advanced as pericarp enlargement gets underway, and seed maturation usually precedes onset of ripening; consequently fruits ingested prematurely still represent vehicles for seed dispersal. A phase of carbohydrate accumulation during fruit maturation gives way to starch hydrolysis and sugar storage during maturation, accompanied by a peak in ethylene output and respiratory activity as fruits ripen.

FERTILIZATION AND FURTHER GROWTH :

Phase II and Phase III are marked by periods of rapid cell division and rapid cell expansion, respectively. These periods coincide with the growth of embryo and endosperm, it has been suggested that auxin and cytokinins produced by the embryo and endosperm have a role in fruit growth.



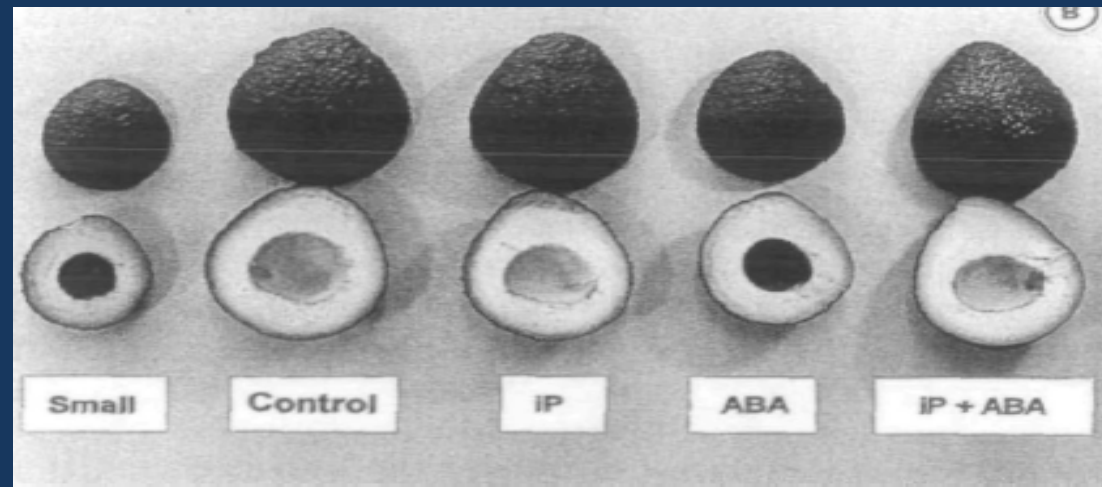
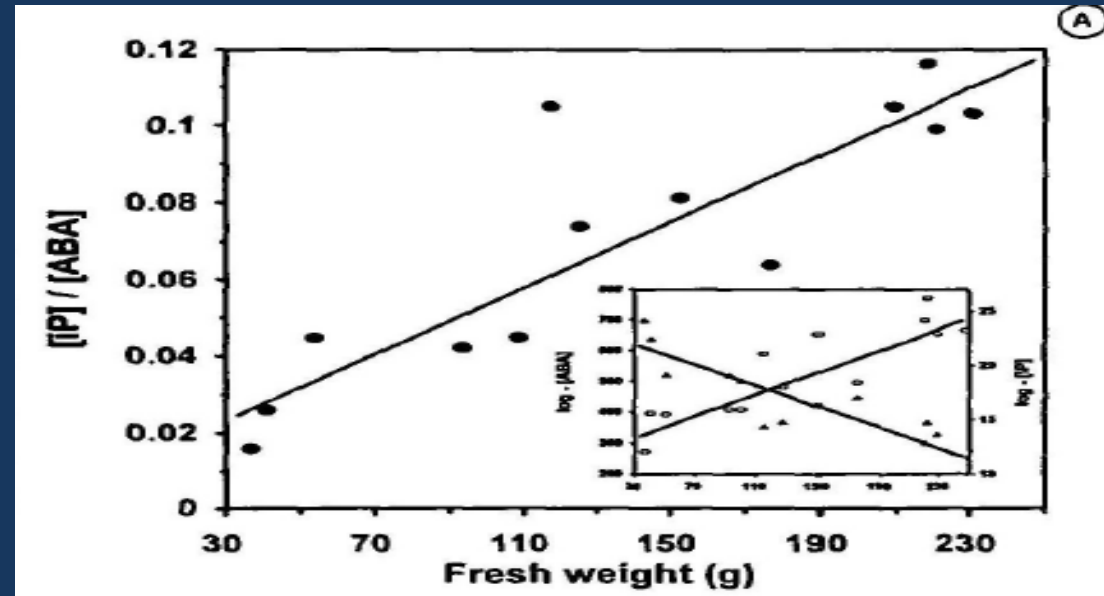
Endogenous IAA levels in tomato during fruit growth.



Ck levels are high at the earliest stages of growth which is correlate with maximum cell division activity. (Kiwifruit)

✓The number of cells in the mature unfertilized ovary and subsequently in early fruit growth is a critical parameter for eventually fruit size.

The cultivar Hass of avocado produces two populations of fruits – smaller and normal. The cell size in two phenotypes is the same, but the smaller phenotype results from a reduced number of cell divisions, which in turn related to reduced CK/ABA ratio in the smaller compared to the normal phenotype.



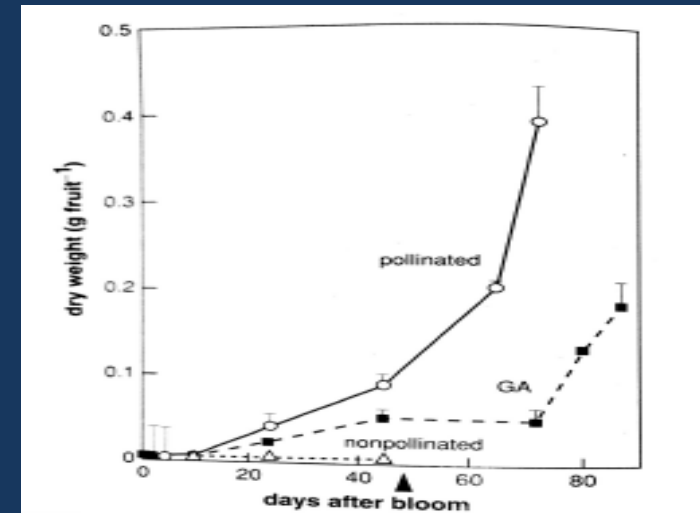
Parthenocarpic Fruits:

- ✓ Lack of pollination
- ✓ Pollination occurs but fertilization does not
- ✓ Fertilization is followed by embryo abortion

Auxin and GAs are well known to induce parthenocarp. These hormonal treatments are given to ovaries of unopened, unpollinated (or emasculated) flowers just before anthesis or during the receptive period after anthesis.

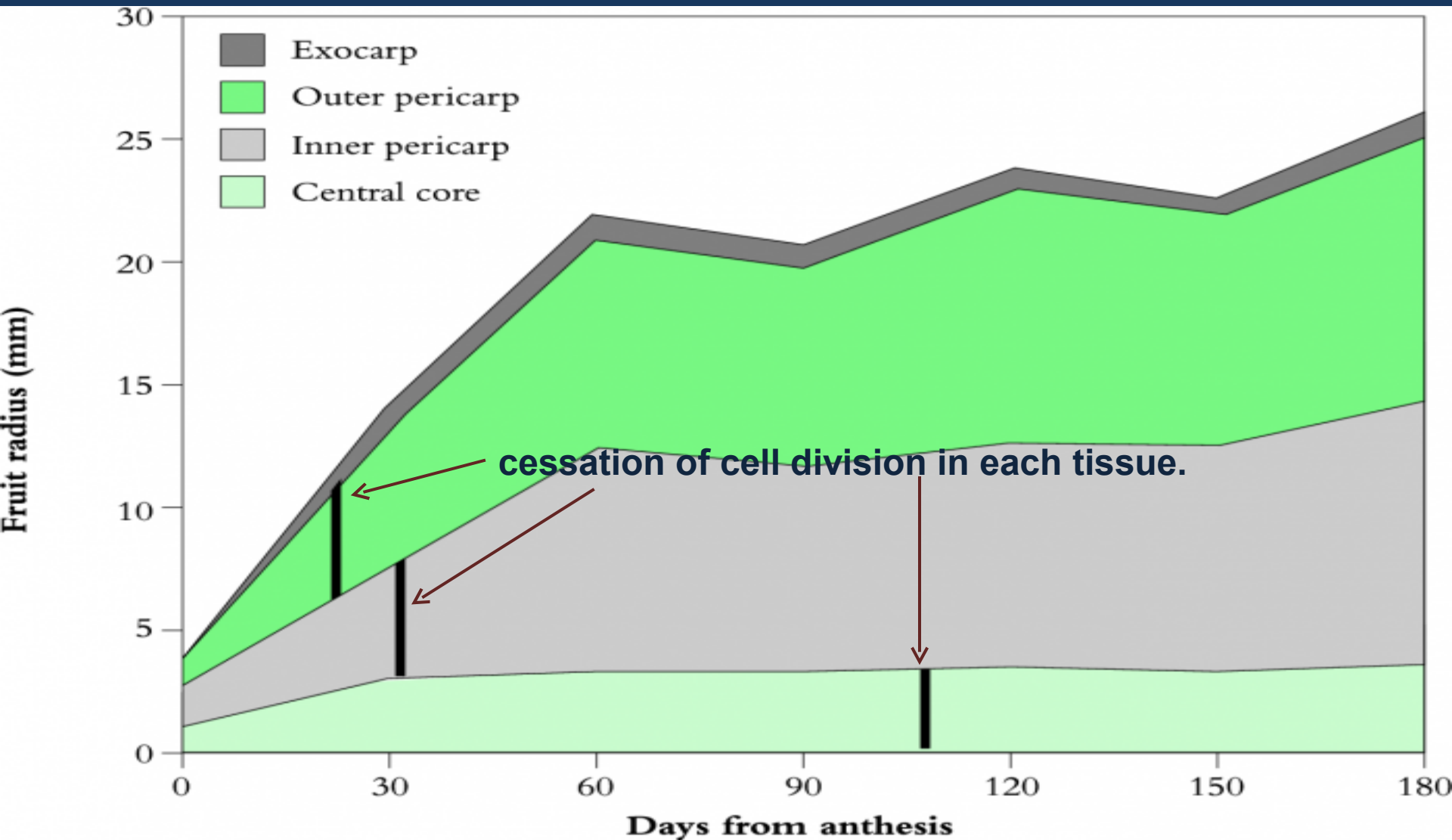
Cultivar differences in induction of parthenocarp is attributed to their internal hormonal differences.

The fertilization/pollination provide other stimuli that are lacking in auxin- or GA induced parthenocarpic fruit.



Changes in dry weight in GA3 treated but unpollinated, pollinated and nonpollinated blueberry fruits.

Radial growth in kiwifruit is due mainly to enlargement of outer and inner pericarp.





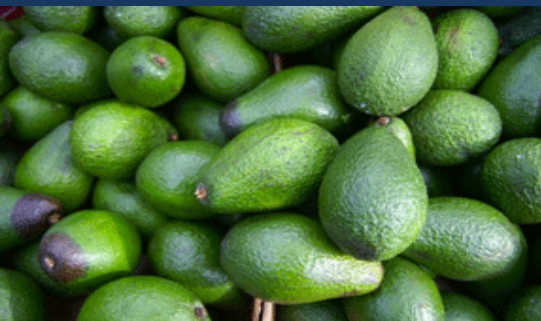
Longitudinal growth, where cells enlarge parallel to the long axis of the fruit, will often be a big factor for development of elongated fruit such as cucumber.



Radial growth increases diameter as in some pumpkins. Increases in cell volume during fruit growth can be considerable.



Mature watermelons end up with some of the largest parenchyma cells in the Plant Kingdom, about 0.7 mm in diameter.



In contrast to this general pattern where cell division ceases after a few weeks, pericarp cells of avocado fruit continue to divide over the whole growth period so that cells in mature fruit are still relatively small

Cell enlargement is not a uniform process. Cells in various regions of a fruit often enlarge at different rates and in different planes, so that many mature fruit show strong gradients in cell size from their surface to the centre.

In apple fruit, cells closest to the core are smallest, with cell size increasing towards the fruit surface.

Conversely in many berries, such as cucumber, kiwifruit and grape, the smallest cells are found in outer regions of the pericarp, with size increasing progressively towards inner regions

CELL DIFFERENTIATION

Patterns of cell growth and differentiation in cell layers can influence the quality of mature fruit.

For example, fruit with a compact exocarp composed of tightly packed cells are less likely to damage during postharvest handling than cultivars having large intercellular airspaces.

As cell size increases during development, other accompanying characteristics also change, such as cell wall thickness, differentiation of specific cell types (e.g. sclereids) and the formation of cell inclusions such as oil droplets or calcium oxalate crystals (raphides).

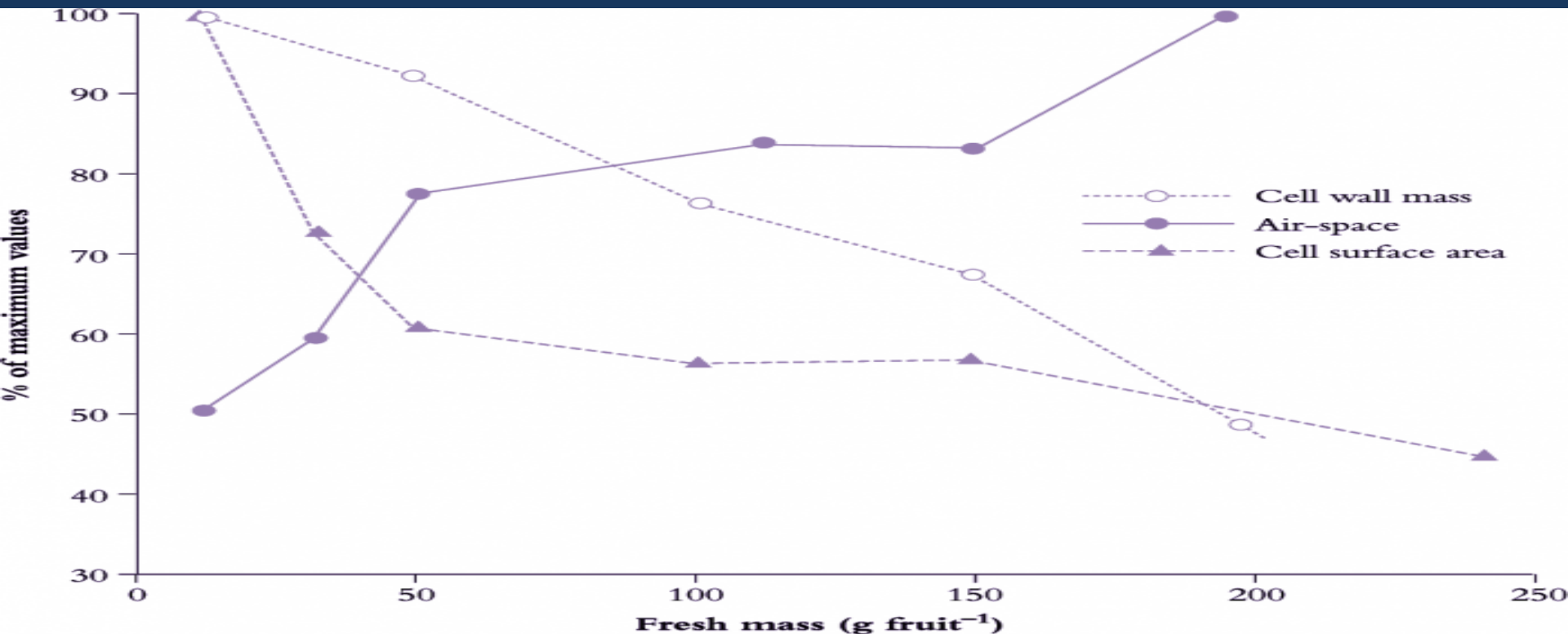
In pear, development of sclereids in the mesocarp provides the characteristic rough texture.

Juiciness of orange depends on prior differentiation of juice sacs in the endocarp.

The extent and distribution of airspaces are particularly important, affecting both fruit texture and physiological properties.

Such changes affect gas exchange and diffusion of solutes through pericarp tissues due to increased tortuosity.

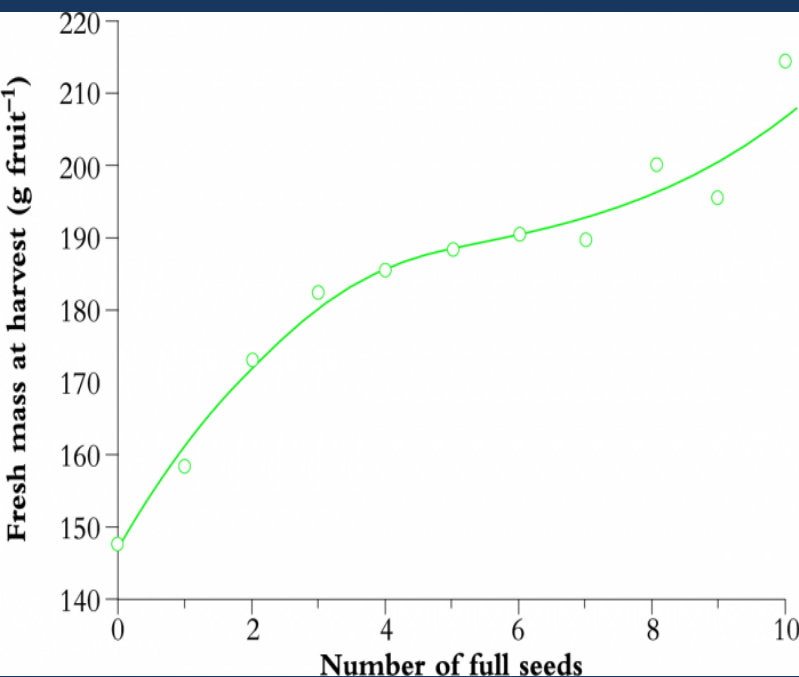
In apples, airspace relative to fruit volume can double during development, while cell wall thickness and relative cell surface area both decline. Such changes affect gas exchange and diffusion of solutes through pericarp tissues



SEED DEVELOPMENT AND FRUIT GROWTH :

As fertilised ovules develop into seeds, this influence on pericarp growth continues where production of hormones by the endosperm and developing embryo promotes pericarp growth. Indeed, there is usually a positive correlation between the number of seeds in the fruit and final fruit size

Applying auxin and gibberellins to unfertilized embryos is one way of achieving parthenocarpy; another is to use auxin transport inhibitors such as chloroflurenol to prevent loss of auxin from embryos so that a threshold level for pericarp response is exceeded. Studies of parthenocarpy in tomato and cucumber indicate that high auxin levels enhance embryo cell division, and this cell division phase seems to be more critical than subsequent cell expansion in determining final fruit size



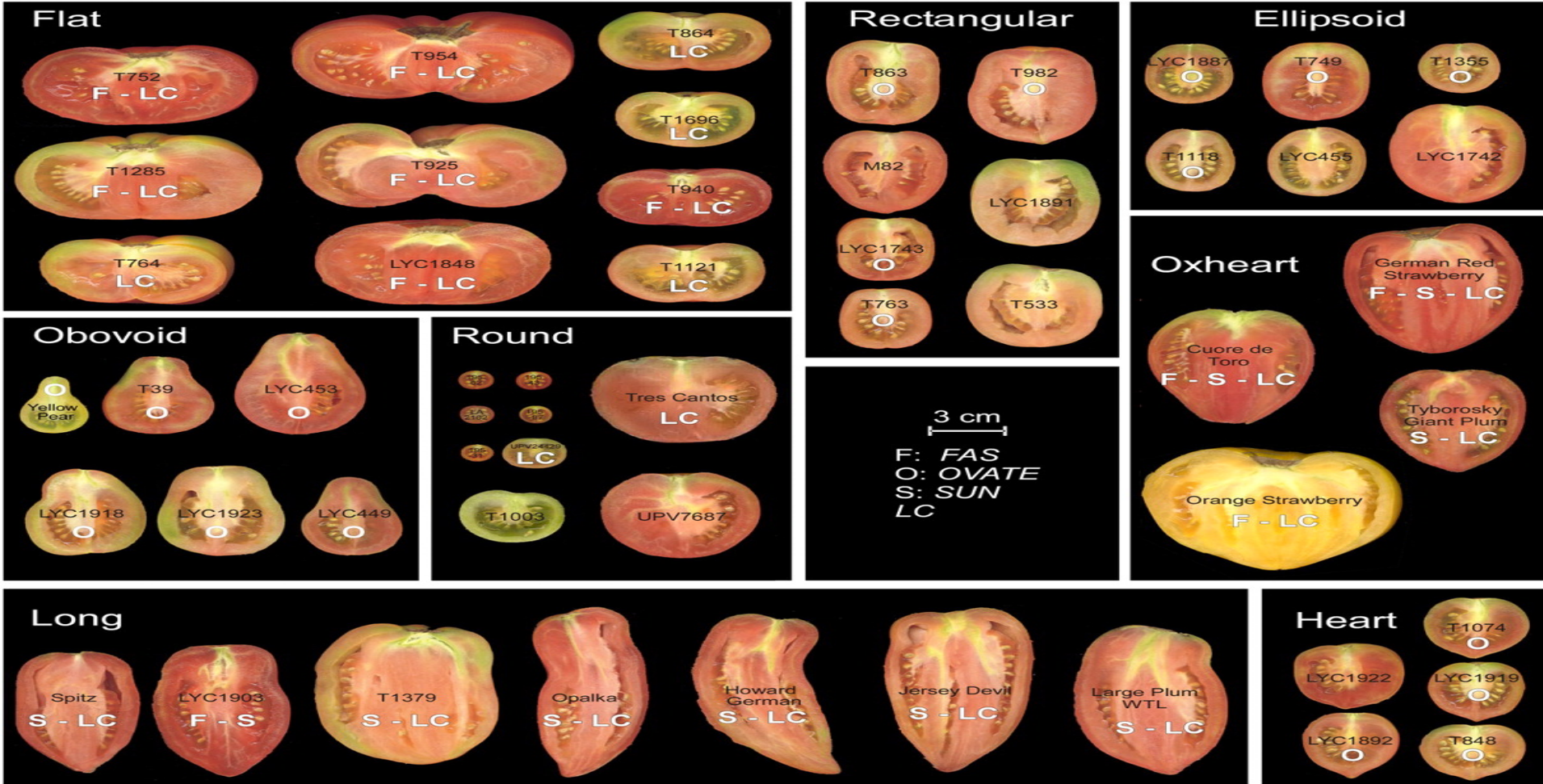
Seed cytokinins and cell division are similarly related because tomato seeds accumulate cytokinins that subsequently influence cell division in surrounding pericarp tissue

Fruit size in apples depends closely on 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

Despite ample evidence that natural control of fruit shape is primarily exerted by plant hormones originating from seeds and stimulating growth to varying degrees, this is not true for all fruit.

In banana, fertile seeds actually suppress development of the fleshy pulp. In this anomalous case, fertilization failure *allows* an ovary to grow

In tomato and kiwifruit, ovary shape dictates spatial distribution of seeds. They in turn influence pericarp growth, so that fruit size and shape then become a function of initial ovary shape plus subsequent fertilization and seed development.



By assembling 368 heirloom, modern and wild genotypes from Europe and the Americas, which they then classified into 8 fruit shape categories: flat, rectangular, ellipsoid, obovoid, round, oxheart, long and heart. 4 genes (*SUN*, *OVATE*, *FAS* and *LC*) have so far been discovered to make major contributions to these differences in fruit shape. The *SUN* mutation creates elongated fruit, apparently due to a mis regulation of the phytohormone auxin. The *OVATE* mutation (an early stop codon) creates pear shaped fruit. *FAS* (*FASCIATED*) and *LC* (*LOCULE NUMBER*) both contribute to tomato size and locule number.

Resources for fruit growth

As fruit grow, proportions of cell wall, carbohydrate, organic acid, lipid, phospholipid and volatile (aroma) compounds change dramatically; and within each of those groups there are changes in the proportion of individual group members. Of these, by far the most important in practical terms is carbohydrate economy.

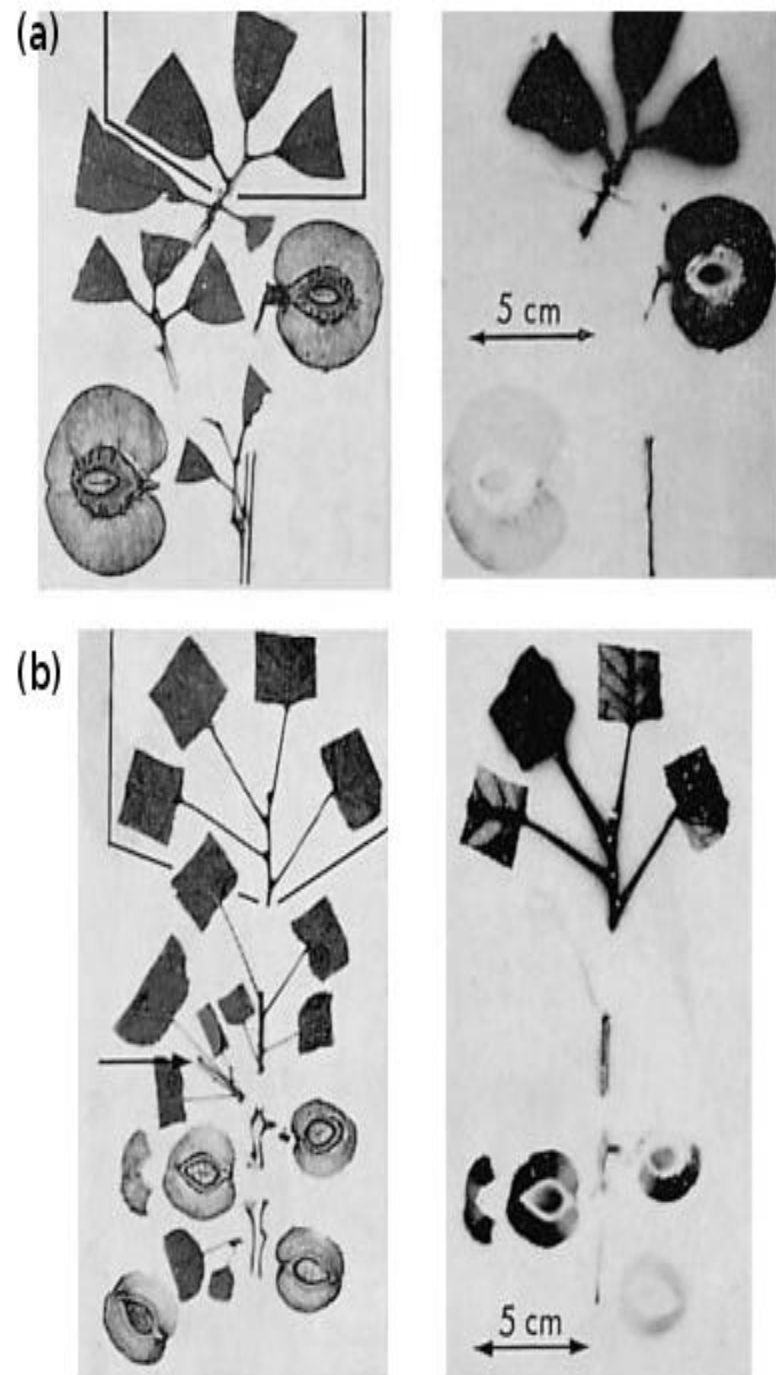
Enlarging fruit require carbohydrate to sustain cell division, enlargement and tissue specialisation. Only in later stages are carbohydrates typically retained as either starch or soluble sugars. Soluble carbohydrate is mainly imported as photoassimilate, with only a minor contribution from local CO_2 fixation, and reassimilation of respiratory CO_2 .

During peak fruit expansion, there is an intense flow of photoassimilate from mature leaves (sources) into rapidly enlarging fruit (sinks). Sugars generated by photosynthesis, along with amino acids and phosphate within the plant's vascular network, move via the phloem into enlarging fruit.

Photoassimilate distribution

Photoassimilate moves from mature leaves of peach (a) and apricot (b) into the pericarp of maturing fruits nearby. $^{14}\text{CO}_2$ was administered for about an hour to source leaves (boxed area top left side in (a) and (b)) and movement of ^{14}C -labelled photoassimilates over the subsequent 24 h was traced by autoradiography of harvested material (right side a and b). Intense labelling of source leaves indicates a high level of residual activity, but strong incorporation of ^{14}C photoassimilates into the pericarp of adjacent fruits is also evident. Endocarp tissues had hardened and failed to import current photosynthate, although seeds developing inside the endocarp did become labelled.

Source and sink strength and vascular connection and phyllotaxis.



Composition of photoassimilates:

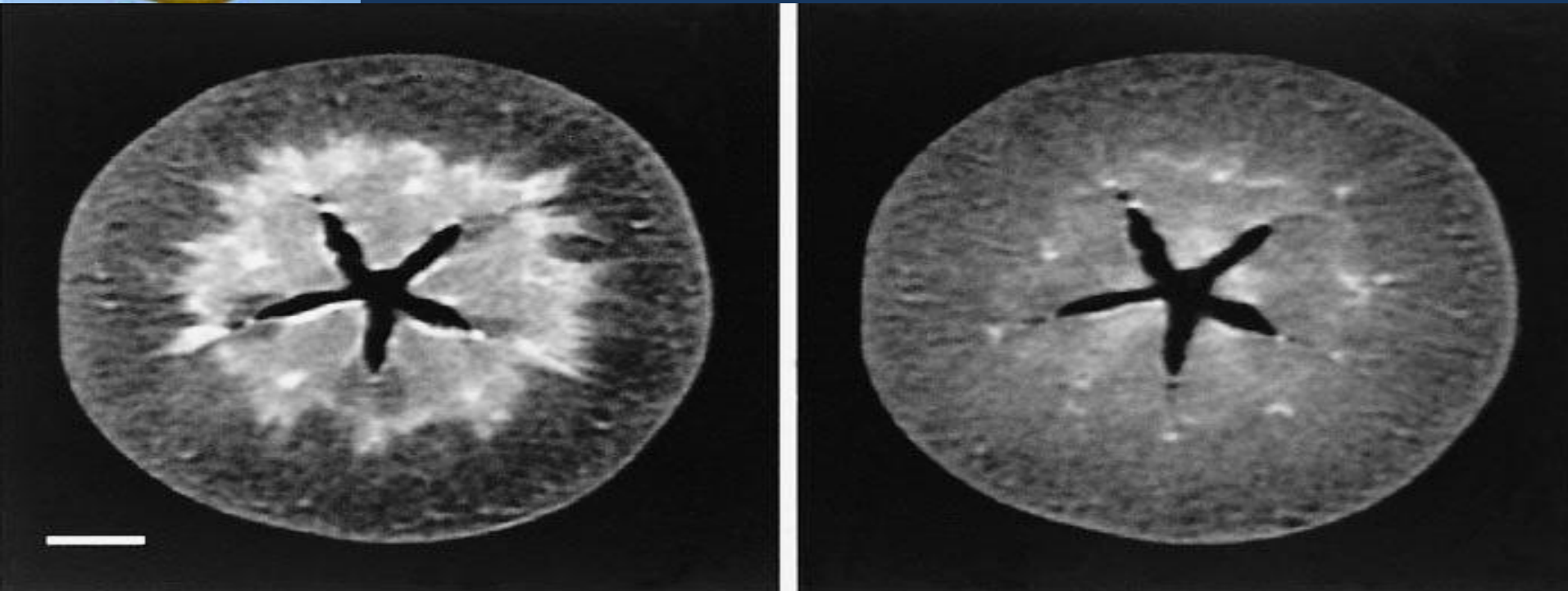
Photoassimilate is commonly transported from leaves (sources) to fruit (sinks) as sucrose, and most agricultural plants fit this model. Even genera as diverse taxonomically as *Yucca* and *Vitis* (grapevine) transport sucrose almost exclusively, but stonefruit and pipfruit (pomefruit) of the woody *Rosaceae* (e.g. apple) use sorbitol. Ash trees translocate most of their photoassimilate as mannitol. As a further variant, some *Cucurbitaceae* (e.g. squash) use stachyose and related compounds. In all cases, translocated sugar is an energy-rich source of carbon, but sucrose is not the universally translocated sugar, as indicated below.

Sugar	Yucca	Grapevine	Ash	Apple
Sucrose	97	93	11	22
Glucose	2	4	1	4
Fructose	1	3	1	3
Sorbitol	—	—	—	71
Mannitol	—	—	65	—
Other	—	—	22	—

✓ Soluble carbohydrate is mainly imported as photoassimilate, with only a minor contribution from local CO₂ fixation, and reassimilation of respiratory CO₂.



If sorbitol reaching fruit is not fully metabolised, apoplastic accumulation results and pericarp tissues become glassy in a disorder called 'watercore'). This is a common problem with some apple cultivars such as Fuji. Sugar transport and accumulation can thus have economic importance — both in terms of desired taste characteristics and postharvest fruit quality.



NMR images from the equatorial plane of an apple show watercore (waterlogging) as an intense white region. The first scan (left) was taken from a Fuji apple with severe watercore at the time of harvest. The second scan (right) was taken of the same fruit after cool storage for 15 weeks at 0°C, when symptoms had disappeared due to reabsorption of apoplastic water.

FRUIT COMPOSITION AND SENSORY ATTRIBUTES

Taste and flavour, are directly dependent on carbon transport and subsequent metabolism.

In particular, sugar–acid balance and contents are primary determinants of the taste attributes of fruit. Too much acid and the fruit is tart and unpalatable; too little and the fruit is insipid and bland (Titrable acidity).

Another indicator used is the refractive index of the expressed sap (recorded as °Brix). This is a measure of the soluble solids concentration (SSC %) of expressed juice and represents the sum of organic acid, salts and sugar contents.

Several organic acids may be present, but certain ones are characteristic of particular species or cultivars. For example, malic acid predominates in pipfruit (pomefruit), citric acid is dominant in citrus, while tartaric acid is dominant in grape. In kiwifruit, malic, citric and quinic acids are the major ones, and in total may exceed 1.5% of the fresh weight.

Acids are not transported into fruit via phloem connections, but are synthesised *in situ*. Part of the acid component comes from metabolism of the sugar imported through the phloem, but part can be synthesised by local fixation. In citrus, dark fixation of CO₂ by mature fruit makes a meagre contribution to acid balance, but inter-conversion of imported carbon is of more consequence. In that case, citrate synthase and subsequent enzymes in the citric acid cycle appear to determine whether imported carbon (as sucrose) is transformed into other sugars or is metabolised further to organic acids.

The dynamic between starch breakdown and soluble sugar increase can be a critical index of fruit maturity. Starch content of fruit at harvest (commonly estimated from fruit dry matter content) is used commercially as a proxy for potential fruit taste.

Fruit are rich sources of vitamins, particularly vitamin C (L-ascorbic acid). Moreover, vitamin C can may account for a notable absence of browning in kiwifruit and citrus when sliced (in conjunction with relatively low levels of polyphenols and polyphenol oxidase in those tissues). Vitamin C levels increase in the fruit during early growth, and tend to be stable through to maturity.

Phenolics such as anthocyanins and tannins are also important in fruit and are responsible for much of the visual appeal of intact fruit (e.g. tamarillo), exposed flesh (e.g. cherry) or extracted juice (e.g. guava). They also contribute to flavour characteristics, adding a slight and pleasing astringency (as with the dessert apple) or a more aggressive one (as with cider apple and green banana)

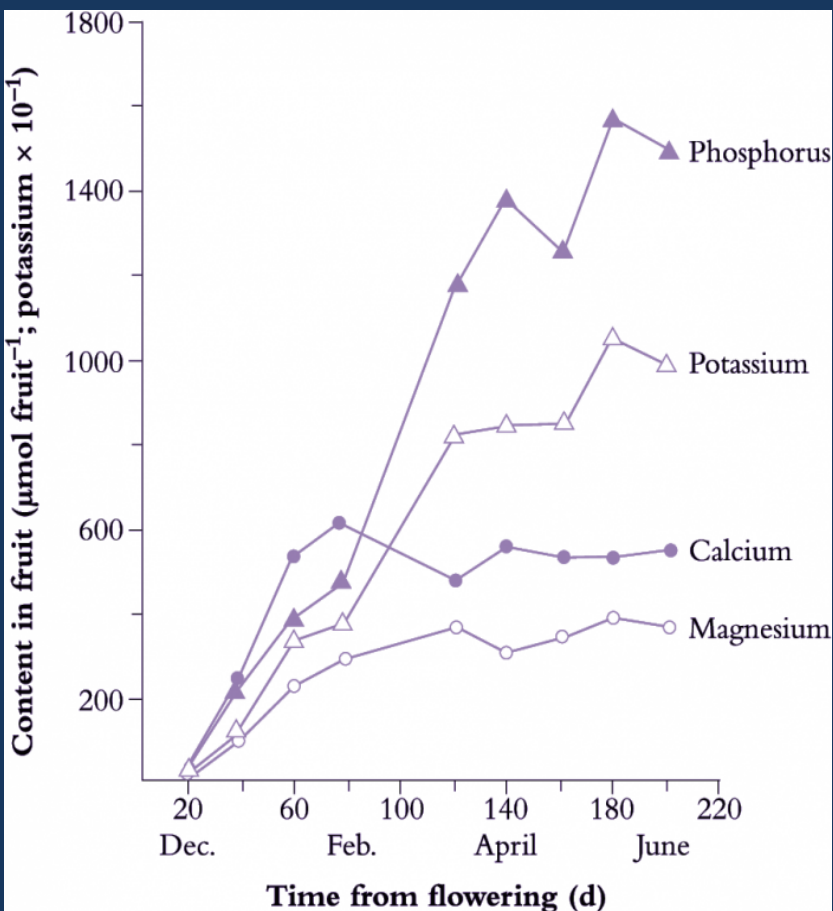
Tannins: Determining how a given fruit is used. (Astringent-high tannins)

Water-soluble tannins are compartmented in specific tannin cells of the mesocarp tissue.

Tannin accumulation ceases with cell growth, and in non-astringent cultivars astringency declines both through soluble tannin dilution and through polymerisation, where soluble tannins are condensed into an insoluble form.

MINERAL NUTRIENTS

As a rule, concentrations of the major mineral nutrients in fruit are lower than in other organs such as leaves, and the patterns of phosphorus, potassium, calcium, magnesium and nitrogen accumulation usually differ.



Accumulation of calcium is confined to early stages of development that coincide with cell division.

Mineral nutrients move into the fruit most rapidly during the early stages of development at a time when xylem water flow dominates. As fruit approach maturity, surface to volume ratio declines, the skin becomes less permeable to water loss, and large amounts of photoassimilate are imported via phloem connections. As a result, a significant part of the water reaching fruit now enters through the phloem. Mobile ions such as K^+ and HPO_4^{2-} travel in the phloem and so reach fruit over the whole growing season. In contrast, less mobile nutrients such as Ca^{2+} fail to reach fruit during later stages, so that Ca^{2+} concentration remains steady or even declines slightly

Nutrient deficiencies in fruit are relatively uncommon, except for those associated with calcium.



Blossom-end rot in tomato



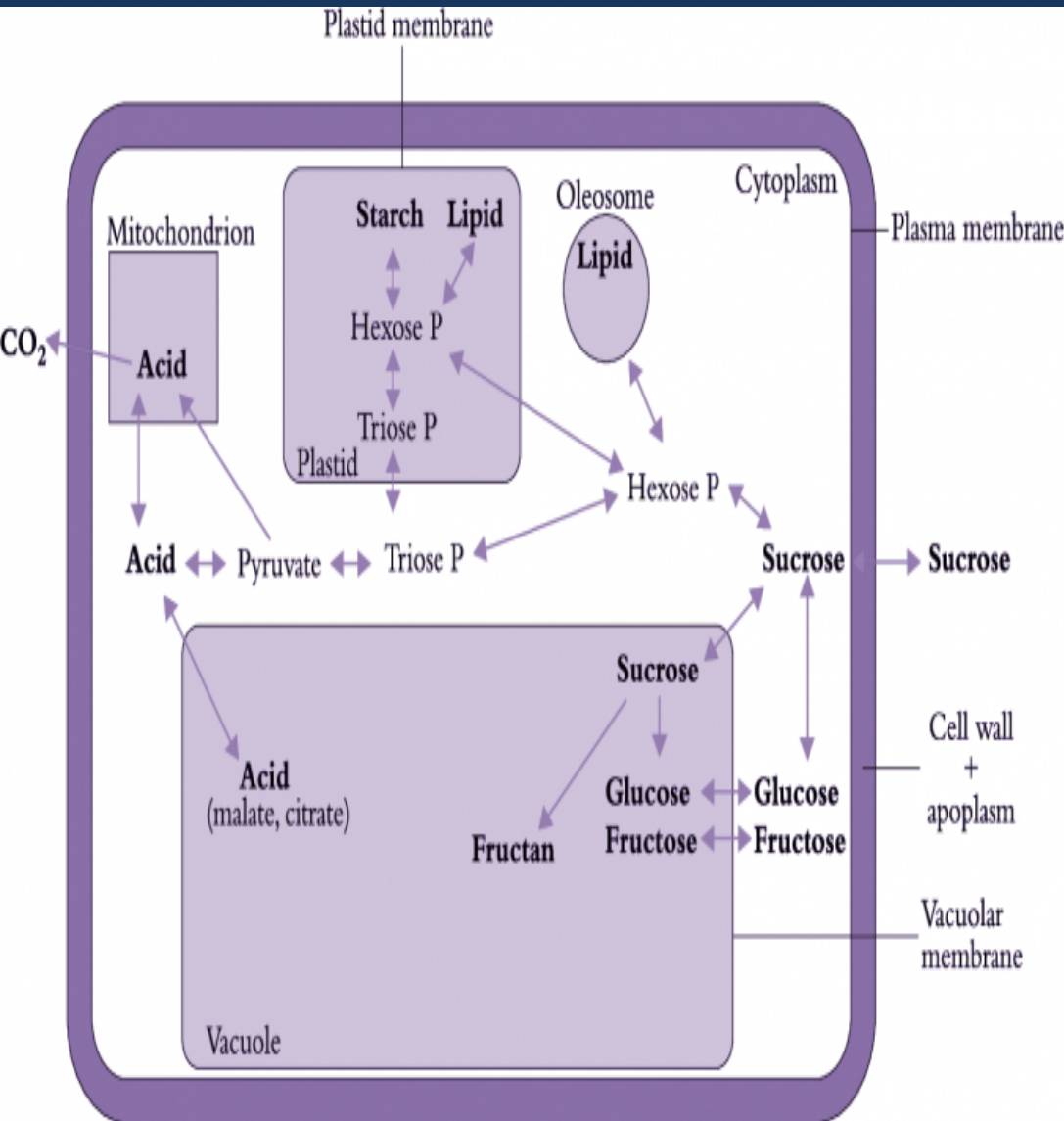
Bitter pit plus lenticel blotch in apple fruit

Carbon accumulation :

- ✓ Fruit that store carbon in a soluble form (e.g. berry fruit, peach, persimmon, melon, grape, citrus) need to remain on the plant until nearly ripe if they are to survive postharvest storage and meet customer expectations. In most cases the major and rapid increase in soluble sugar content does not occur until late in development, signalling the beginning of ripening.
- ✓ In contrast, there are other fruit that store their carbon in insoluble forms, particularly starch. This allows greater efficiency in accumulating carbon, as the storage product is more compact, osmotically inactive and better segregated from metabolic processes. Examples are avocado, which stores carbon as both starch and lipid, and kiwifruit, apple, pear, mango, papaya and banana, all of which store carbon as starch.
- ✓ In fruit that store carbon as sugars (tomato) and organic acids during development, colour changes followed by the initiation of softening signal that fruit are becoming mature and ready to harvest. (Challenge of firmness and sugar balance).
- ✓ In fruit that store carbon as starch (mango, banana kiwifruit), time of picking is less dependent on sugar content, since a doubling or more of sugar concentration by starch hydrolysis can still take place after the fruit are picked. (Brix reading ?)

Thus, when fruit store carbon in insoluble forms, they can often be harvested while still hard, lending greater flexibility to postharvest handling and ensuring a longer storage life.

Carbohydrate economy in developing fruits is driven by import and recycling of photoassimilates between different metabolic compartments.



Sucrose or less commonly other forms of translocated carbon arrive via phloem conduits and are loaded into cytoplasmic compartments. Carbohydrate can then be partitioned to vacuolar storage or converted to other sugars and, in the form of hexose phosphate, transferred to plastids where it is used to synthesise starch. Each step is reversible, and as happens during ripening, starch in plastids is transformed back to sugars that subsequently accumulate in vacuoles. Other specialised organelles (oleosomes) store lipids while mitochondria draw upon imported and locally fixed carbon for ATP generation.

Sugar storage :

In sugar-storing fruit a major shift in metabolism generally takes place when fruit expansion is almost complete, heralding a rapid increase in sugar content. Unloading of sugars from the phloem usually occurs by a symplastic route, but in some species is interrupted by an apoplastic step.

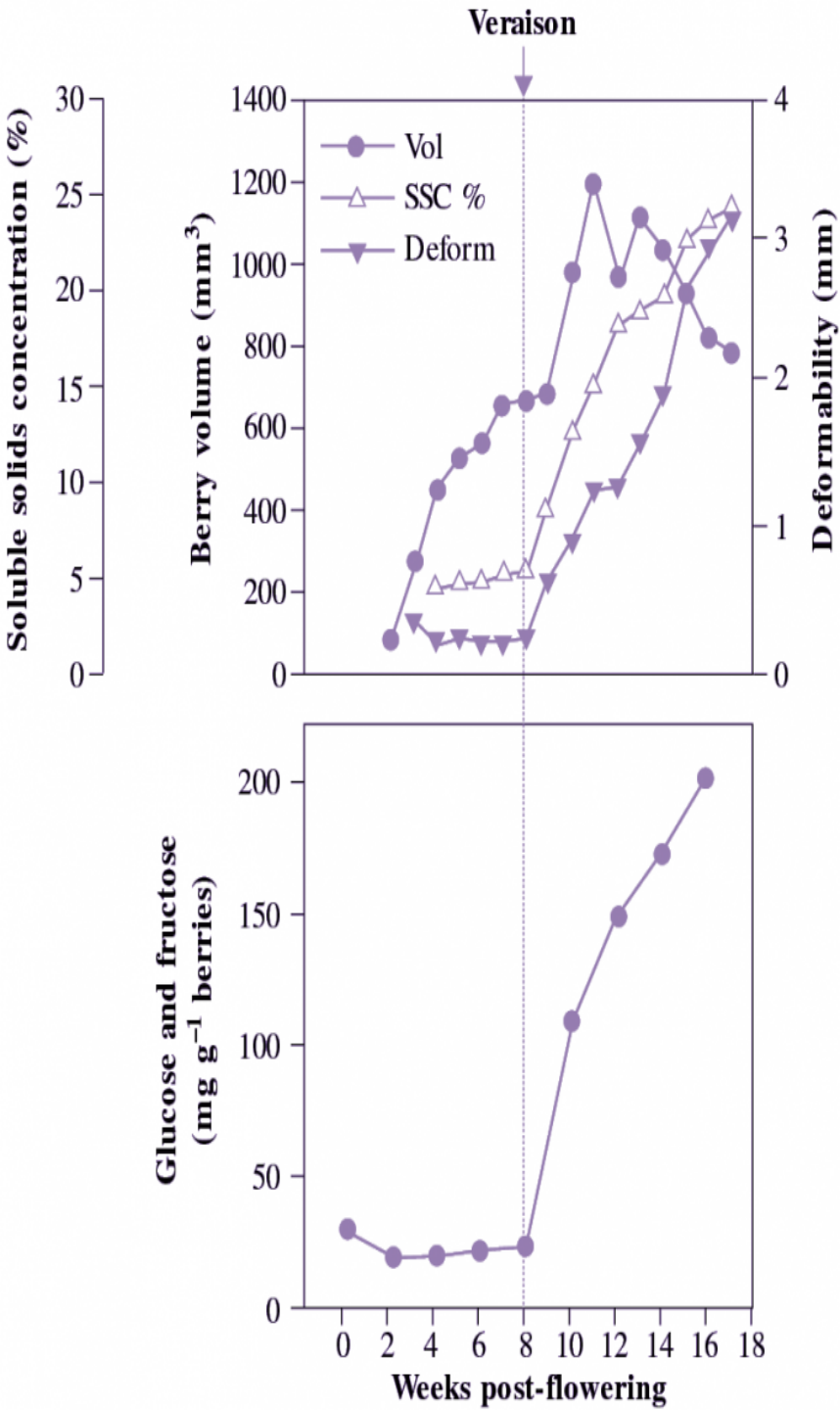
Control points for sugar entry and accumulation by fruit include:

- ✓ Rate of sugar production by leaves and delivery to transport pathways;
- ✓ Reallocation of sugar from supporting vegetative growth towards fruit growth;
- ✓ Enhanced unloading of sugar from transport streams into fruit;
- ✓ Enhanced transfer of sugar across plasma membranes into cells or through plasmodesmatal connections between cells;
- ✓ Onward metabolism of sugar in the cytoplasm, or transfer to storage in vacuoles;
- ✓ Increased respiratory utilisation of sugar to provide energy for metabolic processes.

In tomato, there are different genotypes that accumulate either hexoses or sucrose. Most cultivars are hexose accumulators, in which acid invertase is active during growth and ripening. In transgenic tomatoes in which acid invertase activity was suppressed by expression of an antisense invertase transgene, sucrose accumulation occurred in a normally hexose-accumulating cultivar.

Conventional breeding studies using crosses between sucrose-accumulating and hexose-accumulating types of tomato showed that an acid invertase gene is not transcribed during ripening of the sucrose accumulators, and that sucrose accumulators therefore lack acid invertase .

In melon, where sucrose is the main sugar to increase, there is a corresponding decrease in acid invertase and an increase in sucrose phosphate synthase (SPS) activity



Grape undergoes an abrupt change in physiology midway through development. For about 8 weeks after flowering, berry volume increases steadily but fruit are hard (low deformability) and sugar content low. At 'veraison' invertase activity rises abruptly and reducing sugar content increases rapidly, reaching about 20% of fresh weight when ripe. Berries attain full size by 10–12 weeks, and approach an asymptote in sugar content 2–3 weeks later.

Starch storage :

Fruit that store starch switch from starch synthesis during development to starch hydrolysis during ripening. Starch–sugar interconversion involves a larger number of enzymes and a greater complexity of control than is required for sugar storage alone.

Where fruit store carbon in an insoluble form, there are several potential control points for sugar metabolism including:

- ✓Hydrolysis of starch to glucose;
- ✓Transfer of sugar precursors from starch-containing plastids (amyloplasts);
- ✓Synthesis or degradation of sucrose;
- ✓Synthesis of hexoses;
- ✓Transfer of sugar to vacuoles or export from cells;
- ✓Carbon flow between sucrose and malate or citrate;
- ✓Production of CO₂ from sugar or acid precursors;
- ✓Transfer of malate or citrate across the vacuolar or mitochondrial membranes.

Fruit ripening :

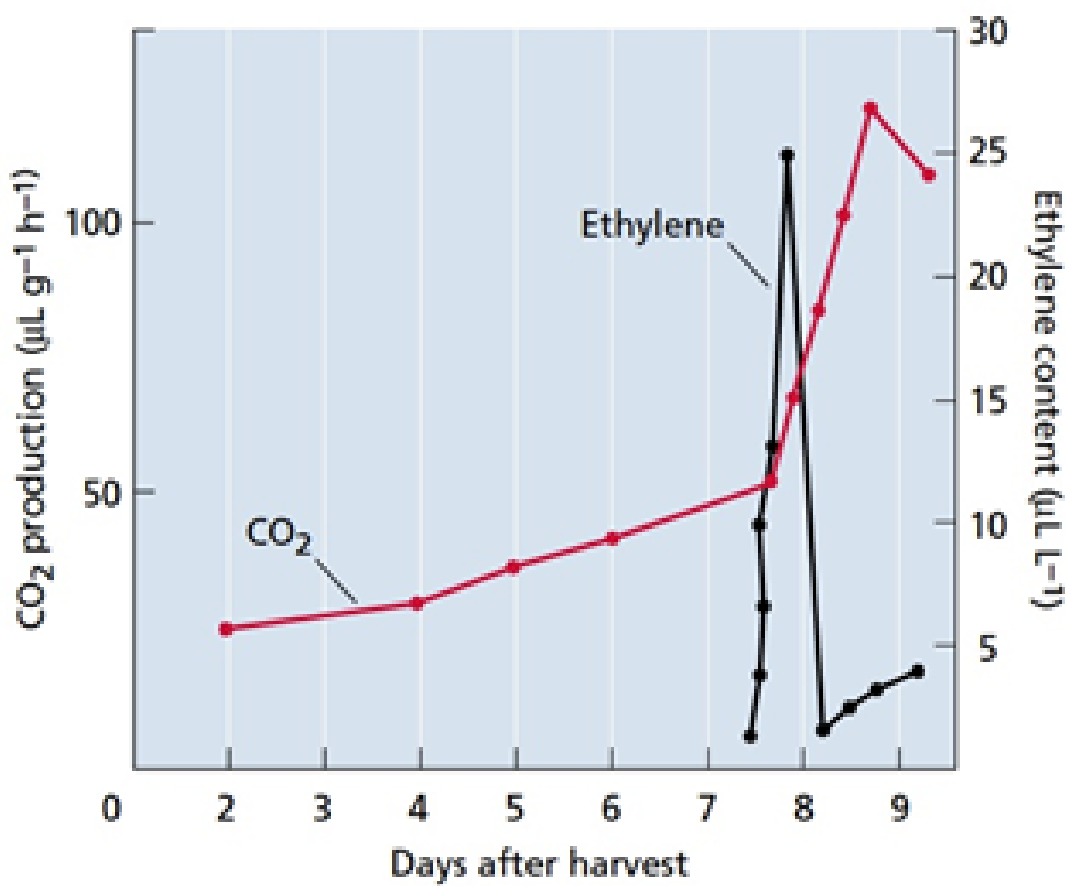
Several major changes take place as fruits ripen, and taken collectively they characterize ripening processes. They include:

- ✓ Changes in carbohydrate composition, resulting in sugar accumulation and increased sweetness;
- ✓ Change in colour;
- ✓ Flesh softening and textural change;
- ✓ Formation of aroma volatiles;
- ✓ Accumulation of organic acids with associated development of flavour

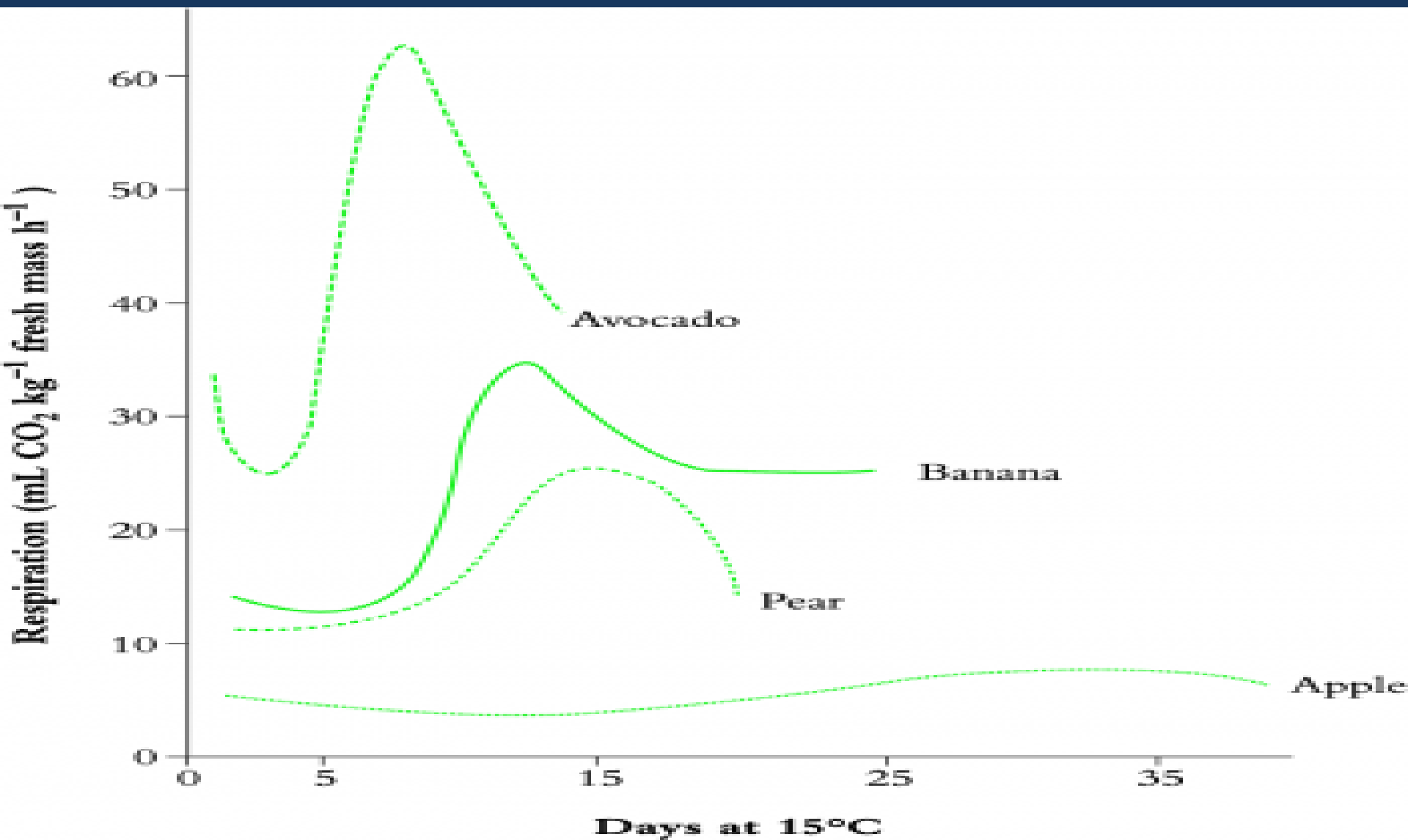
Fruit progress towards edibility the respiratory rate increases followed by a decline as fruit senesce. This is known as the climacteric rise

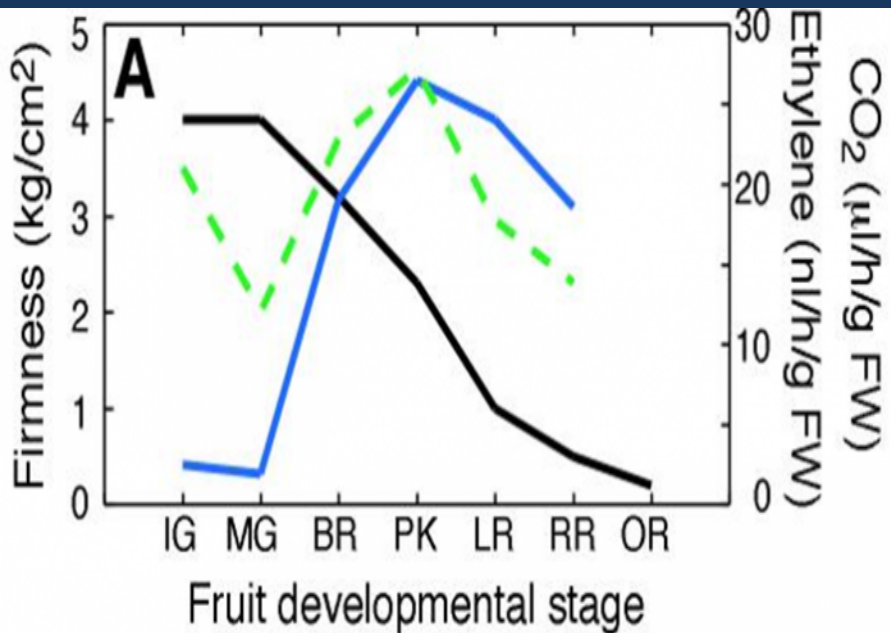
Ethylene production also increases sharply to a maximum at this time, and then declines before fruit rots intervene and lead to a renewed output. The major rise in ethylene production may take place before, just after or close to the respiratory peak

Unripe climacteric and non-climacteric fruit both increase their respiration rate when exposed to exogenous ethylene.

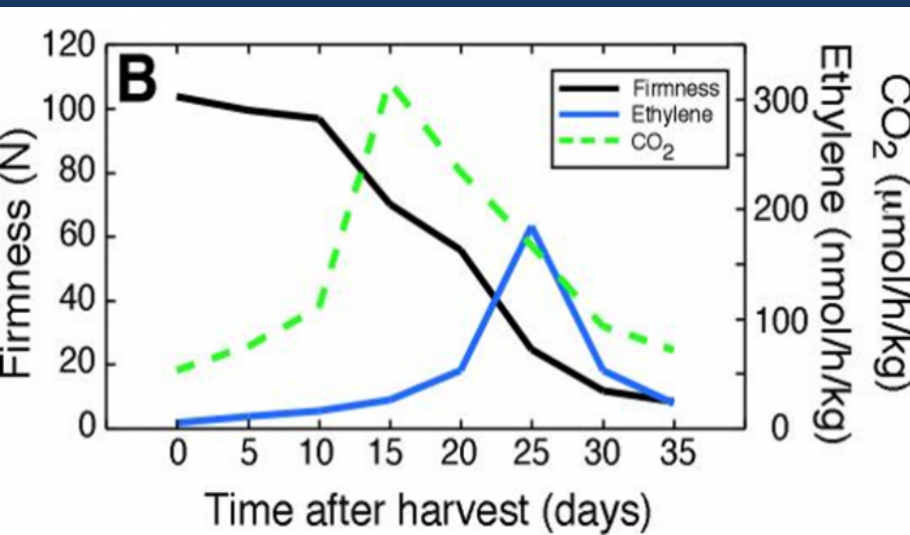


Climacteric	Non-climacteric
Apple	Cherry (sweet, sour)
Apricot	Cucumber
Avocado	Grape
Banana	Lemon
Blueberry	Pineapple
Cherimoya	Satsuma mandarin
Feijoa	Strawberry
Fig	Sweet orange
Kiwifruit	Tamarillo (tree tomato)
Mango	
Papaya (paw paw)	
Passionfruit	
Pear	
Persimmon	
Rockmelon (cantaloupe)	
Tomato	
Watermelon	





In tomato, the peak of ethylene production and respiration occur relatively early in ripening, shortly after the first visible sign of red coloration on the outside of the fruit (known as the breaker stage)



In kiwifruit, that were harvested and stored at 20°C, the peak of ethylene evolution occurs very late, when substantial softening has already occurred and the fruit are almost at the eating ripe stage. The earlier peak in respiration may have been caused by harvest.

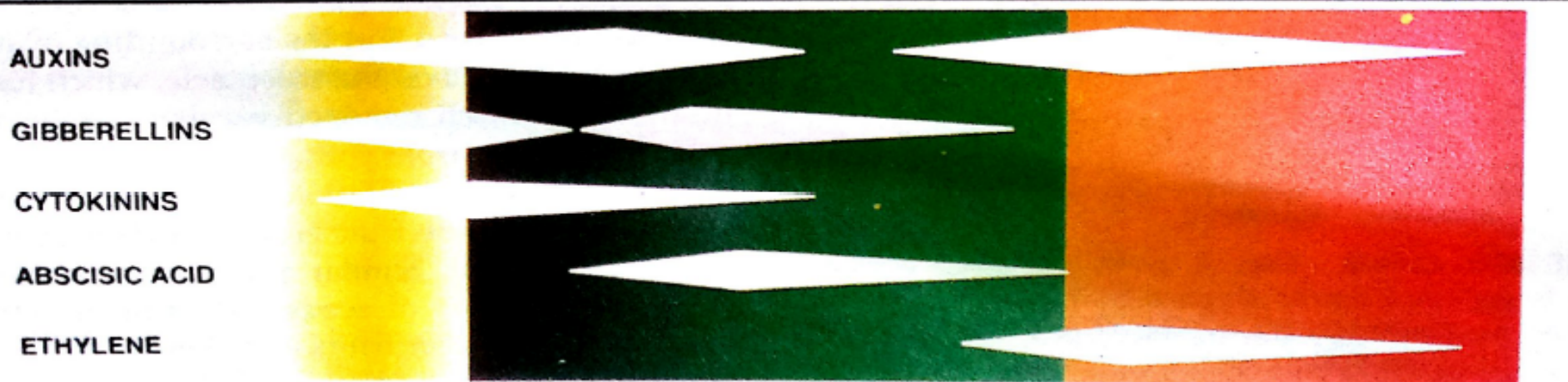
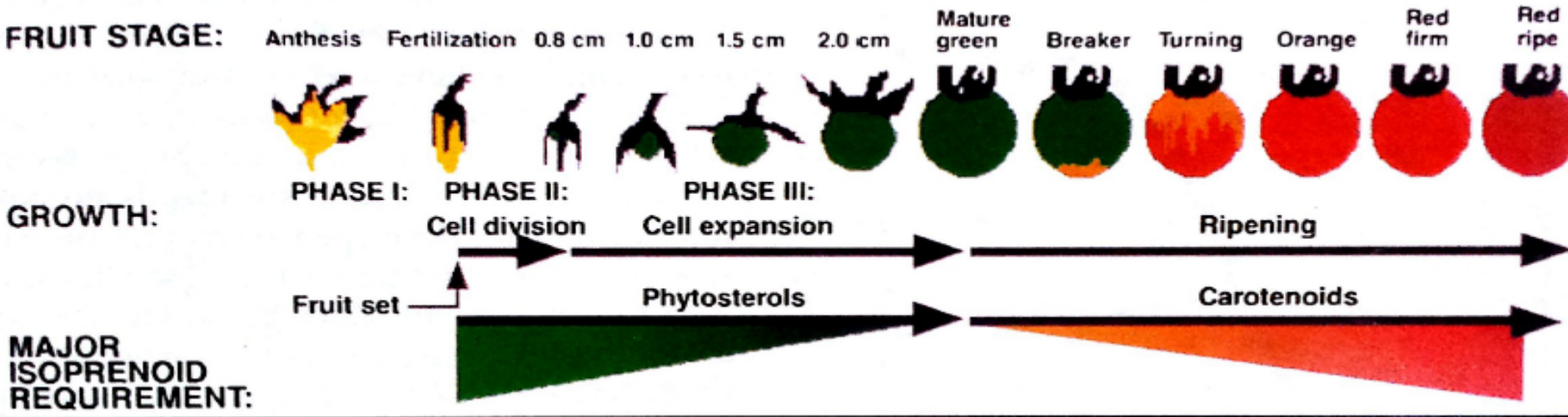
Developmental control of ripening :

Ethylene is not the only regulator of fruit ripening. A cold treatment can trigger ripening in detached apple and kiwifruit, acting either independently of ethylene or by increasing sensitivity to existing very low levels of ethylene.

- ACC oxidase and chlorophyllase are ethylene independent
- Respiratory genes, lycopene, volatile and ACC synthase are ethylene dependent

Other hormones also appear to play important roles; particularly, declining levels of auxin and increasing levels of abscisic acid may control the onset of ripening in non-climacteric species such as grape and strawberry. Abscisic acid may also play a role in controlling the onset of ripening of climacteric species.

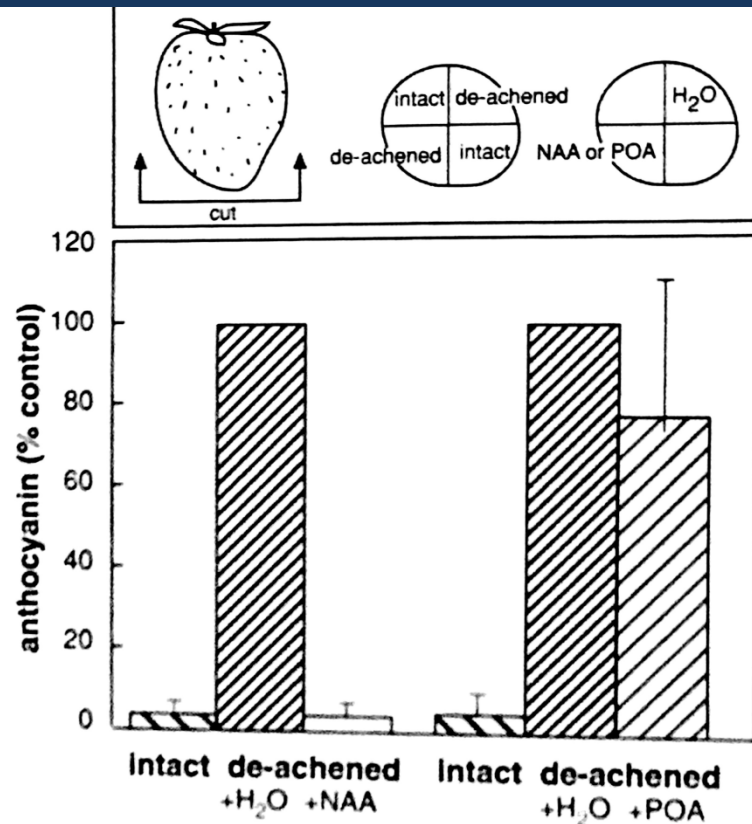
Fruit development and ripening in tomato, a model fleshy fruit:



Phase I-III represents period of fruit set and growth, phase IV represents ripening. Changes in levels of different hormones at different stages are indicated by white diamonds.

RIPENING IN NONCLIMACTERIC FRUITS:

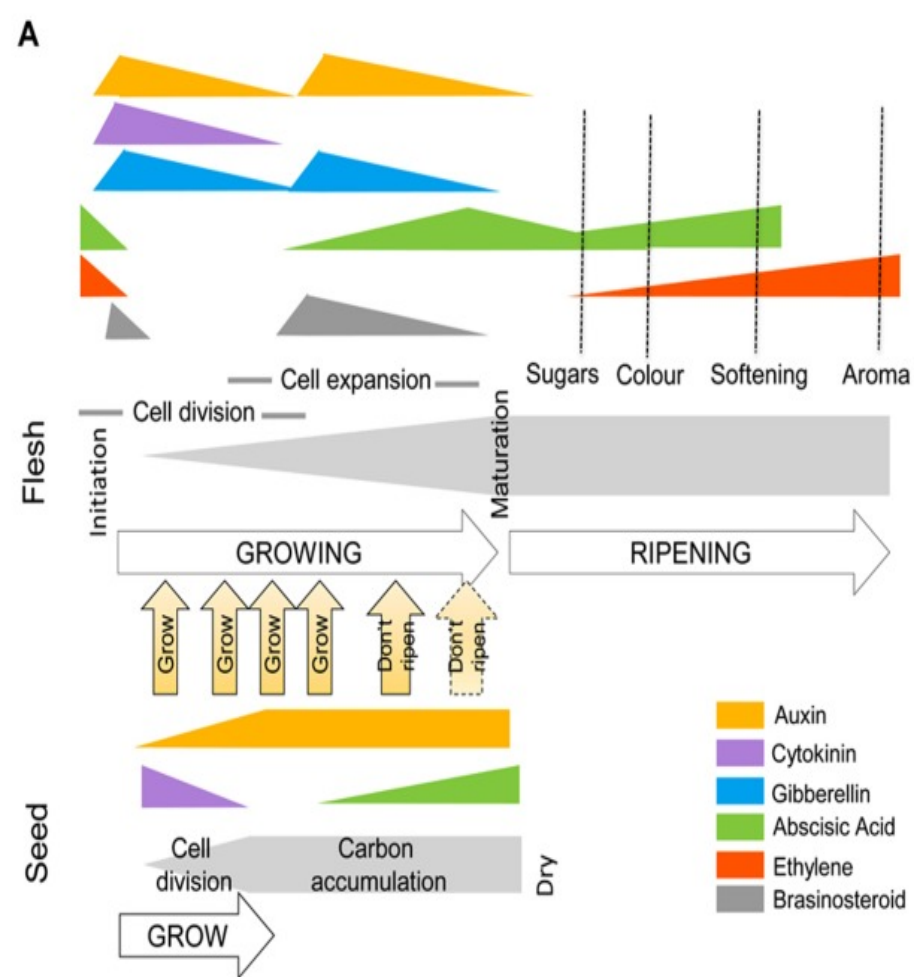
- ✓ The ripening of non climacteric fruit involves many of the same changes as climacteric fruit.
- ✓ Many studies have shown that , in strawberry
 - ✓ Ripening is not affected by exogenous ethylene
 - ✓ Ethylene biosynthesis inhibitor or action inhibitor do not affect ripening.



Since developing achenes are rich source of auxin, deachened fruits accumulate much more anthocynin than the control and application of auxin to deachened segment results in much reduced accumulation of anthocynins.

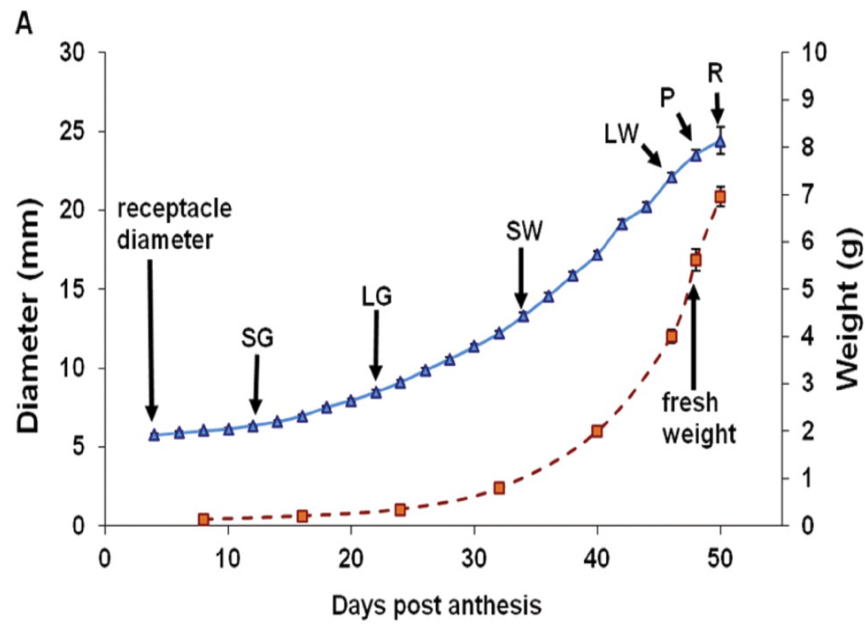
Auxin retard or inhibit ripening related changes.

Grape and citrus are two other nonclimacteric fruits. In grape, auxin treatment retard ripening. Citrus fruit is unusual and carotenoid synthesis in the orange peel is ethylene regulated.

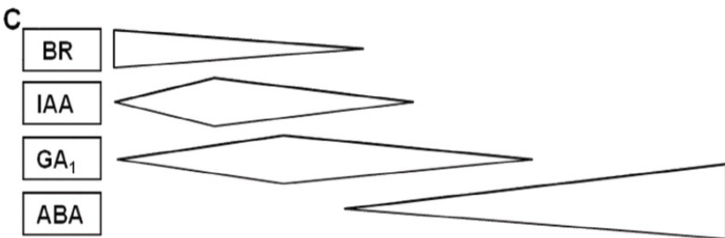
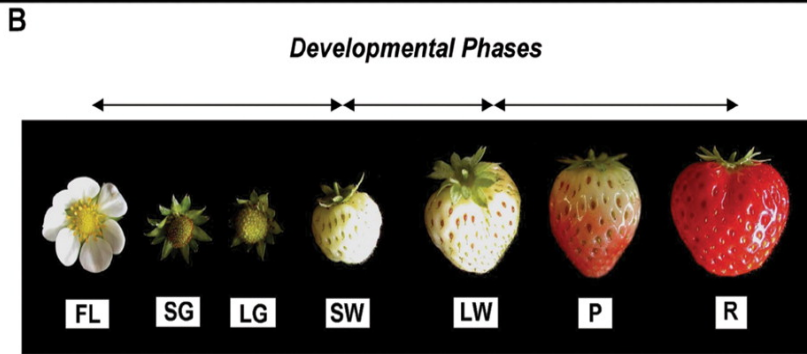


Hormonal changes that occur in a generic fruit during development and ripening. Differential hormone concentrations occur in the seed and the surrounding tissue with the developing seed influencing its environment. Multiple studies have shown that increases in auxin, cytokinin, gibberellin, and brassinosteroid 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.

The spectrum of ripening dependencies to ABA and ethylene. All fruit appear to respond to ABA and ethylene. In historically considered "climacteric fruit," ABA indirectly regulates ripening through ethylene. In "non-climacteric" fruit, the ABA has a more dominant role but the fruit still have ethylene-dependant ripening characters.



The various stages of strawberry fruit development: FL, flower; SG, small green; LG, large green; SW, small white; LW, large white; P, pink/turning; R, red



Texture and softening:

During fruit ripening, softening and textural changes (including the development of juiciness) are components of the suite of modifications that make ripe fruit attractive to animals that might disperse the seeds. The texture of ripe fruit differs drastically between species, with crisp, hard apple and deformably soft avocado representing the extremes. The characteristic textures of different fruit and their manner of softening can be linked both with anatomical features and with changes that occur to the cell wall during ripening

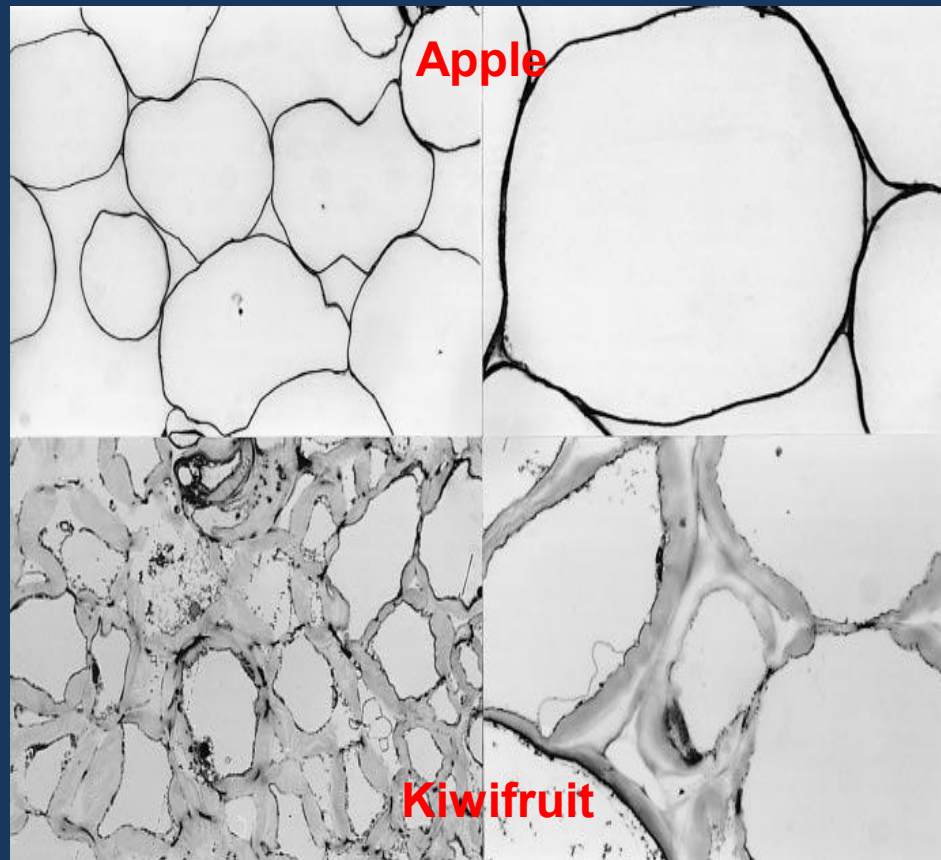
Some fruit that are picked while hard, such as kiwifruit and tomato, will subsequently soften markedly as a result of extensive modifications to the cell wall structure that include substantial swelling. Other fruit, such as apple or watermelon, remain crisp and soften only slightly. Their thin cell walls remain relatively unaltered. Both types of softening occur in the pear family: Asian pear (Nashi) shows a crisp apple-like texture, whereas many European pears soften to give ripe fruit with a melting texture. Interspecific crosses between the two types show that texture is heritable

Many textural characteristics relate to the fate of fruit flesh when it is fractured and crushed in the mouth. Contributing factors include cell size, cell adhesion, turgor and packing, wall thickness, wall composition and the reaction of cells to shearing stress as they are chewed

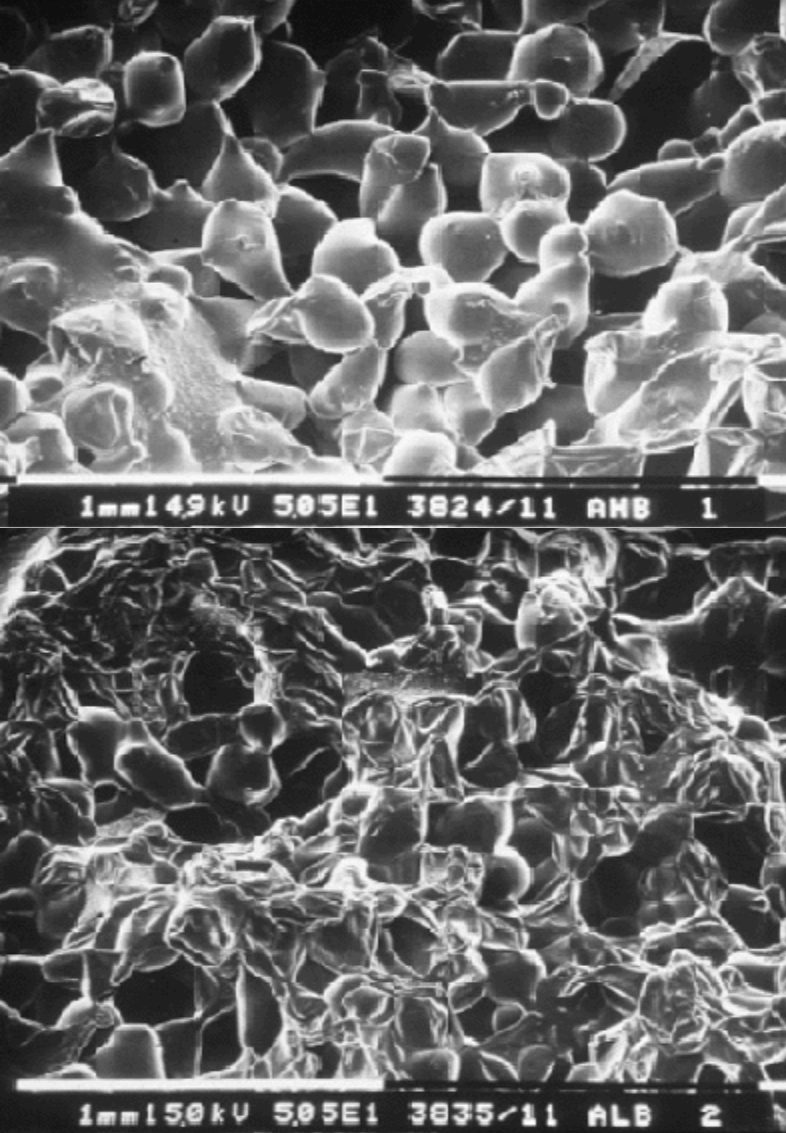
SENSORY TEXTURE ATTRIBUTES AND THEIR DEFINITIONS.

Attribute	Definition
Crispness	Amount and pitch of sound generated when the sample is first bitten with the front teeth
Firmness	Force required to bite into the sample
Initial juiciness	Amount of juice released from the sample in the first three chews, when chewing with the back teeth
Crunchiness	Amount of noise generated when chewing with the back teeth
Ease of breakdown	Amount of chewing required to break down the flesh so that it can be swallowed
Sustained juiciness	Amount of juice released from the sample during prolonged chewing
Pulpiness	Amount of wet, web-like material that develops during chewing
Mealiness	Degree to which the flesh breaks down to a fine lumpy mass
Flouriness	Degree to which the flesh breaks down to very fine dry particles

Anatomical features such as cell size, wall thickness and the distribution of intercellular gas spaces greatly influence our perception of fruit texture and eating pleasure. The apple tissue shows cells having densely staining thin walls. Tissue from kiwifruit shows cells with thick, swollen and weakly staining walls.



A ripe apple has large (0.1–0.3 mm diameter), turgid, thin-walled cells that are loosely packed (airspace c. 20% of fruit volume). When that flesh is chewed, cells fracture and release their sugary contents as free juice. In contrast, ripe kiwifruit has minimal airspace (c. 2% of fruit volume) and cell walls are thick and hydrophilic. Such cells tend to pull apart when the flesh is chewed, resulting in a paste moistened by liquid held in cell walls or released by damaged cells. Avocado also has cells with walls that are thick and soft and which tend to pull apart, but also has a high proportion of oil that gives the pulp an oily quality in the mouth



There are three distinct mechanisms for tissue failure during tensile testing of tissue strength :

- The cells may break cleanly through the equator and abruptly releases the juice from inside each cell (described as cell fracture)
- A small piece of the cell may be pulled off causing the subsequent collapse and release of juice (described as cell rupture)
- Intact cells may separate from neighboring cells without breaking or releasing juice (described as cell-to-cell debonding).

As apples soften, the mechanism of tissue failure changes from cell fracture to cell rupture to cell-to-cell debonding. Fruit firmer than about 15 lb tend to fail by cell fracture, while fruit softer than about 9 lb tend fail by cell-to-cell debonding, and have a mealy texture.

Fracture surfaces of mealy (upper picture) and crisp (lower picture) Braeburn apples. The upper picture shows cell-to-cell debonding while the lower picture shows cell rupturing.

OTHER FACTORS INFLUENCING FIRMNESS, THAT GROWERS AND PACKERS HAVE SOME CONTROL OVER INCLUDE:

Crop Load :

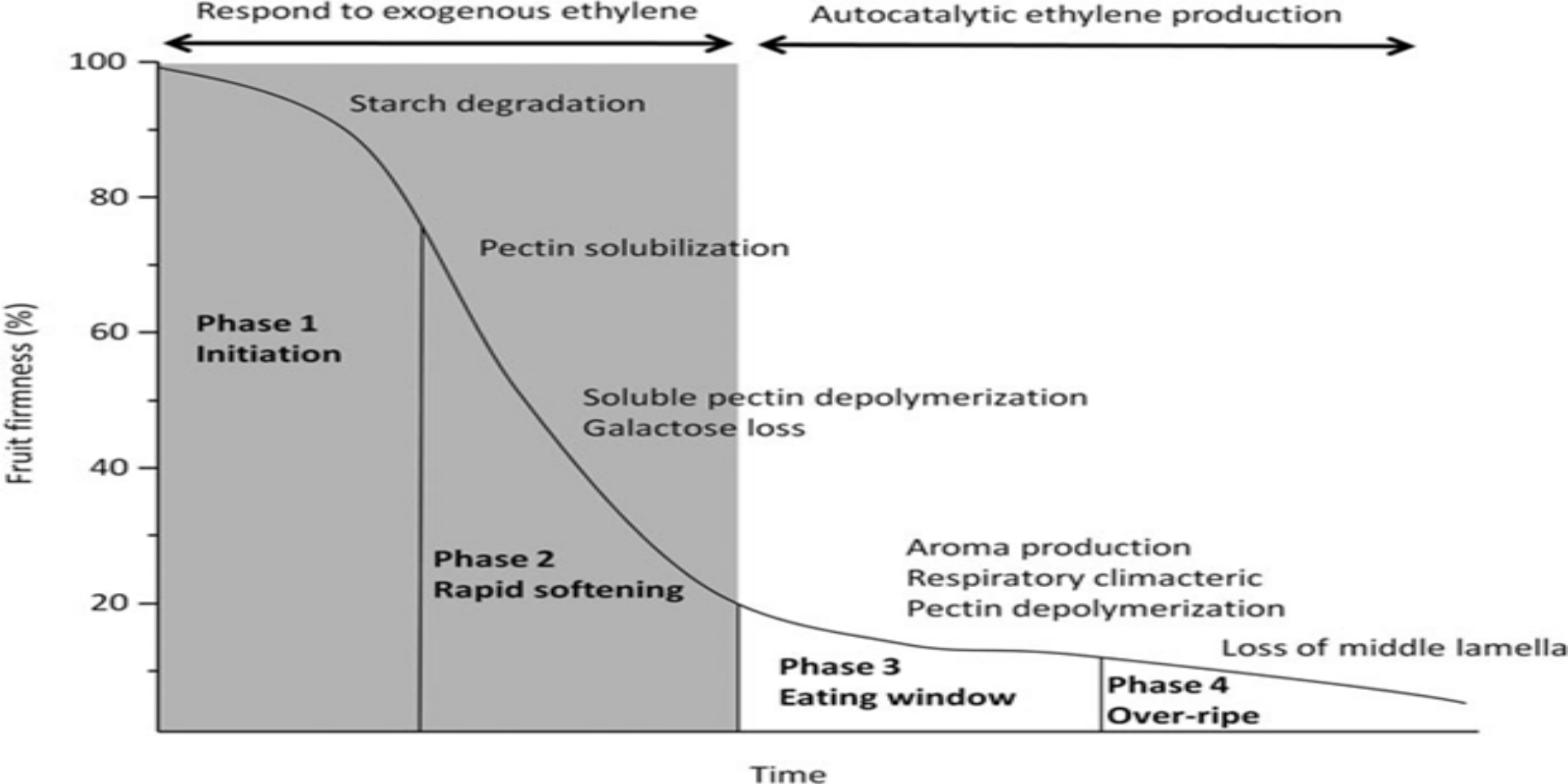
The number of fruit on the tree will influence both fruit size and fruit firmness. Large fruit tend to be softer than small fruit. This influence of size on firmness is generally thought to be a consequence of differences in cell expansion. Large fruit tend to have the same number of cells as smaller fruit, but the cells are larger and exhibit less cell-to-cell contact.

Calcium Content:

Increasing the calcium content of fruit has a beneficial influence on firmness. Postharvest dipping and vacuum infiltration with calcium solutions have had a consistent beneficial effect on maintaining firmness during storage.

Temperature Management and CA Storage:

In general, the treatment of fruit at harvest and during storage has a far bigger impact on the firmness of fruit than the pre harvest factors. Two key factors during storage are temperature and CA conditions. It is likely that the loss of water from fruit during storage, and the associated decline in turgor (internal pressure of cells) may reduce firmness .



Schematic representation of postharvest ripening in kiwifruit, showing the timing of key physiological events. At harvest, fruit do not produce ethylene but are highly sensitive to exogenous ethylene. Softening is initiated (phase 1) and becomes rapid (phase 2). Relatively late in softening, compared with other fruit species, endogenous autocatalytic ethylene production begins, aroma volatiles are produced and fruit become soft enough to eat (phase 3). If fruit progress to the over-ripe stage (phase 4), they become unacceptably soft and exhibit 'off-flavour' notes

Chemical analyses of cell wall components in a range of species, notably kiwifruit and tomato, show some consistent changes during the early stages of ripening. In kiwifruit, these include:

- Solubilisation of pectin (but without further degradation)
- The cell wall swells and shows an increased affinity for water (become more hydrophilic)
- Loss of galactose from pectins (especially of a galactan that is tightly associated with the cellulose microfibrils)
- De-esterification of some pectins.

As softening progresses, two more important changes begin, both of which appear to be regulated by ethylene:

- Depolymerisation (a reduction in size) of the hemicellulosic polysaccharide xyloglucan, which is associated with a reduction in cell wall strength;
- Depolymerisation of pectin, which is associated with dissolution of the middle lamella and reduced intercellular adhesion.

Softening of the Pericarp :

- ✓ Various hydrolases are required for degradation of cell wall and softening of the pulp.
- ✓ EGases expressed during fruit ripening are similar to those induced during abscission. Both are induced by ethylene and are downregulated by auxin.
- ✓ In contrast, EGases expressed during fruit growth are similar to those expressed during stem elongation and induced by auxin.
- ✓ Expansins and XET are belongs to multigenic families, and those expressed during fruit ripening are ethylene induced.

Hemicellulose–cellulose network

Expansins

Xyloglucan endotransglycosylases

Endo-1,4- β -glucanases (EGases or cellulases)

α - and β -galactosidases

Pectin network

Polygalacturonases

Pectin methylesterases

✓ *Pectin solubilisation and cell wall swelling are important events in the control of softening in kiwifruit and probably most other species with a melting texture.*

✓ *Cell wall modification is much less extensive in fruit with a crisp, fracturable texture such as apple and capsicum pepper.*

✓ *As fruit become fully ripe, dissolution of the middle lamella means that it eventually virtually disappears as a visible structure under the microscope. Dissolution of the middle lamella results in a great reduction in intercellular adhesion, and cells now have fewer regions of attachment to each other and become more rounded in appearance as they pull away from neighbouring cells.*

✓ *The primary walls are also weakened by the various changes that have occurred, and cells easily rupture when bitten or chewed, releasing the cell contents as juice.*

Transgenic tomato fruit in which polygalacturonase was suppressed found only a small reduction in softening during ripening, although there was a very substantial increase in the storage life of the fruit. Because transgenic fruits retained firmness for longer, they were left on vines longer, resulting in more carbohydrate accumulation prior to harvest. Moreover, fruit could be harvested partially coloured rather than mature green, thereby allowing ripening processes to progress more naturally and yielding fruit with better flavour and appearance.



Other enzymes viz. pectate lyase, expansin, β -galactosidase and pectin methylesterase making specific contributions to the softening process.

In addition to cell wall disassembly, work in several species has shown that a decrease in cellular turgor accompanies fruit ripening and is an important component of softening.

COLOUR AND FLAVOUR :



Colour diversity in ripe kiwifruit and apple is determined by the presence or absence of chlorophyll, carotenoid and anthocyanin compounds in different fruit tissues.

Colour :

Their bright colour, which evolved to attract dispersal agents such as birds, browsing animals and primates, has now become a particularly important visible indicator of maturity and ripeness.

By analogy with senescence in most green tissues such as leaves, colour change in fruit typically involves chlorophyll loss and an increase in production of yellow, orange, red or purple pigments. (chloroplasts are converted to chromoplasts as is typical for ripening fruit).

The gold, orange and red colours of many fruit such as tomato and citrus are formed by carotenoid. Carotenoids are divided into two classes: the hydrocarbon carotenes, e.g. lycopene (red) and b-carotene (orange); or the oxygen-containing xanthophylls, e.g. lutein (yellow).

Other red and purple pigments of the type seen in grapes, are anthocyanins, which are products of the phenylpropanoid pathway. Anthocyanin pigments are water-soluble, synthesized in the cytosol and localized in vacuoles. Their specific colour is modified by pH, metal ions and co-pigments to produce the subtlety of colours seen in nature

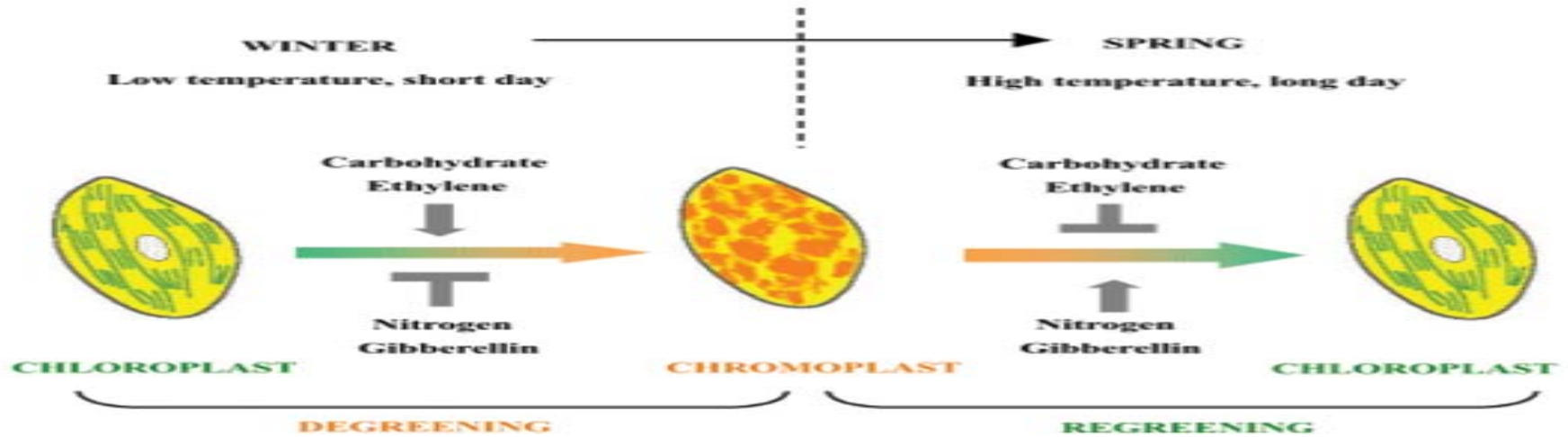


Figure 4. Regulation of color break in citrus fruits. External fruit ripening is dependent upon the conversion of chloro- to chromoplast and involves the progressive loss of chlorophylls and the gain of carotenoids, changing peel color from green to orange. The changes associated with external ripening are influenced by environmental conditions, nutrient availability and hormones. De-greening in subtropical areas generally takes place in mid-autumn when temperatures go down and day length diminishes. Depletion of nitrogen appears to be a pre-requisite for color break but carbohydrate accumulation is thought to stimulate the process. Similarly, ethylene promotes de-greening and gibberellins counteract this process. Interestingly, the chloro- to chromoplast conversion is a reversible processes, even from fully differentiated chromoplasts. During spring, temperature rises and day length increases and these new environmental conditions induce new re-growth that results in nitrogen uptake, carbohydrate utilization and gibberellin synthesis. These changes presumably drive re-greening of the fruit peel.

Regulation of colour break in citrus fruits:

External fruit ripening is dependent upon the conversion of chloroplast to chromoplast and involves the progressive loss of chlorophylls and the gain of carotenoids, changing peel colour from green to orange. The changes associated with external ripening are influenced by environmental conditions, nutrient availability and hormones. De-greening in subtropical areas generally take place in mid-autumn when temperatures go down and day length diminishes. Depletion of nitrogen appears to be pre-requisite for colour break but carbohydrate accumulation is thought to stimulate the process. Similarly ethylene promotes de-greening and gibberellins counteract this process. Interestingly, chloro- to chromoplast conversion is a reversible processes, even from fully differentiated chromoplasts. During spring, temperature rises and day length increases and these new environmental conditions induce new re-growth that results in nitrogen uptake, carbohydrate utilization and gibberellin synthesis. These changes drive re-greening of the fruit peel.

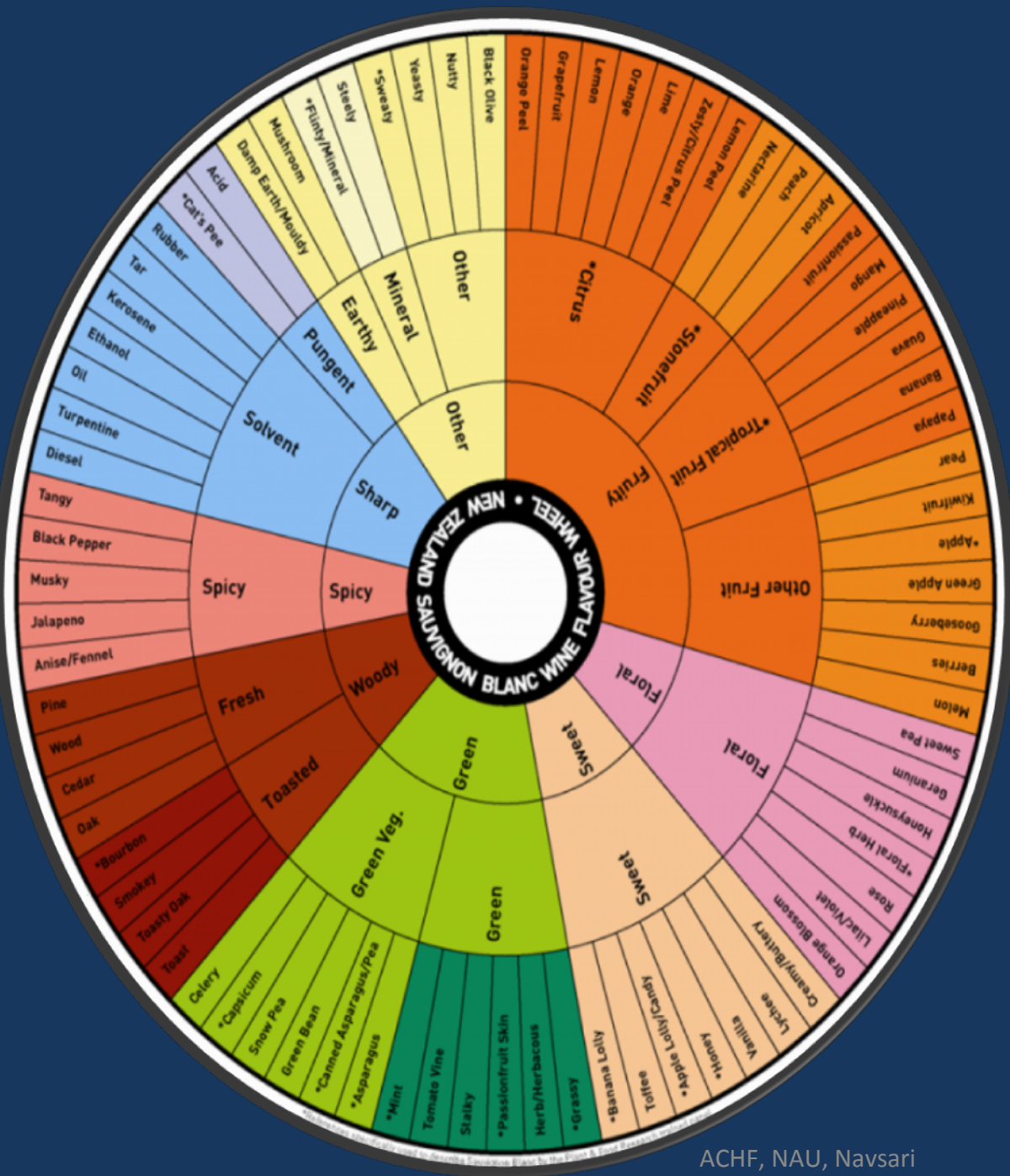
Flavour and aroma:

Two main factors determine a fruit's characteristic flavour – the correct sugar/acid balance and the production of aroma volatile compounds. These volatile compounds can include a mixture of volatile acids, aldehydes, alcohols, esters, terpenoids and aromatics.

Sesquiterpenes and monoterpenes also contribute to fruit flavour and aroma profiles, often by adding 'floral' or 'spicy' top notes.

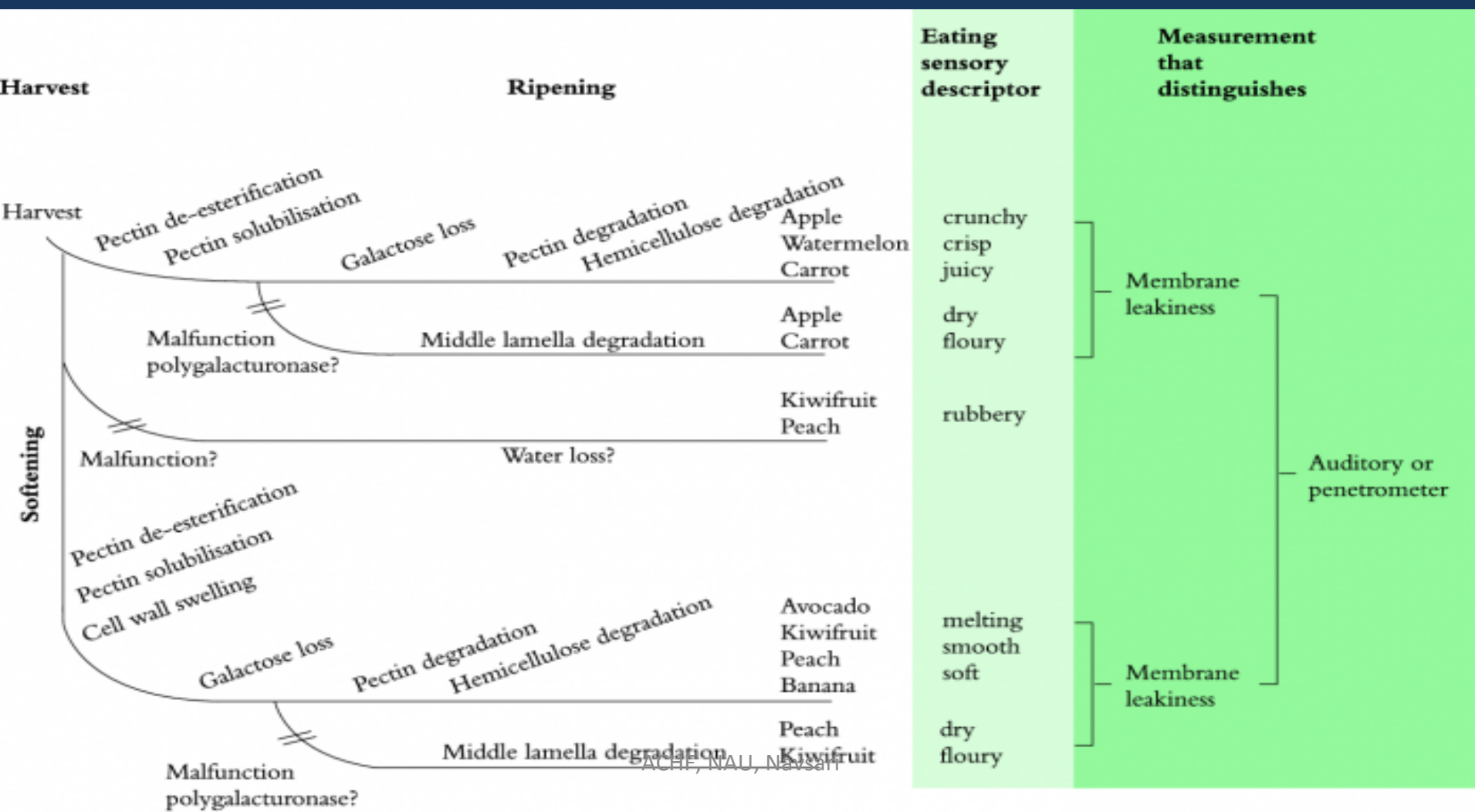
Generally, the absolute concentration of a volatile compound itself does not determine how important it is to perceived flavour and aroma.

Compounds are given odour activity values (compound concentration divided by the minimum concentration that can be detected by the human nose) to show their importance to aroma.

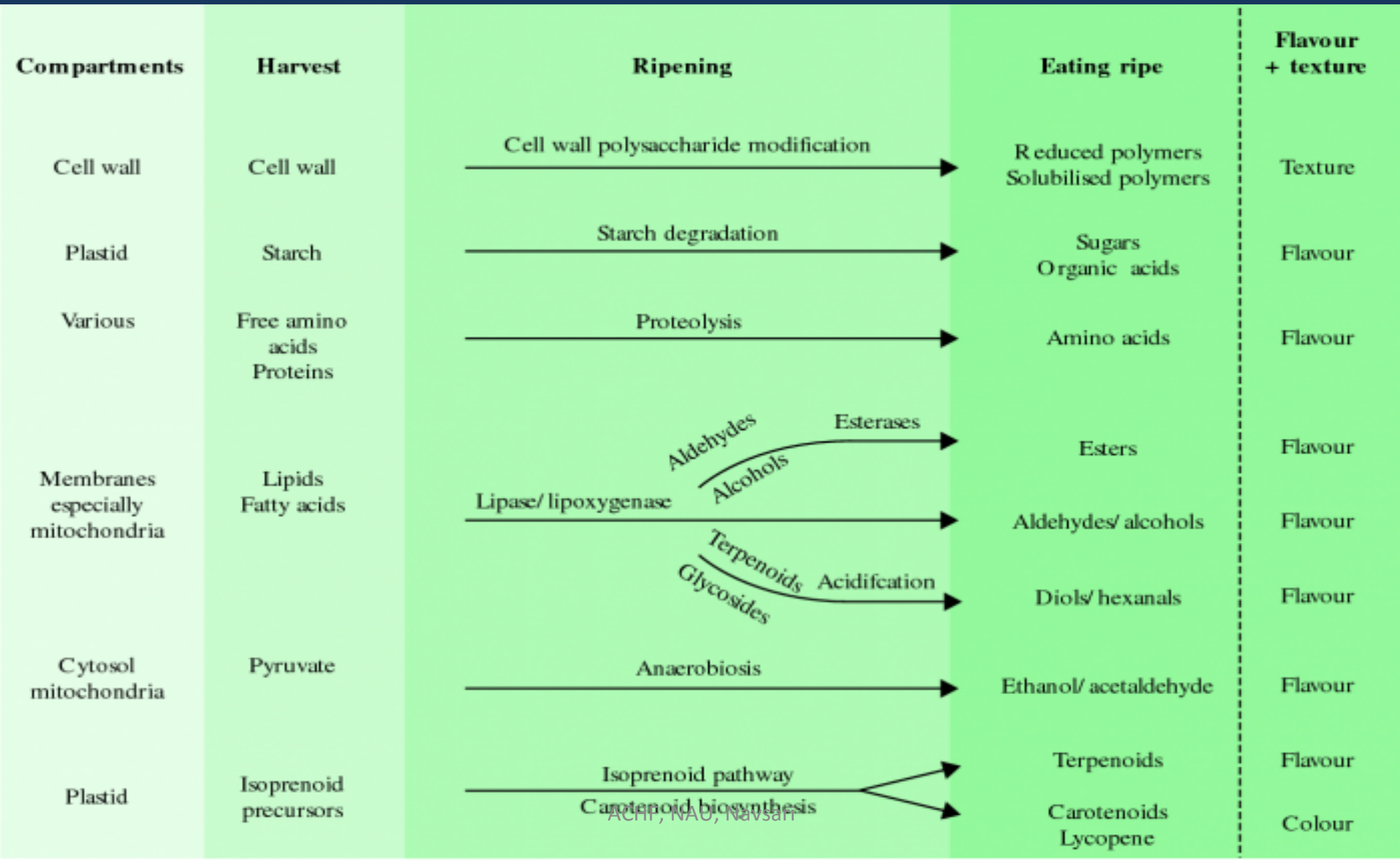


Human taste sensations and experiences play an important part in characterising volatile compounds in fruit and wine, so a vocabulary has been developed to describe their sensory nature. The terms used relate a particular flavour sensation to that of a widely available standard, and have led to terms like 'woody', 'grassy', 'floral', 'spicy' and 'citrus'.

A schematic diagram of ripening processes in different types of fruit that result in distinctive eating qualities. Limited degradation and swelling of cell walls results in turgid cells that burst as the fruit is chewed, giving a crisp and juicy texture. If degradation proceeds further, cell walls become swollen and some cells tend to pull apart as the fruit is chewed, giving a smooth paste in the mouth with a melting texture. If the middle lamella is completely broken down, there is even less release of cell contents and a floury texture is experienced.



A schematic diagram of biochemical changes in different cell compartments as fruit mature, ripen and become edible. Numerous compounds contributed by various processes combine to create the sensory properties associated with texture, flavour and colour that are found attractive.



Extending storage life

Reducing the fruit temperature to slow metabolism. Refrigerated storage slows the rate of ripening and senescence of the fruit, and also slows the development of any rots.

The basic effect of refrigerated storage on fruit can be supplemented by modification of the atmosphere in the cold store, by reducing oxygen and increasing carbon dioxide concentrations.

More recently, the application of the inhibitor of ethylene action 1-methylcyclopropene (1-MCP) has become common to slow the ripening of a range of fruit.

The way in which all these technologies impact on the fruit is dependent on the physiological state, or maturity, of the fruit at harvest. What may be described as a 'correct' physiological state at harvest is not fixed, but may differ dependent on the commercial requirements of the fruit, i.e. a short or long storage period.

- KMnO₄, Ag⁺⁺, STS

Temperature :

‘Best’ temperature can be sharply defined, and may differ between species or even cultivars. To obtain the maximum benefit from cold temperatures, the temperature must be as low as possible without causing damage to the fruit; this is termed the lowest safe temperature. Below the lowest safe temperature, but at non-freezing temperatures, the fruit may develop symptoms of chilling injury.

Temperatures at which chilling symptoms occur are around 8°C for subtropical species and may be anything up to 14°C for some tropical fruit: for example unripe banana and mango need to be shipped at 13–14°C.

At 0°C, respiration is reduced to a level that is just enough to maintain cell function. Sugar is slowly consumed during this process so that fruit with a low sugar content at harvest are less durable.

Timing of cooling after harvest (Field heat),

It is generally considered that the field heat should be removed from fruit as soon as possible after harvest, there are circumstances where delays may be advantageous for the postharvest performance of the fruit. So whilst highly perishable berryfruit tend to be cooled as soon as possible after harvest, kiwifruit and some stonefruit benefit from a delay at ambient temperature before cooling.

Exactly what happens during this delay period is not clear; it may simply be a continued progress of fruit development or the loss of a small amount of water.

However, the delay tends to make the fruit more tolerant of storage at low temperatures.

The rate of cooling :

Simply placing fruit, either in bulk bins or packed, in a coolstore will result in the fruit being cooled, the rate of which will depend on the initial fruit temperature, the cooling capacity of the refrigeration equipment, the airflow in the store and any insulating effects from the packaging, especially if the fruit are packed in boxes with polyliners and held on pallets.

The rate of cooling can be increased by forced air cooling, also termed precooling, in which cold air is actively drawn past the fruit. This is a rapid method for removal of field heat, after which temperature management in a coolstore removes the smaller heat load that results from continued respiratory activity during storage. In some cases fast precooling may induce high incidences of chilling damage.

The expression of chilling injury symptoms may be reduced in long-term storage by intermittently warming the fruit. However, whilst there are numerous reports of such treatments in the scientific literature, the practicalities of the procedure and detrimental side effects to fruit quality make it commercially uncommon.

Relative humidity :

Once harvested, fruit will continuously lose water to a point where quality will be affected. In some species, a small amount of water loss may accelerate ripening (e.g. avocado), but in all fruit there eventually comes a point at which loss of water, usually first seen as shrivelling, results in the fruit becoming unacceptable.

Water loss from the fruit is driven by the vapour pressure gradient between the fruit and the surrounding environment. While the capacity for air to hold water is reduced at low temperatures, there is always a gradient driving water from the fruit into the coolstore atmosphere.

The less fruit there is in a coolstore, the greater the water loss from each fruit before an equilibrium relative humidity is reached.

Water may be lost from the coolstore atmosphere by condensation on the refrigeration coils that are colder than the room atmosphere, and the greater the temperature differential between the coils and atmosphere the greater the loss of water. When storage is at about 0°C, this can be seen by ice developing on the coils that must be removed by defrosting.

Small volume of fruit, high air flow and temperature differential on the refrigeration coil will intensify water loss.

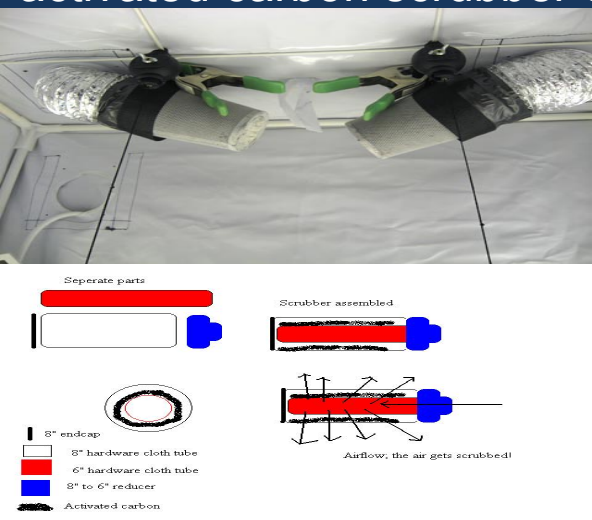
(Packed into fibreboard packs with a polyethylene liner or bag ?)

Controlled and modified atmospheres :

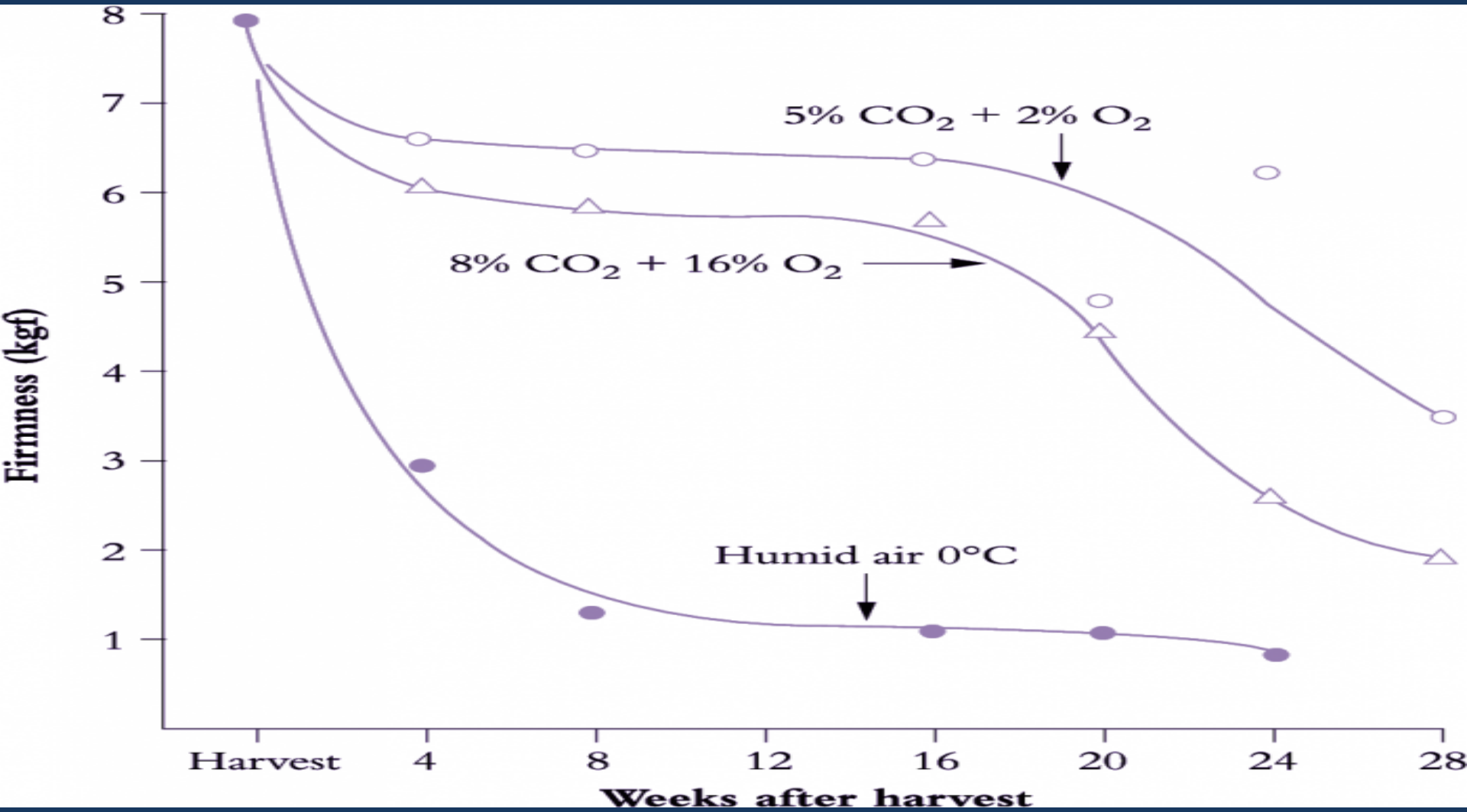
The storage life achievable by refrigerated storage can be extended by modifying the store atmosphere by reducing the oxygen and increasing the carbon dioxide concentrations. Elevated CO₂ and reduced O₂, used either separately or together, can delay ripening and slow the onset of senescence. When both high CO₂ and low O₂ concentrations are combined then the beneficial effects may be additive.

Initial low O₂ concentrations may be achieved through the use of nitrogen generators or O₂ scrubbers, or the fruit may be allowed to reduce the O₂ concentration through respiratory activity. To prevent the O₂ concentration from becoming too low, air can be exchanged with the atmosphere. CO₂ accumulates from respiration, but can be prevented from increasing excessively by absorbing it with lime, by removal with an activated carbon scrubber or by clean throughly from the store with nitrogen.

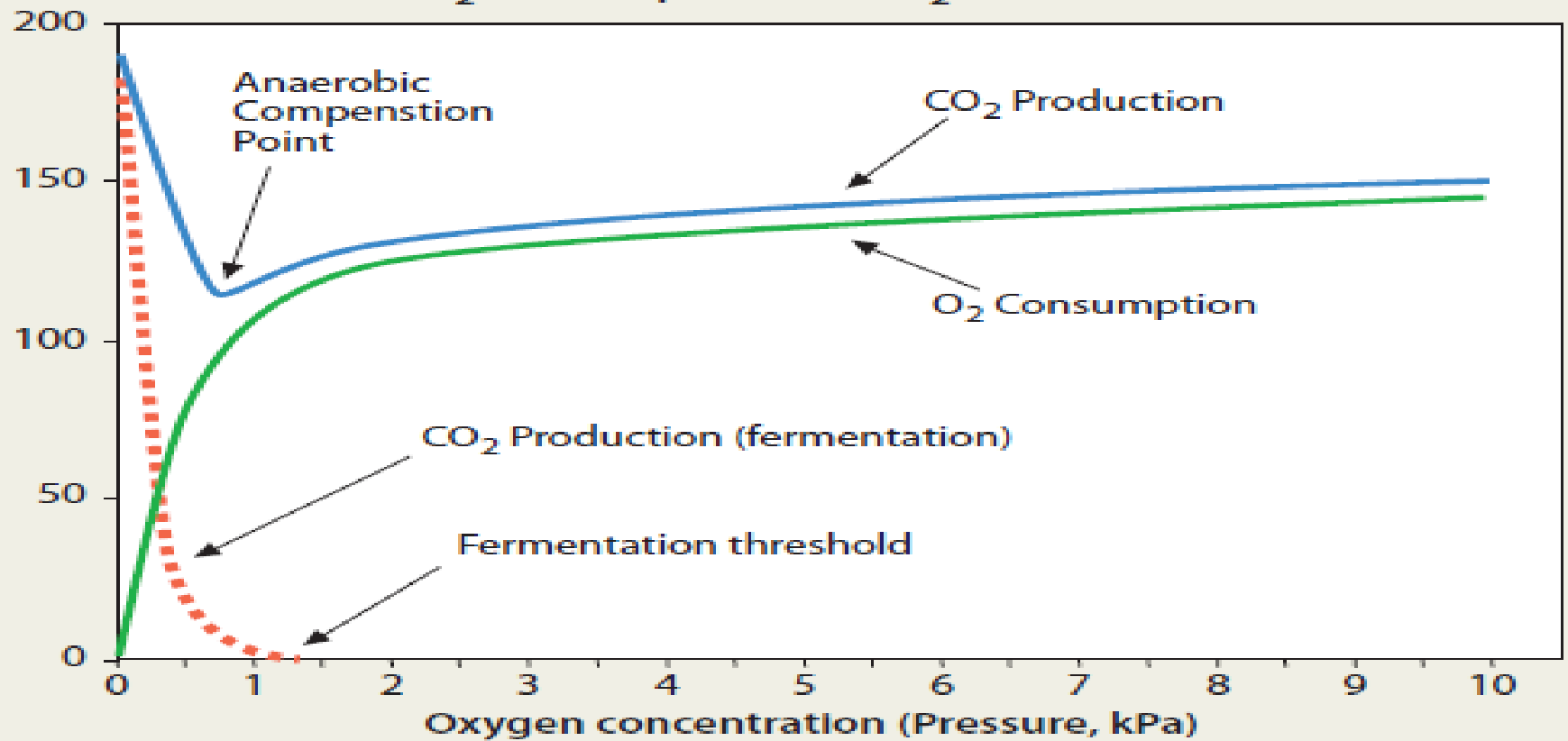
In a closed CA system it is also possible to scrub ethylene out of the atmosphere.



Storage life of kiwifruit can be greatly extended by controlled atmospheres. Under standard conditions (humidified air, 0°C) firmness declines exponentially over time, reaching limited acceptability by 8 weeks. Softening in cold store was slowed and storage life greatly extended by holding fruit in atmospheres containing either 5% CO₂ + 2% O₂ (top curve) or 8% CO₂ + 16% O₂ (middle curve).



Effect of Oxygen Concentration on O_2 Consumption and CO_2 Production



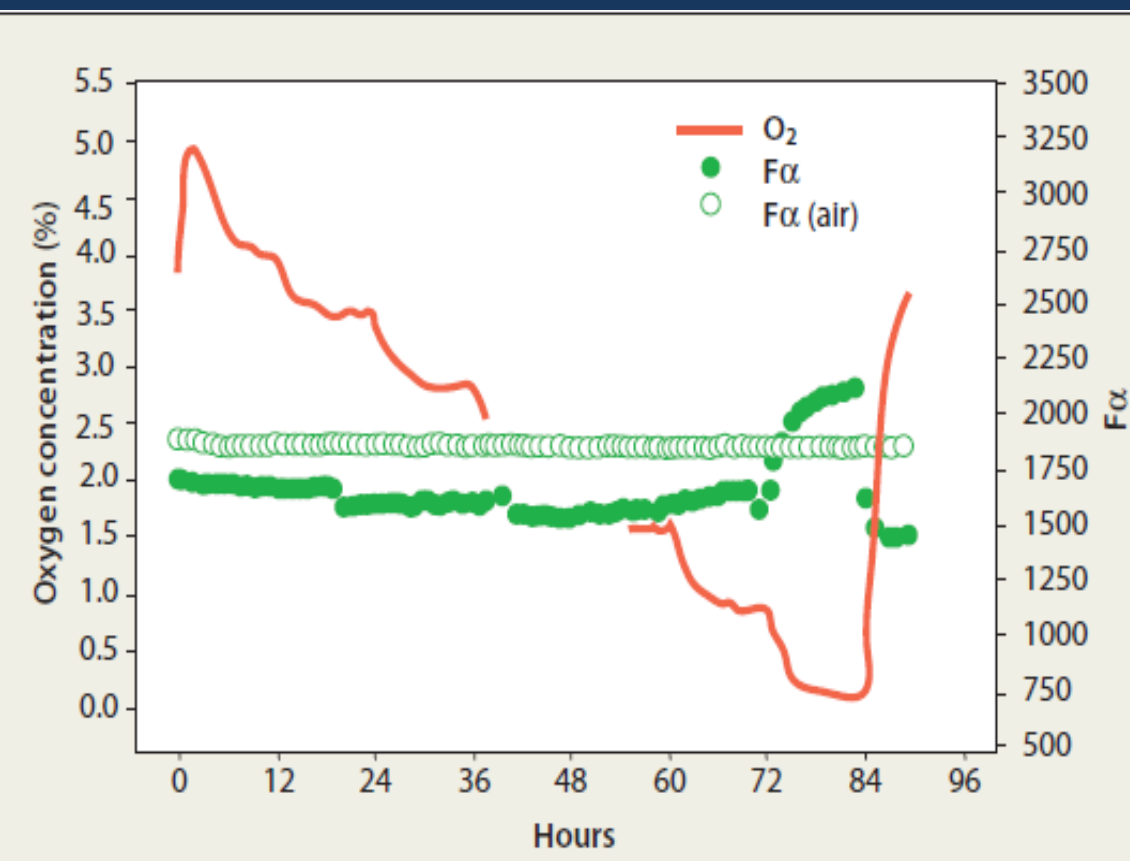
DYNAMIC CONTROLLED ATMOSPHERE STORAGE :

In which the O_2 concentration in the store is determined by the response of the fruit. Dynamic CA optimizes the CA process, since using a predetermined atmosphere tends to make a mistake on the side of safety by setting the O_2 concentration well above the lowest safe level to allow for the variability in low O_2 tolerance amongst fruit from different orchards or seasons.

While early attempts at dynamic CA utilized ethanol sensors to detect if fruit metabolism was becoming anaerobic, it was the development of a fluorescence sensor that could give a rapid measurement of the fruit response to low O_2 stress that allowed the commercialization of dynamic CA.

The sensor is placed over a sample of the fruit in the store, the O_2 concentration is decreased until a response is detected from the fruit and then the O_2 concentration is increased slightly above the low O_2 stress point. The procedure can be repeated throughout the storage period so that the O_2 concentration can be continually matched to the capacity of the fruit to withstand low O_2 .

Chlorophyll fluorescence can be used to measure stress in the apple fruit. As the O₂ level in the storage environment decreases over time, a point is reached when the fluorescence signal increases. The increase is a signal that the fruit is under low O₂ stress. In response, the O₂ level around the fruit can be raised. Relief from stress is reflected in a decrease of the fluorescence signal.



An example of the F α fluorescence signal detected in 'Summerland McIntosh' apples held at 20°C in air (open circle) and in a progressively diminished oxygen environment (dark circle). The spike in F α begins as the chamber oxygen levels fall below 1% at 72 h and continues upward until the oxygen concentration is increased at 84 h (Prange et al., 2003)

Modified atmosphere (MA) storage:

Fruit respiration is used to reduce the concentration of O_2 and increase that of CO_2 inside an enclosed space.

The fruit is prevented from becoming anaerobic by making such enclosures out of plastic films that are partially permeable to O_2 and CO_2 . Both gases come to an equilibrium based on respiration rate, the specific permeability of the film, the surface to volume ratio of the package and the amount of fruit in the package.

This form of storage is highly dependent on being able to control the fruit temperature, since this determines the rate of respiration.

In practice any inability to maintain adequate cold chain conditions can result in fruit spoilage as packages turn anaerobic at higher than desired temperatures.

Coating fruit in waxes or other compounds may act in a similar way to MA, by modifying the gas permeability of the fruit skin, thereby reducing the flow of O_2 in and CO_2 out of the fruit. As with MA, if the restriction of oxygen flow into the fruit is too great, the fruit may turn anaerobic and ferment.

HOW DO ALTERED ATMOSPHERES DELAY RIPENING AND RETARD SENESCENCE?

Fruit respiration is suppressed in response to the changed atmosphere. This could occur via acidification of the cytosol, resulting from an elevated CO_2 concentration redirecting metabolism towards alcohol or lactate/succinate or malate production rather than CO_2 production.

Another alternative is a direct effect of ultra-low O_2 concentrations (<2%) on cytochrome c oxidase in the mitochondrial electron transfer pathway, preventing that enzyme from functioning properly.

YOU CAN'T STORE ALL FRUITS ON SAME LEVEL OF GASEOUS COMPOSITION.

Fruit differ with respect to critical values for tolerance to low O_2 or high CO_2 concentrations, and ideally we might make a model for predicting the tolerance limits for a new cultivar or fruit from specific background information on its physiological behavior.

The critical gas composition exists within the flesh of a fruit, not in the environment around it, while differences in genetic background cause each cultivar to behave differently with respect to metabolism and thus internal gas composition. Species vary in their response to the altered atmospheres of CA, and can even differ according to cultivar and harvest.

Normally, an internal 0.5% (0.5 kPa) partial pressure is the minimum O_2 level tolerable, and 10% (10 kPa) is the maximum for CO_2 .

Blocking ethylene action

Successful use of 1-MCP (1-methylcyclopropene) to delay ripening depends on the physiology of the fruit, most likely on the natural rate of replacement of the ethylene receptors that are blocked by 1-MCP.

Since binding of 1-MCP to existing ethylene receptors is irreversible, a single period of exposure can delay ripening for several to many days, depending on the rate of synthesis of new receptors.

The rapid uptake for apple is associated with the way in which apple fruit ripen, which involves only limited softening and with firmness retention being a key quality component. This contrasts with the physiology of other species in which ripening involves a softening of the fruit coordinated with changes in flavour and colour.

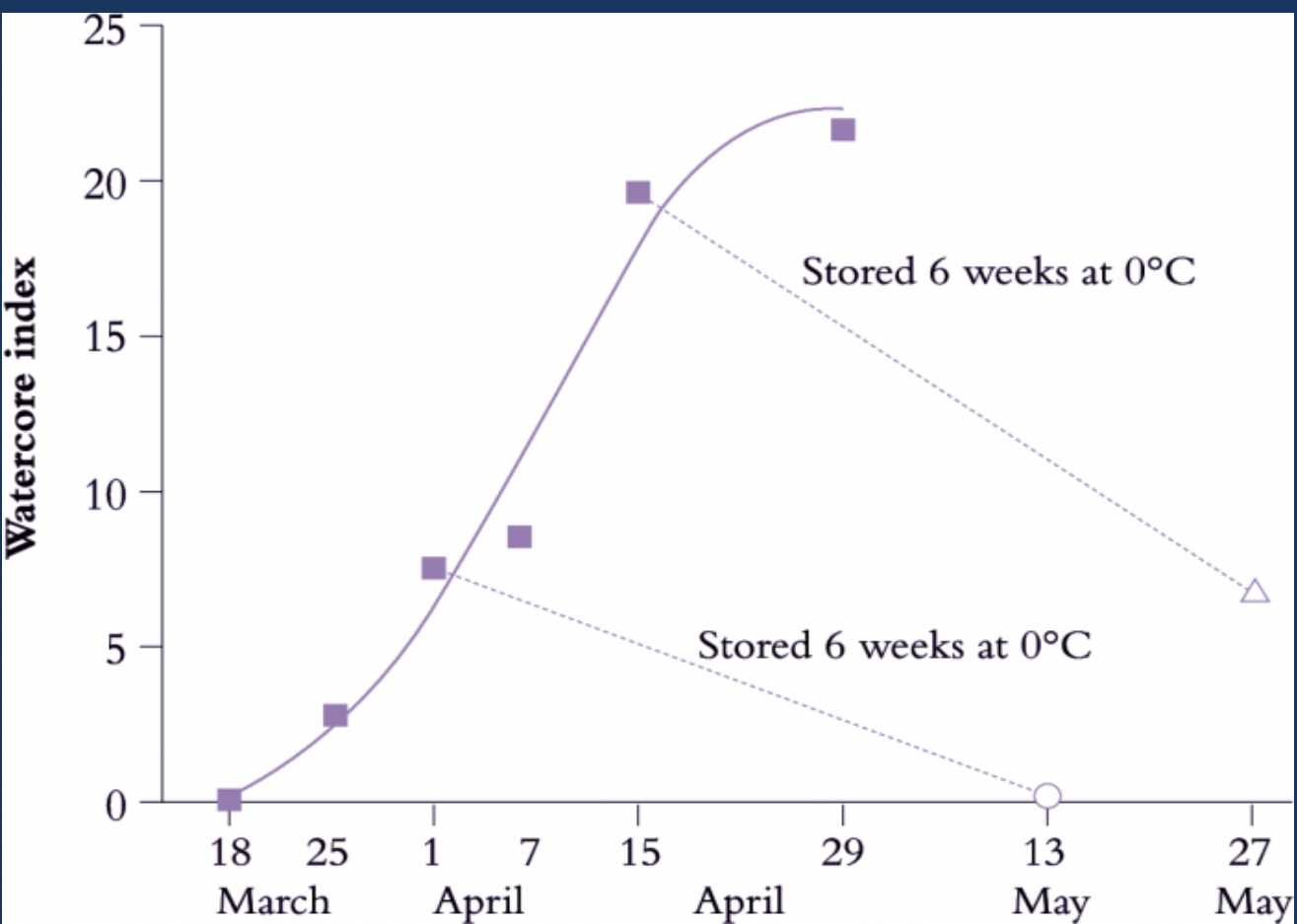
For example, while 1-MCP prolongs storage life in species such as avocado, pear and banana, obtaining uniform ripening afterwards may be difficult. This may be because the softening, flavour, and colour aspects of ripening have varying sensitivities to ethylene that are affected differently by partial suppression of ethylene perception and the climacteric, resulting in poorer flavour and colour.

In stonefruit such as peach, the ripening inhibition is rapidly overcome, and repeated exposure to 1-MCP may be necessary, which can be commercially unfeasible. For all cultivars, careful optimisation of maturity stage, 1-MCP concentration, exposure frequency and duration and storage temperature is required.

STORAGE DISORDERS

Several storage disorders have physiological origins, which may be chilling related, and are often highly specific to species, cultivar, season and even growing region.

Fruit maturity at picking is one important factor with less mature fruit generally being more susceptible to chilling injury.



Postharvest incidence of the storage disorder watercore in Fuji apple is related to picking date. Watercore index represents the percentage fruit volume occupied by water-soaked tissue. Fuji is prone to this disorder, especially when fruit are picked mature. Early harvesting thus becomes an important control method.

Other factors :

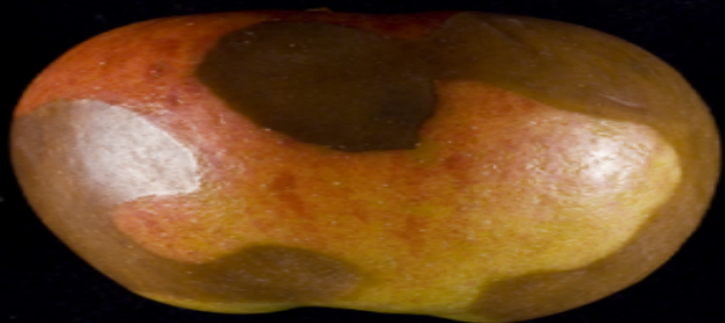
- ✓ A lack or imbalance of nutrients and adverse growing conditions.
- ✓ Even if fruit are susceptible at harvest, the expression of disorder symptoms is dependent on storage conditions and duration, and symptoms may not always develop.
- ✓ The development of chilling injury is often described as a time by temperature relationship, i.e. it develops sooner at lower temperatures. This is true for damage that is a direct result of exposure to low temperature and which is seen almost immediately after exposure.
- ✓ However, many chilling disorders develop only after long periods in storage and are associated with an inability of fruit to ripen correctly at low temperatures (e.g. kiwifruit, peach, avocado).
- ✓ It seems that at low temperatures the natural highly co-ordinated process of ripening is disrupted by an element that is temperature sensitive. If removed from storage early enough, no symptoms of chilling develop when the fruit ripens at higher temperature.



Bitter pit, a disorder associated with calcium deficiency. It can be partially controlled by pre harvest sprays of calcium salts directly onto the fruit.



Superficial scald, a low temperature disorder of the skin that can be controlled by 1-MCP treatment prior to cool storage.



Soft scald, a low temperature disorder with symptoms of brown lesions that extend into the flesh. Incidence can be increased by over-maturity of the fruit at harvest and preharvest climatic conditions.



Core flush, a browning within the core line, that is a form of senescent breakdown.



Uneven ripening- early harvested fruit might not ripen properly after prolonged cold storage.



De-greening- Slowing the loss of green color even by slight cooling



water soaking- exposure to cold of leafy vegetables and some fruits like papaya



Increasing the sensitivity to pathogens- chilling injury damage the cellular compartments and results the release of amino acids, sugars, minerals and other factors that serves as excellent substrates to pathogens

Thank You