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Physiological and biochemical interactions for extending the shelf life of fruits and vegetables: A review

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Abstract

Postharvest Physiology is the scientific study of the physiology of living plant tissues after they are denied further nutrition by picking from the parent plant. About one -third of the fruits produced worldwide are never consumed by humans due to loss at various stages and the loses are generally more in developing countries in comparison with developed countries especially when compared between production and retail sites (Kader 2005). Fruits, in general, show two distinctive respiratory patterns during ripening and on this basis fruits are categorized into climacteric and non-climacteric groups (Kader and Barrett 2003). Post-harvest physiology has direct applications to postharvest handling in establishing the storage and transport conditions that best prolong shelf life, for example 1- Methyl Cyclopropene (1-MCP) is an inhibitor of ethylene perception that can delay or prevent ripening and senescence processes in plant tissues (Sisler and Serek, 2003). Pre harvest factors also effect the post-harvest life of fruits and vegetables. Controlled atmosphere storage has been shown to be effective in reducing the post-harvest losses and prolonging the life of the produce by proper management of respiration via alteration in the gaseous composition and storage temperature. Proper understanding of the biochemistry and the underlying physiological factors will go a long way in minimising the post-harvest losses and thereby improving the socio-economic condition of the farmers particularly in the developing countries.

Keywords: Postharvest physiology, biochemical interactions, fruits, vegetables, postharvest handling

Introduction

The scientific study of the physiology of living plant tissues after they have denied further nutrition by picking is known as Postharvest physiology. It has direct applications to postharvest handling in establishing the storage and transport conditions that best prolong shelf life. An example of the importance of the field to post-harvest handling is the discovery that ripening of fruit can be delayed, and thus their storage prolonged, by preventing fruit tissue respiration. This insight allowed scientists to bring to bear their knowledge of the fundamental principles and mechanisms of respiration, leading to post-harvest storage techniques such as cold storage, gaseous storage, and waxy skin coatings. Another well-known example is the finding that ripening may be brought on by treatment with ethylene. The fruit processing industry is one of the major businesses in the world. While basic principles of fruit processing have shown only minor changes over the last few years, major improvements are now continuously occurring, and more efficient equipment capable of converting huge quantities of fruits into pulp, juice, dehydrated, frozen, refrigerated products, etc. make possible the preservation of products for year-round consumption. The fruit processing and storage, even under the most industrially available-mild conditions, involves physical and chemical changes that negatively modify the quality. These negative or deteriorative changes include enzymatic and non-enzymatic browning, off-flavour, discoloration, shrinking, case hardening, and some other chemical, thermo-physical, and rheological alterations that modify the nutritive value and original taste, color, and appearance of fruits. The ability of the industry to provide a nutritious and healthy fruit product to the consumer is highly dependent on the knowledge of the quality modifications that occur during the processing. In postharvest, fresh harvested food crops can be considered isolated small scale systems. Postharvest research aims to understand the quality of these systems as influenced by postharvest conditions. The phenotypic quality of horticultural produce is based on genetic traits that are expressed through a cascade of reactions subject to complex regulatory mechanisms and diverse environmental conditions. Ultimately, to fully understand postharvest phenomena, a systemic approach that links genetic and environmental responses and identifies the underlying biological networks is required. Thanks to the development of high through putomics techniques such system-wide approaches have become a viable option to support traditional postharvest research (Hertog *et al*., 2011) [4]. The structure of a biological system is defined by its physical parts e.g., tissues, cells, organelles and their composition e.g., DNA, proteins, metabolites, lipids. Their behaviour involves inputs e.g., external stimuli such as light, temperature, atmospheric composition, pH and nutrient levels and internal stimuli such as proteins, metabolites, hormones and various other compounds that might act as signal molecules, processing e.g., via catabolic and anabolic pathways, or processes such as gene expression, differentiation and cell division and outputs of material e.g., proteins, metabolites, information e.g., transcripts or energy e.g., heat, ATP, movement. Finally, a biological system is characterized by a high degree of interconnectivity between its various parts, showing both functional relationships e.g., through metabolic, signalling and gene regulation pathways and structural relationships between each other e.g., through compartmentalisation, receptor molecules, membrane transporters, plasmodesmata, vascular tissue, and the cytoskeleton. Systems biology relies on a multidisciplinary approach to integrate data from various disciplines of biology (Friboulet and Thomas 2005) [3] bringing together molecular disciplines e.g., genetics, biochemistry, molecular biology with those involving more complex systems e.g., cell biology, microbiology, plant or human physiology. The aim of systems biology is to link the quantitative data in a mathematically defined sense across the different scales of biological organization from DNA, RNA, protein to cell, tissue, organs. Mathematical modelling is used to drive integration with an aim of reaching a unified understanding of biological systems (Hertog *et al*., 2011) [4].

Role of post-harvest physiologists

1. To minimize post-harvest losses of horticultural crops.
2. To maintain nutritional value of the product.
3. To ensure safety of the product.
4. To maintain market value.

Harvested produce is subjected to various stresses

1. Wounding
2. Physical pressure
3. Low temperature
4. Altered atmosphere
5. Pathological stress
6. Physiological stress

Deterioration & Death (Senescence)

Senescence or biological ageing is a gradual deterioration of function characteristic or most complex life forms, arguably found in all biological kingdoms, that on the level of the organism increases mortality after maturation.

Approximately 33% of all harvested products worldwide are discarded prior to utilization, due to:

a) Senescence
b) Stress responses
c) Pathogen activity
d) Insect attack
e) Mechanical damage

Control of post-harvest losses

Almost all postharvest technologies manipulate metabolism of the harvested product by inhibiting respiration rate of the product and ethylene action.

Respiration

Fruits and vegetables are living tissues and they should be alive in order to maintain their keeping qualities. Like all living entities, they respire, consuming oxygen and liberating carbon dioxide. The principle task of the respiratory process is production of energy needed for various metabolic activities. They rely on organic matter that generally is replenished during growth. Upon removal from the mother plant, the fruits and vegetables are cut off from their normal supplies of water, minerals and organic matter, provided to them from other parts of the plant. The produce, however, remains capable of continuing a wide range of metabolic activities, breaking down stored organic matter in order to meet energy requirements. Some of these physiological activities are highly desirable for the attainment of the optimum eating qualities: example, ripening of fruits like banana, mango, papaya, pineapple, etc. These activities also are desirable because they help to maintain the vigour of the tissue and provide a kind of defense against attack by spoilage organisms. Otherwise, they are less desirable and unnecessarily result in loss of stored organic matter. But, however undesirable they are, they still have to be continued at some minimal level in order to maintain quality. The primary physiological activity in fruit and vegetable tissues is respiration, which is the complex process of oxidation of organic matter (starch, sugars, acids, fats, proteins, etc.) to simpler molecules, such as CO2 and H2O with the concurrent production of energy and other intermediate products. The undesirable consequences of respiration in produce are:

I. Loss of food value (stored organic matter is degraded).
II. Hastening of senescence (process of aging).
III. Loss of saleable weight.
IV. Reduced quality (usually after a ripening process for fruits).

On the other hand, respiratory activity has several desirable functions

I. It provides the energy for numerous metabolic processes.
II. It provides valuable intermediates.
III. It maintains tissue vigour (Hosahallis ramaswamy)

Factors influencing respiration

Respiration is the most important physiological activity and has a direct bearing on produce quality. The deterioration of produce quality increases rapidly with the respiration rate. However, respiration rate is not an absolute index of quality deterioration rate because commodities with the same respiration rates can have a different storage life. Other factors influence produce respiration: temperature, commodity, variety, maturity, climacteric behaviour, availability of oxygen, presence of carbon dioxide, ethylene, growth regulators and others (Stresses, Injuries, etc.). Some of these are discussed below.

Temperature

Temperature is perhaps the most important factor influencing respiration rate. The respiratory process involves coordinated activity of several enzymes and hence the temperature influence on respiration somewhat resembles that on enzymes. However, since several enzymes act simultaneously, conditions limiting any one enzyme could limit the respiratory activity. Generally, with every 10°C rise in temperature, the respiration rate increases about twofold.

Temperature Quotient of Respiration (Q10)

It is an indicator of the temperature sensitivity of respiration rate based on Vant Hoff‵s Law: Simple Relationship:

Q10 = R (T+10°C)/R (T)

Where, R (T): Respiration rate at T°C R (T + 10°C): Respiration rate at T + 10°C

More General Relationship

Q10 = [R2/R1] {10/ (T2 – T1)}

where R2: Respiration rate at T2 R1: Respiration rate at T1 While chemical reactions may be characterized by a single Q10 over a broad range of temperatures, the Q10 concept for respiration and postharvest quality changes is applicable only in narrow temperature ranges because of the complex reactions involved. Q10 for the respiration rate can be calculated either by taking the ratio of respiration rate between two successive temperatures differing by 10°C or by taking the slope of the log Respiration rate (R) vs Temperature (T) curve.

Commodity, Variety and Stage of Maturity

Respiration rates differ for different commodities. The rates relate in general to the structure of produce. Leafy and tender vegetables (spinach, peas, corn, broccoli) have very high rates of respiration while sturdy vegetables like potatoes and onions will have a lower rate. Again, with fruits, the ones with well-developed skin (apple, orange, melons, etc.) will have rates of respiration lower than those that are soft skinned (strawberries and raspberries). The respiratory activity is higher at higher temperature for each commodity. In general, with the type of tissue or organ, the rate of respiration is highest with leaves, followed by ―regular‖ fruits and vegetables and is lowest with root vegetables. Generally, smaller size produce has a higher respiration rate than the larger type. The respiratory activity generally also is high in the developing stage and gradually decreases as the tissue matures. In some fruits, the respiratory pattern is characterized by the appearance of a peak with reference to CO_2 or ethylene production generally coincident with the onset of ripening or senescence (on or off tree). These fruits are called climacteric fruits. Others which do not show this characteristic behaviour are called non-climacteric fruits. Examples of fruits demonstrating climacteric behaviour are apples, apricots, bananas, cherimoyas, mangos, papayas, pears, plums, etc. Cherries, grapes, oranges, raspberries and strawberries are examples of non-climacteric fruits. The incidence of the peak respiration rate of climacteric fruits varies with the commodity.

Nature of the Substrate

The nature of the respiration process—i.e., the amount of O_2 consumed and CO_2 released depends on the type of substrate, as can be seen from the following equations:

1. Glucose C6H12O6 + 6O2 = 6CO2 + 6H2O + Heat
2. Malic acid C4H6O5 + 3O2 = 4CO2 + 3H2O + Heat
3. Stearic acid C18H36O2 + 26O2 = 18CO2 + 18H2O + Heat

While here is a one-to-one correlation between O2 consumed and CO2 liberated with glucose as the substrate, the oxygenated substrate such as organic acids (malic acid) will need less oxygen because of the higher oxygen to carbon ratio. Oxygen-limited long-chain fatty acids (stearic acid) will need more oxygen because of their lower oxygen to carbon ratio. The ratio of CO2 produced to O2 consumed is termed the-Respiratory Quotient (RQ)‖ and often is used to identify the nature of the respiring substrate: Respiratory Quotient (RQ) = CO2 produced/O2 consumed RQ generally is 1 for simple carbohydrates, > 1 for organic acids (1.33 in example 2 for malic acid) and < 1 for fatty acids (0.7 for stearic acid in example 3). Oxygenated substance like organic acids generally have an oxygen to carbon ratio more than 1 in their molecule, and hence require less O2 for respiration. On the other hand, the long chain fatty acids have less oxygen per carbon (ratio less than 1) in the molecule, and therefore require more oxygen for the respiratory process. RQ may have some implications in postharvest storage especially in terms of interpretation of respiration rates. Unusually high RQ values with normal substrates may indicate onset of anaerobic respiration, while unusually low RQ values may suggest incomplete oxidation to CO_2

Availability of Oxygen

Respiration can take place with (aerobic) or without (anaerobic) oxygen. Anaerobic respiration generally is undesirable because of the production of off flavours. Oxygen levels higher than in air (21%) do not necessarily increase respiration rate while levels below 20% decrease the respiration rate. The minimum oxygen level necessary to maintain aerobic respiration in a storage chamber is called the Extinction Point (EP). Storage chambers should have proper ventilation to maintain O_2 levels above the EP. Waxing of produce alters the skin porosity and rates of diffusion of O_2 into and CO_2 out of the produce. In effect, it reduces the availability of O_2 to the tissue thereby permitting microrespiration, which offers potential for improving produce storage life. Care must be taken to ensure that the diffused O2 stays above the EP level. Similar precautions must be taken while establishing CA storage facilities.

Presence of Carbon Dioxide

CO_2 is a product of respiration, and excess CO_2 favours suppression of respiration. Generally, CO_2 concentrations up to 5% have a beneficial effect in minimizing respiration, while in higher concentrations CO_2 also has a fungicidal effect. However, the produce must be tolerant of the high CO2 level. Strawberries can tolerate short-time exposure to high concentrations of CO2 and hence are generally transported under a high CO_2 environment to suppress mould growth.

Ethylene

Ethylene is a physiologically very active compound even in trace amounts. It has a profound influence on the rate of respiration as well as on ripening of fruits. It is commercially used as a ripening agent and is produced in trace amounts as a result of respiratory activity. Storage systems, therefore, must have appropriate devices (for example, KMnO4, activated charcoal) to scrub ethylene. With climacteric fruits, the respiratory peak (level) usually is not much influenced, but the peak occurs at an earlier date (time shift) with an increase in ethylene concentration. With non-climacteric fruits, however, the rate of respiration is dramatically increased with the application of ethylene.

Growth Regulators

Several growth regulators used in pre- and postharvest applications influence product quality as well as respiration rates. Examples are: delayed or accelerated ripening (Alar); higher yield, greater disease resistance (GA); improved colour (Alar); prevention of abscission (NAA); sprout inhibition (MH); and fruit thinning (NAA, Ethephon).

Other Stresses

Injury (chilling injury, freezing injury, physical and mechanical damage) to produce tissue results in hastening of respiration rates. This permits the normally isolated enzymes and substrates present in the food systems to come into contact with each other thereby triggering various biochemical reactions, such as browning, tissue softening, etc. (Hosahalli s. ramaswamy)

Control measures to minimize respiratory losses

a) Temperature control

1. Harvest at cool times;
2. Cool down and transfer produce to cold store as fast as possible;
3. Maintain lowest permissible temperature (beware of chilling and freezing injury!);
4. Maintain the cold storage properly (good air circulation and refrigeration).

b) Maturity

1. Harvest vegetables at stage appropriate for intended use;
2. Harvest fruits at mature but at sufficiently pre climacteric stage.

c) Reduce availability of oxygen

1. Use controlled atmosphere (CA) storage (lowered oxygen level);
2. Apply appropriate wax where permissible.

d) Add carbon dioxide to environment

1. Use CA storage;
2. Use excess CO_2 where permissible.

e) Ethylene

1. Avoid ethylene-producing chemicals on produce intended for long storage;
2. Scrub ethylene form storage rooms.

f) Others

Handle the produce with care, to avoid physical damage.

g) Aerobic oxidation of glucose

In simple terms, the aerobic oxidation of glucose can be represented by its conversion to carbon dioxide and water with the liberation of heat (exothermic reaction). During aerobic oxidation, glucose combines with oxygen to produce carbon dioxide, water and heat, as represented in the equation:

C6H12O6 + 6O2 = 6CO2 + 6H2O + Heat

h) Biochemical Pathways

The earlier equation representing glucose oxidation is only a simplified overall reaction. The biochemical reactions go through a sequence of metabolic pathways trapping the liberated energy as ATPs in several stages. Oxidation of glucose follows two major biochemical pathways: The EMP pathway or glycolysis and The TCA (tri-carboxylic acid), Krebs or citric acid cycle.

Glycolysis or EMP Pathway

Glycolysis refers to the conversion of glucose to pyruvate. EMP stands for Embden Meyerhof-Parnas. The enzymes in the initiation and propagation of glycolysis are known as -kinases. These enzymes catalyze phosphorylation reactions. The first step is the conversion of glucose to glucose-6 phosphate, a phosphorylation reaction catalyzed by the enzyme hexo-kinase meaning it is the kinase enzyme acting on a hexose, glucose in the above example, leading to glucose-6- phosphate which exists in isomerism with fructose-6-phosphate. The next step is the further phosphorylation to fructose-1-6-diphosphate by the enzyme phospho-fructo-kinase or PFK in short. This is a key enzyme in the glycolytic process. Plant cells control their energy supply by controlling the activity of this enzyme. Enzyme PFK is inhibited by the presence of excess ATP, although it actually needs energy from ATP for some phosphorylation reactions. What follows a series of reactions resulting in splitting of the six-carbon glucose to three carbon glyceraldehyde, which goes through transformations and dephosphorilation leading to the formation of pyruvic acid. Following the reactions carefully, one will notice that this series of reactions results in only a small gain in energy with only eight net ATP`s being formed. But an important point is that the reactions do not require oxygen. They can proceed even in the absence of oxygen. The reactions that follow glycolysis, however, differ widely based on the presence or absence of oxygen.

TCA, Krebs or Citric Acid Cycle

The TCA/Krebs cycle breaks down pyruvate to carbon dioxide and water and traps the energy in the form of ATPs. It is a complex series of reactions with several key enzymes and coenzymes. Most of the energy is trapped by the action of dehydrogenase enzymes that assist in removing a molecule of hydrogen and adding it to an atom of oxygen to give water (basically a process of oxidation). But it is not a simple process of removing molecular hydrogen and adding it to atomic oxygen. This happens with a chain of events involving the transfer of electrons in the mitochondria through what is called an-electron transport system. The net gain from glycolysis and the TCA cycle is 38 ATPs. Several nucleotides assist in this energy transformation: NAD-Nicotinimide adenine dinucleotide (old name DPN, Diphospho pyridine nucleotide); NADP-Nicotinimide adenine dinucleotide phosphate (old name TPN, Triphospho pyridine nucleotide); FAD-Flavin adenine dinucleotide; GDP—Guanosine diphosphate; GTP-Guanosine tri-phosphate. The oxidation process (removal of H) in the electron transport system goes from NAD to FAD, cytochrome and finally to oxygen for the formation of water. The net number of ATPs synthesized varies depending where the process enters the electron transport system. From the NAD step 3 ATPs are accumulated (6 per glucose molecule); from the FAD step, only 2 ATPs result (4 per glucose molecule). In addition to providing the energy, the TCA cycle also provides the carbon skeleton in the form of citric, oxalic, fumaric and succinic acids, all of which occur in considerable amounts in fruits. The usual substrates for respiration in plant tissues are the carbohydrates and organic acids, which apart from being relatively abundant, generally are utilized in preference to other possible energy sources such as fats, proteins, etc. However, the breakdown products of these other macromolecules also can enter the Krebs cycle upon breakdown by various processes into simple compounds. For example, starch may be degraded by enzymes to glucose and then goes through the usual glycolysis and Krebs cycle. Pectic substances get broken down to galacturonic acid and then to glucose. Fats are converted to glycerol, and then to pyruvic acid before entering the Krebs cycle. The fatty acids from the fat will enter the citric acid cycle through the acetyl coenzyme A. Proteins are degraded to amino acids and enter the chain at different points like alanine, serine and cysteine via pyruvic acid, aspartic acid, tyrosine, phenyl alanine via oxaloacetate and citric acid. Pentose Phosphate Pathway The metabolic scheme outlined above, though probably the most common pathway for carbohydrate metabolism in plant tissue, is not the only one which is known to occur. In some cases the citric acid or TCA cycle may be short-circuited by formation of glyoxylic acid from isocitric acid which in the presence of acetyl coenzyme A forms malic acid directly (glyoxalate shunt). The pentose phosphate pathway is another route for the metabolism of glucose. The glucose (or hexose) entering the cycle exits as a pentose; in other words, each time the cycle is repeated, only one of the six carbon atoms is deleted as CO2 or only one out of six glucose molecules becomes completely converted to CO2 and H2O. It is a physiologically important pathway because it provides 5—carbon skeletons (pentoses) for nucleotide synthesis. It is slightly less efficient than TCA because it only yields 30 ATPs net per glucose molecule [(6 – 1) × 6].

Anaerobic Respiration

As indicated earlier, the first step in the degradation of glucose, which is glycolysis, takes place with or without oxygen and results in the formation of pyruvic acid. In the absence of oxygen, the pyruvic acid is decarboxylated to acetaldehyde, which is then hydrogenated to ethyl alcohol, or in the presence of lactic decarboxylase, pyruvic acid is converted to lactic acid. Accumulation of acetaldehyde, ethyl alcohol or lactic acid results in the formation of undesirable flavors. Pyruvate → decarboxylase → Acetaldehyde + CO2 Acetaldehyde → alcohol dehydrogenase → Ethyl alcohol Pyruvate → lactic decarboxylase → Lactic acid (Hosahalli s. ramaswamy).

Transpiration

Transpiration is an effective way of keeping a plant tissue cool. The energy needed for the evaporation of water often comes from the produce itself, which brings down its temperature in proportion to the quantity of moisture evaporated. Assuming that all the energy for the evaporation comes from the produce, it is possible to estimate the degree of cooling achieved by transpiration. The following is a simplistic example. Assume that 1% moisture is lost from 100 kg of an evaporating produce at 20°C. This represents an evaporation of 1 kg of water. Evaporation is a process in which the latent heat of vaporization is absorbed by water resulting in its conversion to vapour or steam. Each kg of water needs to absorb approximately 2260 kJ of heat energy to vaporize. Assuming that this energy comes from the produce, the 100 kg of produce will lose 2260 kJ of energy. Also assuming the specific heat capacity of the produce to be approximately that of water (4.2 kJ/kgC), the temperature difference that the lost energy will bring can be calculated as 2260 kJ/(100 kg × 4.2 kJ/kg C) or 5.4°C. Thus, each one percentage loss in moisture from the surface will bring down the produce temperature by about 5°C.

Significance of transpiration during plant growth

The cooling effect: This was once considered the primary function of transpiration—to keep the plants cool, to dissipate the heat it has absorbed. However, now it is understood, that plants can dissipate heat equally effectively without getting overheated even in the absence of efficient transpiration mechanisms. Mineral salt and water absorption: Both these are present together in soil. Both are absorbed by plant roots. Although the driving force for the mineral salts is a more active metabolic response, some certainly enters along with water. Mineral salt distribution: Transpiration plays a vital role in the distribution and redistribution of mineral salts to various plant organs. (Hosahallis Ramaswamy).

Fruit Ripening

Ripening is a process in fruits that causes them to become more palatable. In general, fruit becomes sweeter, less green, and softer as it ripens. Even though the acidity of fruit increases as it ripens, the higher acidity level does not make the fruit seem tarter. This is attributed to the Brix-Acid Ratio.

Climacteric and non-climactetic fruits

Fruits, in general, show two distinctive respiratory patterns during ripening and on this basis fruits are categorized into climacteric and non-climacteric groups. Tomato, cherimoya, banana, pear, apricot, peach, plum, climacteric groups (Salunkhe *et al.*, 1991, Kader and Barrett 2003) [13, 10]. Apple, mango, papaya, guava, kiwi, avocado and plantain etc. are climacteric fruits. On the other hand, citrus fruits (orange, grapefruit, lemon etc.), berries (cherry, strawberry, blueberry etc.), pineapple, fig, lychee, melon, loquat, pomegranate, cucumber and tamarillo etc. belong to non-climacteric group of fruits. Climacteric fruits show a dramatic increase in the rate of respiration during ripening and it is referred as climacteric rise. The rise in respiration is either simultaneous or it is just followed after the rise in the rate of ethylene production. The time and intensity of this climacteric peak can be delayed and lowered down, respectively by reducing the rate of respiration and in this way one can enhance the shelf life of fruits. Climacteric fruits can ripen fully even if they are harvested at green mature stage from the plant. The nonclimacteric fruits, on the other hand, can ripen fully only if they are allowed to remain attached to the parent plant because the process of ripening does not occur very fast if they were detached from the plant at green mature stage. Further, non-climacteric fruits do not respond to exogenous ethylene treatment for ripening, except the response of degradation of chlorophyll in citrus fruits and pineapples. The production of ethylene by fruits vary substantially from 100ml kg' 11'1. Climacteric fruits, generally, produce a higher amount of ethylene than nonclimacteric fruits.

Climacteric fruit ripening

During the course of ripening of fleshy fruits, colour changes softening, seed maturation, production of volatiles including flavour volatiles, development of wax on skin and abscission are the important activities (Pratt 1975) [12]. Some of the important changes at the level of respiration, ethylene production, tissue permeability, cellular compartmentalization, carbohydrate composition, organic acids and quantitative and qualitative pattern of proteins also take place (Pratt 1975) [12]. Ethylene is one of the main regulators of climacteric fruit ripening. Many of the above listed physiological, biochemical and developmental changes occur during ripening through a coordinated and genetically regulated programme). Ethylene is supposed to start the cascade of events leading to many interactive signalling and metabolic pathways for the progress of ripening in climacteric fruits. It is important to know that ethylene not only interact with plant but also with its immediate environment (Saltveit 1999).

Ethylene and its synthesis

Ethylene is thought of as the-aging‖ hormone in plants. It is a small hydrocarbon gas. While naturally occurring, it can also occur as a result of combustion and other processes. Sources of ethylene include: ripening fruit, exhaust from internal combustion engines/ heaters, smoke including cigarettes, welding, rotting vegetation, natural gas leaks, manufacturing plants of some kinds. Ethylene will cause a wide range of effects in plants, depending on the age of the plant and how sensitive the plant is to ethylene. Ethylene effects include: fruit ripening, induction of flowering, loss of chlorophyll, abortion of plant parts, stem shortening, abscission (dropping) of plant parts, epinasty (stems bend), and dormancy. It can be produced when plants are injured, either mechanically or by disease. Ethylene can be either good or bad, depending on what commodity you work with. It is used in a positive manner in fruit ripening for example. It can also cause damage on crops such as yellowing of vegetables, or abscission in ornamentals (leaves, flowers drop off). Often two of the important things to know are:

a) If a crop naturally produces a lot of ethylene, and
b) If it is responsive to ethylene.

Responsiveness will depend on

a) The crop,
b) The stage of plant development,
c) The temperature,
d) The concentration of ethylene,
e) The duration of exposure.

Ethylene is used commercially to ripen tomatoes, bananas, pears and a few other fruits. Ethylene gas is used to do this and it is a postharvest use. There are commercial liquid products that release ethylene (Ethephon, Ethrel). These are only used preharvest. The recent discovery of ACC synthetase as the enzyme responsible for the biogenesis of ethylene and its inhibition by compounds such as AVG has broadened the ability of the postharvest physiologist to manage ethylene formation and hence ethylene-mediated changes in the crop. Thus, ethylene-generating compounds, such as ethephon, ethrel, and ACC (1-amino-cyclopropane-l-carhoxylic acid) can be used to trigger certain physiological processes (Norman F. Haard).

Ethylene inhibitors

There are several anti-ethylene chemicals. Silver thiosulfate (STS) is used on flowers. AVG (trade name ReTainTM) blocks ethylene synthesis. It is a liquid that is applied preharvest. The fruit (plant) will not produce much ethylene, so there is not an ethylene response. However, the plant can respond to ethylene from another source.

1-MCP

1-Methylcyclopropene (1-MCP) is an inhibitor of ethylene perception that can delay or prevent ripening and senescence processes in plant tissues (Sisler and Serek, 2003) [14]. The commercialization of 1-MCP as Ethylbloc® and Smart Fresh TM for floricultural and food products, respectively, has had a major effect on many horticultural industries around the world. 1-MCP has several features that have resulted in its rapid approval by regulatory authorities around the world – it is a gaseous chemical that is easily applied, it has a nontoxic mode of action, negligible residues, and activity at very low concentrations (Blankenship and Dole, 2003). As of 2009, 1-MCP has been registered for commercial food use on a range of fruits and vegetables in 37 countries. The fruits and vegetables for which registration has been obtained include apple, avocado, banana, broccoli, cucumber, date, kiwifruit, mango, melon, nectarine, papaya, peach, pear, pepper, persimmon, pineapple, plantain, plum, squash and tomato; however, the number of products registered with each country varies greatly and according to the importance of the crop in that country. Of these products, the most successful to date for application of 1-MCP, has been the apple. In contrast, commercial application of 1-MCP to other products is not always straightforward. This is particularly true for those fruit that soften to a melting texture and/or have major colour change during ripening, and therefore where a delay but not inhibition of ripening is essential. Product type, the maturity of the product at the time of treatment, 1-MCP concentration and exposure time are all factors that are important in successful 1-MCP application for these fruits and vegetables (Watkins, 2006; Huber, 2008) [18, 19]. The apple has been an excellent crop for use of 1-MCP, and the technology is used extensively around the world to maintain quality through the whole marketing chain from the storage to the consumer (Watkins, 2006, 2008) [18, 19]. The success of 1-MCP technology for apples is in no small measure because it is a fruit for which maintenance of _at harvest‘ quality and only moderate softening to a crisp fracturable texture is desirable. 1MCP is applied commercially as a postharvest treatment at present, but research and development on preharvest application, as the commercial product Harvista TM, is ongoing. In this presentation, my focus is on general principles for maximum effectiveness of postharvest 1-MCP application, and on its effects on physiological storage disorders. 1-MCP blocks ethylene binding to its receptor (see below). It is applied postharvest. The fruit (plant) may still produce some ethylene but there is no response to any ethylene, regardless of source. In a normal plant response, ethylene attaches to a receptor molecule and a response occurs Ethylene attaching to the receptor is much like a -key‖ fitting in a - lock, ‖ with ethylene as the -key‖ and the receptor as the - lock. ‖ When ethylene attaches to the receptor, it is like the lock turns and a door opens. A cascade of events then takes place such as the fruit begins to soften, leaves turn yellow, or flowers drop off. Another gas, 1-MCP, is also able to attach to the ethylene receptor. It also can act as a -key‖ that goes into the -lock, ‖ but it is unable to turn the -lock‖ and -open the door. ‖ When the 1-MCP -key‖ is in the -lock, ‖ it is not possible for the ethylene -key‖ to go in the lock. The 1-MCP stops the -lock‖ from turning so the door can‘t open. It is in this way, that 1-MCP acts as an ethylene inhibitor in plants. Because gases are often difficult to handle, 1- MCP was put into a solid formulation. The powder, when mixed with water, will release 1-MCP gas into the enclosed area. Depending on temperature and other conditions, this will happen over the course of about an hour. It is expected that an easy-to-use, one-step kit will be provided with the commercial product when it becomes available. A typical postharvest scenario might be to enclose a plant product in an airtight container/room. 1-MCP gas would be released into the air in the container/room and penetrate the commodity. After a short period of time (6 to 24 hours), the commodity would be returned to air or controlled atmosphere. The product would then continue on the postharvest route. 1-MCP is a safe product that leaves no detectable residue. It can be used by small or large operations. The success of 1-MCP treatment depends on a number of things. The concentration of the 1-MCP gas must be sufficient to saturate the receptors and compete with any ethylene present. The treatment time must be long enough for the gas to release and penetrate the plant tissue. The temperatures at which the treatment takes place will influence the length of time needed for treatment. Done properly, there is no problem in using 1-MCP to treat products in cold storage—it can also be used at room temperature, although this will not allow for optimum postharvest life. Monitoring the cold chain is a good idea. Maturity of the plant product will effect the results. If fruit is too ripe or flowers too old, 1- MCP will not work well. In some cases, the effect of 1-MCP is permanent. In other plant products, the effects of the 1-MCP treatment can wear off and this depends, in part, on the concentration of 1-MCP applied. 1-MCP can be a very valuable tool when incorporated into a good post-harvest program.

Cooling and pre-cooling

Cooling is a process of removing heat. In other words, it is a process of lowering the temperature of the produce to below the ambient conditions. With reference to produce, therefore, it is a process of removing the field heat (heat content of the harvested produce above the storage temperature or the sensible heat required to be removed to bring down the produce temperature that existed at harvest to the level maintained at storage). Pre-cooling technically is no different from cooling. This term was coined almost a century ago to mean cooling of produce prior to shipping. At the turn of the century, shippers found that when loads of warm produce were transported in railway cars to distant markets, it turned ripe or overripe and decayed significantly upon arrival at destination markets in spite of the fact that the cars were refrigerated. This was primarily because the fruits, without the pre-cooling, cooled very slowly in the refrigerated railway car, and spoilage or damage probably occurred even before the cooling process was complete. On the other hand, when these fruits were quickly cooled using some rapid cooling device prior to loading onto rail cars, there was significant improvement in their quality. Soon this became a practice, and shippers were required to precool their produce prior to shipping. Even today pre-cooling still has the same meaning, and includes the cooling procedures prior to storage or processing as well.

Advantages of Cooling and Pre-cooling

The primary function of pre-cooling is the rapid lowering of the produce temperature. Hence, it will retard all temperature-dependent reactions: respiration, transpiration, microbiological activity, enzymatic activity and chemical activity. Therefore, it results in improved product quality and reduces heat load in storage. As will be clear, pre-cooling is quite demanding on refrigeration, while cold storage is relatively less. Hence, from refrigeration point of view, since precooling takes care of the field heat, the refrigeration design of cold storage needs only to consider the vital heat (heat of respiration) and other heat loads coming from leakages through walls and ceiling, as well as those added during loading and handling of the produce.

Cold storage systems

A cold storage system generally is referred to as a storage ―system‖ because of the need to control several components: temperature, relative humidity (RH), air velocity, air composition, etc. Proper control depends on structural and constructional details, insulation, air tightness and vapour permeability. The degree of control depends on the type of storage facility and needed functions. While simple storage systems, such as ventilated storage for bulk storage of potatoes or dry onions, only take into account the thermal insulation, air circulation and fan assisted ventilation, others rely on more elaborate controls. Even standard regular atmosphere cold storage needs to take into account the appropriately designed refrigeration equipment to meet the needed goal in addition to proper humidity and air distribution controls. In more complex storage systems such as CA and hypobaric storage, thermal insulation, air tightness, vapour barrier control, precise control of temperature, RH and air composition need to be taken into account.

Temperature

Temperature is the key factor in postharvest storage. Produce must be stored at the lowest permissible temperature. Some tropical produce could be chilling sensitive, and these should not be stored at temperatures below which they are sensitive to cold injury (generally the lower limit is around 10°C). Each produce has its own optimal storage temperature, which generally is the lowest that causes no chilling or freezing injury. The optimum storage temperature for most temperate produce is 30–32°F for the non-chilling-sensitive varieties and 38–40°F for the chilling-sensitive varieties. For tropical produce the desirable temperature ranges are: 45–50°F (non-chilling); 50–60°F (chilling sensitive).

From a storage point of view

Temperature fluctuation in a storage chamber should be within ±2°F. Larger temperature fluctuations will result in a loss of produce quality.

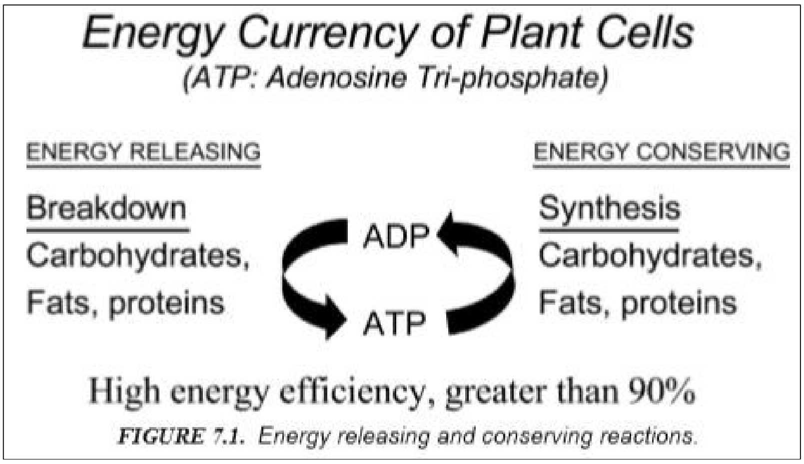

Fig 1: Figure from book post-harvest technology of fruits and vegetables by Hosahalli S. Ramaswamy

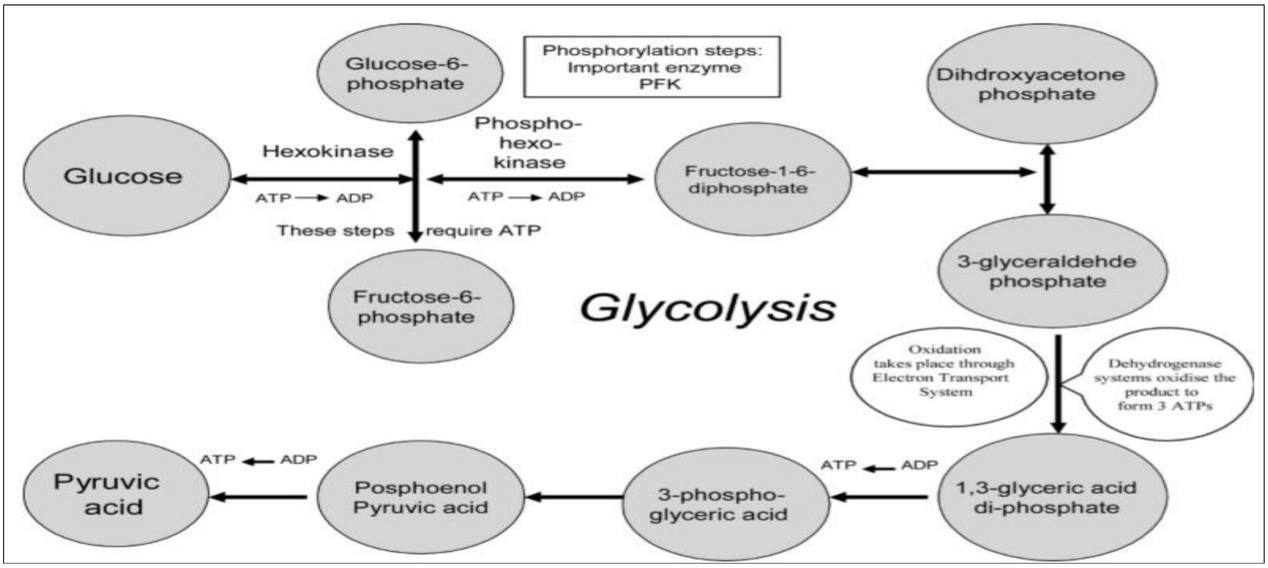

Fig 2: Figure from book post-harvest technology of fruits and vegetables by Hosahalli S. Ramaswamy

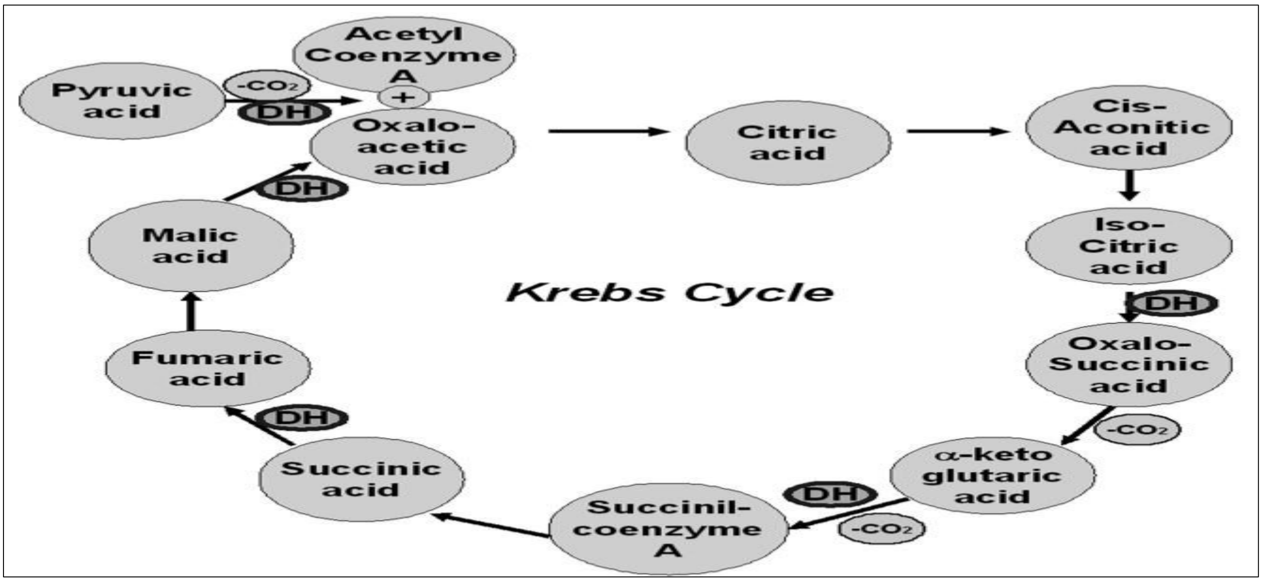

Fig 3: Figure from book post-harvest technology of fruits and vegetables by Hosahalli S. Ramaswamy

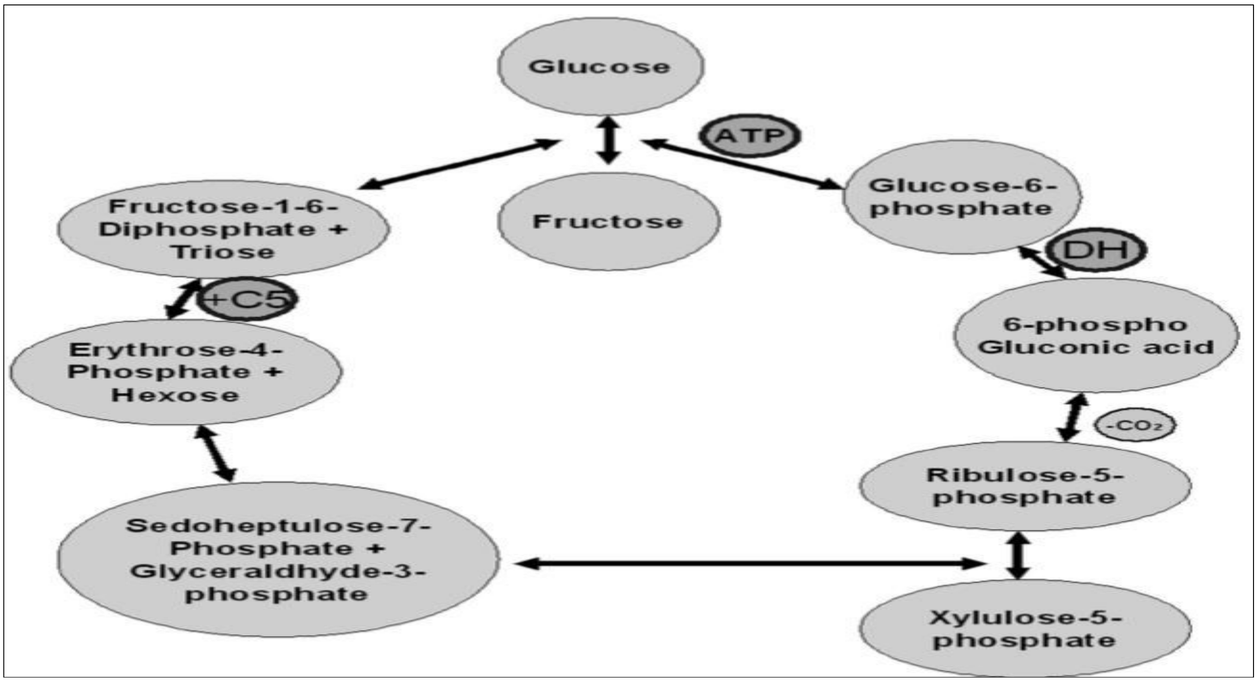

Fig 4: Figure from book post-harvest technology of fruits and vegetables by Hosahalli S. Ramaswamy

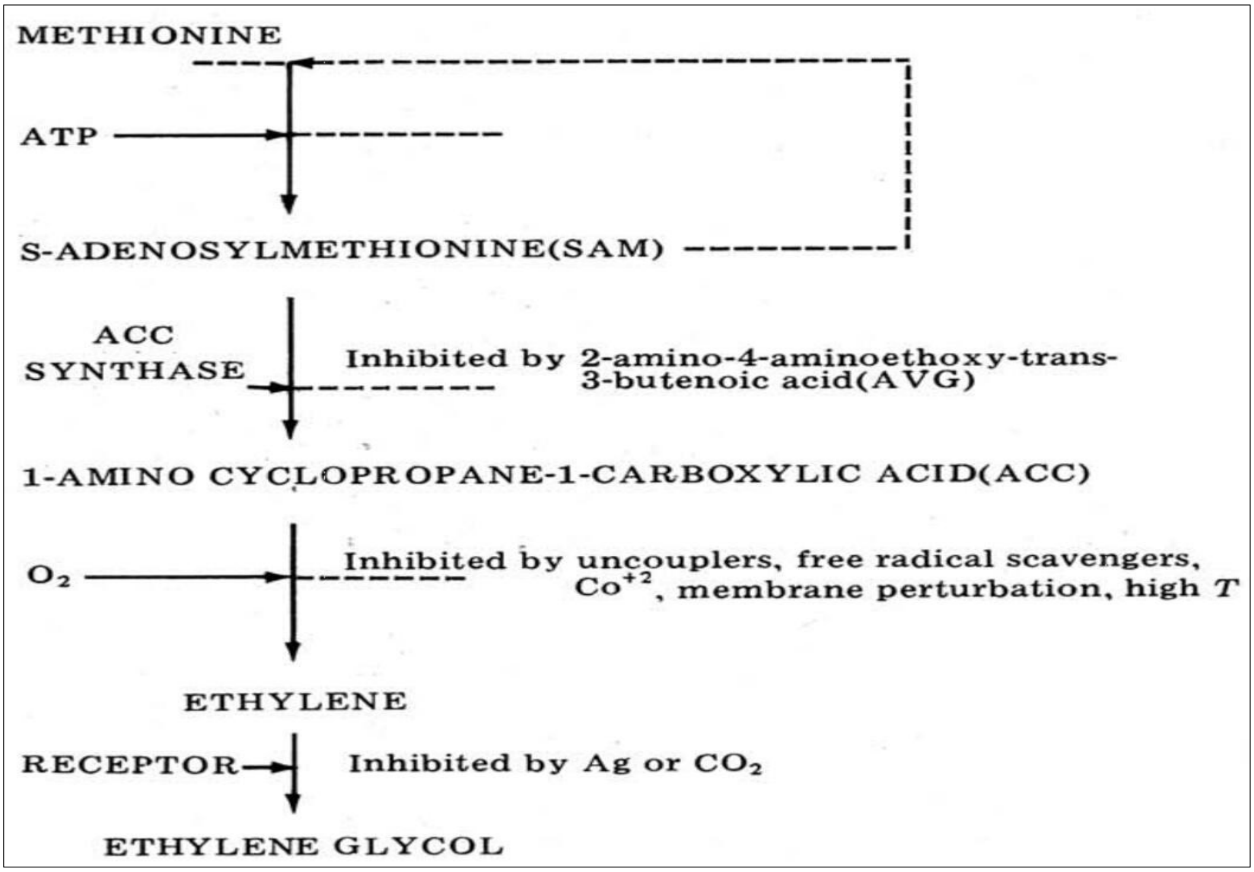

Fig 5: Scheme showing biosynthesis and metabolism of ethylene in plant tissues

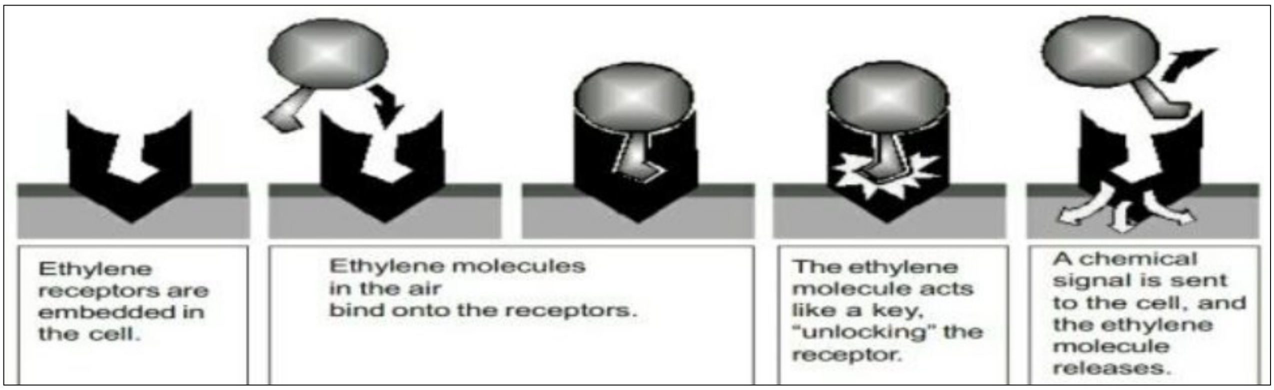

Fig 6: Binding of ethylene molecule with the receptor "Unlocks" the receptor and leads to a chemical reaction in the plant tissue (diagram by jenny Bower, Department of pomology. UC Davis)

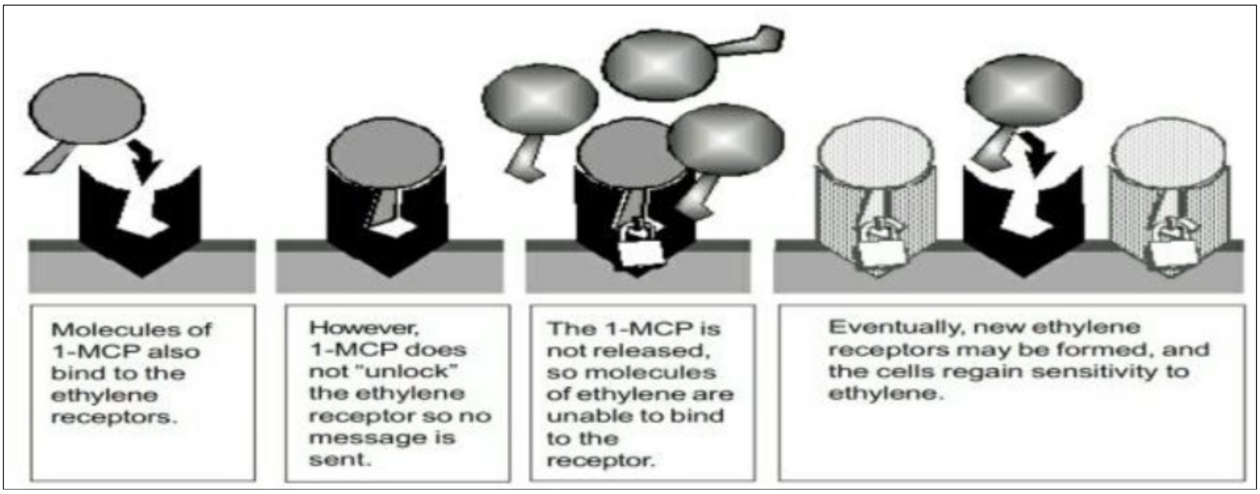

Fig 7: When 1-menthycyclopropene (-MCP) binds to the ethylene receptor. It does not "unlock" the receptor and remains looked to the receptor and receptor and remains locked to the receptor preventing the binding of ethylene and the chemical reaction does not occur (diagram by jenny bower Department of pomology, UG Davis).

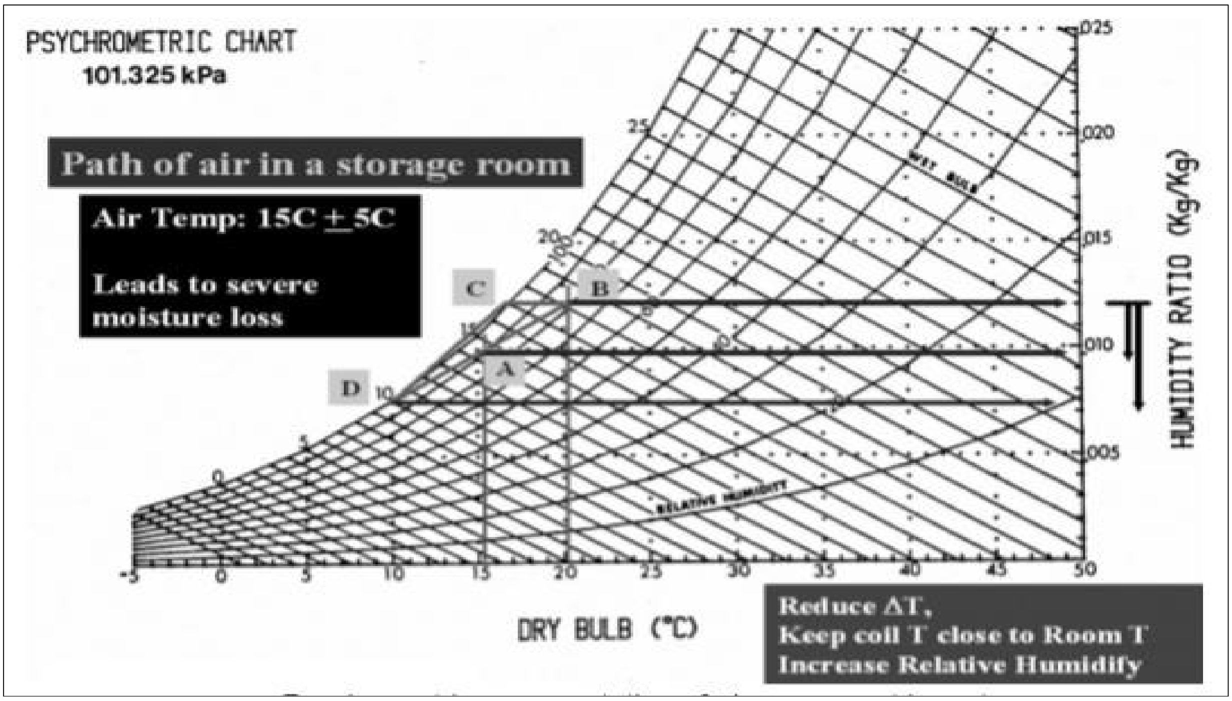

Fig 8: Figure from book post-harvest technology of fruits and vegetables by Hosahalli S. Ramaswamy)

Table 1: Important enzymes and key reactions associated with ripening of fruits (Vijay Paul *et al.,* 2008) [17].

Enzyme	Reaction	Result
Polygalacturonase	Hydrolysis of glycosidic bonds between adjacent polygalacturonic acid residues in pectin	
Pectin esterase	Hydrolysis of ester bonds of galacturonans in pectin	Cell wall breakdown
Chlorophyllase	Cleavage of phytol ring from chlorophyll	Loss of green colour
Cellulase and hemicellulases	Hydrolysis of cell wall	Loss of texture
Amylases	Hydrolysis of amylose and amylopectin	Loss of texture and increase in sweetness due to production of sugars
Polyphenol oxidase, catalase, peroxidase.	Oxidation of phenols	Formation of precursors to coloured and polymers leading to undesirable browning
Lipase	Hydrolysis of lipids	Hydrolytic rancidity
Lipoxygenase	Oxidation of lipids	Production of off-flavour and off odours
Proteases	Hydrolysis of proteins	Loss of nutritional value and increase or decrease in digestibility
Ascorbic acid oxidase	Oxidation of ascorbic acid	Loss of nutritional quality
Glucose oxidase	Oxidation of glucose	Formation of hydrogen peroxide
Phytase	Hydrolysis of Phytic acid	Liberation of phosphates

Warm produce coming in contact with cold air will result in product desiccation if the air is not saturated and result in produce sweating if the air is saturated. On the other hand, cold produce coming in contact with warm air will result in desiccation if the WVPD is positive or condensation of water on produce surface if WVPD is negative. Moisture from the desiccated or sweated produce eventually is carried away by air to the cooling coils. The larger the temperature fluctuation the greater is the loss.

Adequate refrigeration capacity to handle loads: The designed refrigeration capacity should take into account normal load as well as unexpected loads. Storage life of existing and incoming commodities is maximized by pre-cooling the incoming produce to the storage temperature. On the other hand, storage life of all commodities will be at risk with warm products coming into the storage, especially when refrigeration capacity is limited. Undersized refrigeration capacity will result in slow cooling and can cause product warming and large temperature fluctuations. Oversized refrigeration capacity is more expensive and involves more capital investment. Several small size units acting in parallel are preferred over one large one, as they will cause less temperature fluctuation in the chamber.

Room temperature should be close to the refrigeration temperature. This causes less temperature fluctuation when the control system goes on and off between the set limits. The refrigeration system and cooling coils. The refrigeration system and cooling coils should have a large heat transfer surface area. This will result in more efficient heat transfer; fins can be used to increase surface area.

Good air velocity increases proper temperature distribution. Generally, air flow rates of 50–75 cubic feet per minute are desirable; higher flow rates will cause desiccation, especially when a large temperature difference exists between coil and produce; lower flow rates will lead to temperature stratification and improper cooling of the produce.

The room should have adequate thermal insulation to prevent heat ingress from walls, doors, floor, ceiling, etc.

The room should have an appropriate temperature control system, and the temperature should be measured at appropriate locations-preferably not near door or coils.

Relative Humidity

Relative humidity aspect was discussed in detail with reference to transpiration. Try to trace the air path in a storage chamber on a psychrometric chart. Assume that the room is designed for storage of tropical produce at 15°C, 90% RH. Assume an overall temperature fluctuation of +5°C with the cooling coils operating at 10°C (See Figure below). This means that air coming through the produce stack could warm up to 20°C with an assumed RH of 80%. Notice that this is not an adiabatic saturation process because the air picks up heat of respiration, and heat load from the room in addition to heat of vaporization. The warm air travels to the cooling coil where its temperature is lowered to 10°C; moisture condenses on the coil as the air temperature falls below 17°C (dew point temperature of 20°C and 80% RH air). The air leaving the cooling coil will be saturated at 10°C; however, as it travels through the stack it warms up to 20°C and 80% RH. The difference between these two humidity values (0.012–0.0075 = 0.045 kg H2O per kg dry air) is the amount of moisture picked up by the air through each cycle. In the cyclic process of air travelling around, moisture is continuously removed from the produce. Moisture loss can be reduced by narrowing down the temperature difference between the coil and the air. Moisture loss can also be reduced by narrowing down the temperature fluctuation as well. Moisture loss is offset by humidifying the air externally using special techniques for storage: a jacketed storage system, Filacell® storage system or fog spray system.

Air Velocity

Air circulation can be natural or forced, the latter being common in storage systems. Air circulation promotes both heat and mass transfer; while heat transfer is desirable, mass transfer is not. Air velocity is important for establishing less temperature fluctuation, also for bringing down the temperature difference between air and cooling coil. Further, air circulation also is important for establishing uniformity of CA conditions. The air circulation pattern depends on the nature of circulation (natural or forced), fan type and capacity, the air delivery system, as well as produce package design and stacking.

Atmospheric Composition

In regular atmosphere systems, the atmospheric composition is not controlled. Excessive CO2 & ethylene accumulation is prevented by scrubbing. In CA/MA storage systems, the atmosphere is altered. Low oxygen levels and high CO_2 levels are intentionally created to reduce the rate of respiration and heat production. Removal of ethylene (C_2H_4) in a must in these systems because ethylene even in trace quantities can trigger accelerated ripening of some fruits. Sometimes, carbon monoxide (CO) is added as a CA supplement. It has been shown to inhibit discoloration of cut surfaces. It also has been shown to have some fungistatic activity at a 5–10% concentration level. It is flammable at >12.5% concentration. Addition of 2–3% CO at 2% O_2 has been found to be successful for lettuce.

Structural Aspects

A fruit and vegetable storage chamber is built to provide storage at a desired temperature that is normally different from the ambient (room temperature could be cooler than ambient in summer and warmer than ambient in winter months) with some control over the relative humidity and air flow rate. Additionally, specialized storage chambers are built that permit controlled modifications of air composition to desired levels (for example 2.5% oxygen and 5% carbon dioxide) different from those at which they normally exist. While most construction would require appropriate thermal insulation and structural rigidity, the specialized ones need to take into account vapour and gas barrier properties as well. (Hosahalli s. ramaswamy)

Controlled Atmosphere (CA) storage systems

Controlled atmosphere storage has been referred to as one of the most important innovations in fruit and vegetable storage since the introduction of mechanical refrigeration. In conjunction with low temperature and high relative humidity, this method involves the alteration of the gaseous environment inside the storage chamber. Oxygen concentration generally is lowered to about 2–3%, and carbon dioxide is added up to 5%. As discussed in the chapter on respiration, both of these help to retard the rate of respiration, the former by limiting one of the reactants (oxygen), and the latter by accumulating a product of respiration (CO_2). In addition, lowering of temperature obviously has a significant effect on lowering the respiration rate. These three factors taken together have a synergistic effect, thereby providing opportunity for enhancing the postharvest shelf life by a margin greater than that possible by the added effects of the individual components. Sometimes, CA storage also may entail the addition of other gases, such as carbon monoxide, to provide additional fungistatic effects. Ethylene, a growth promoter, and a natural product of respiration, is also removed.

Several advantages have been recognized for products in CA storage

a) Lowered respiration rate.
b) Retarded senescence.
c) Suppressed ethylene production rate.
d) Reduced fruit sensitivity to ethylene.
e) Improved retention of green colour.
f) Improved texture.
g) Improved retention of nutrients like ascorbic acid.
h) Alleviation of physiological disorders like russet spots on lettuce, internal breakdown.
i) Suppressed activity of pathogens.
j) Control of insect activity (only possible at high CO_2 concentrations, not usually tolerated by fruits and vegetables).

Some undesirable effects observed are

a) Elevation of physiological disorders in certain produce, such as black heart of potatoes or brown heat in some varieties of apples and pears.
b) Irregular ripening: banana, pear.
c) Development of off flavours, especially at low levels of oxygen.

Stimulation of sprouting and retardation of periderm development in some tubers like potatoes. As CA storage takes place in sealed rooms for extended periods of time, there is the possibility for enhancing production of metabolic and other volatiles. These arise not only from the fruits, but also from degradation of wooden bins, the growth of moulds, etc. In normal ventilated rooms, the concentration of such volatiles will be low. Generally, these volatile accumulations will be lower in CA systems equipped with activated charcoal scrubbers intended for removal of ethylene and excess carbon dioxide. Under low oxygen tension as in CA rooms, acetaldehyde and ethanol production can result from partial anaerobic fermentation. Such volatiles can be removed from the fruits after they are taken out of the CA room and stored under regular atmosphere for some time. It should be noted that the CA storage is really intended for long term storage and unlike the regular atmosphere storage the produce is not generally taken in and out at frequent intervals. Further, the environment inside the storage does not support human life, and therefore the people who enter CA storage area and work there need to wear an oxygen mask to enter. Again, CA storage is not practical for all fruits and vegetables. It is expensive to construct and operate a CA room and requires specialized structures, equipment and control systems. Highly skilled workers are required for both operation and maintenance. It would add significantly to the product cost and therefore it is used for only those commodities for which the additional cost is acceptable.

CA Generation and Control

There are two issues concerning CA systems

a) CA generation and
b) CA control.

The generation implies lowering of oxygen concentration and elevating carbon dioxide to levels appropriate for the CA room operation (generally 2–3% O_2 and 5% CO_2). This can be done by two methods:

a) Passive process and
b) Active process.

It is well recognized that for produce respiration, oxygen is required and CO_2 is released as a product of respiration. Hence, in a closed CA room, if the produce loaded into the room is allowed to respire, oxygen available in the room (air has about 21% O_2) will be gradually used up and CO_2 will begin to accumulate. With ongoing produce respiration, oxygen concentration in the room is continuously lowered and carbon dioxide level is continuously increased. By the time 5% CO_2 is accumulated, oxygen concentration will decrease by about 5% (assuming an RQ of 1.0). While O2 needs to be lowered further, CO_2 has reached the limit. From now on the CO_2 needs to be maintained at this level by removing excess CO_2.

Further respiration would eventually deplete sufficient O_2 to reach the target level and then the amount of oxygen required for respiration needs to be added to the room to maintain the 2% concentration. This process is called passive modification of the CA environment and is a very slow process. In the active process, the storage atmosphere is modified using rapid means to lower the oxygen level through oxygen control systems and quickly elevate the carbon dioxide level by adding it through a gas cylinder. Then they need to be controlled. For oxygen level control, the required amount of O_2 is maintained by adding a calculated amount of air and for maintaining the CO_2 level, a CO_2 control system is periodically activated to remove CO_2 from the room.

Lowering of Oxygen

External Gas Generators

External gas generators operate either on an open-flame or catalytic burner to remove O2 from the incoming air. The heat added by the burners needs to be removed, which is done by a water spray that cools the air and humidifies at the same time. The disadvantage of these types of system is that fuel is required and CO2 is produced as a product of combustion and must be removed. Filtration may also be necessary before letting air back into the storage room. The advantages of these systems are flexibility of operation and the rapidity with which O2 is depleted in the initial stages of storage. The catalytic system is preferable in ensuring better combustion and fewer combustion by-products. Catalytic burners are more expensive to install. The operation can be carried out in either a re-circulating configuration or purge system to flush out the oxygen. In the re-circulating type, the CA air is pulled out, sent through the burners and readmitted after depleting the O2. This will continuously deplete the oxygen from the room until the desired level is reached. In the purge system, fresh air from outside is fed to the gas generators, and the oxygen-free air after cleaning and humidification is continuously fed into the CA room and vented out from the opposite end of the room. As continuously oxygen-free air is entering and oxygen rich air is leaving, the oxygen concentration will progressively decrease until reaching the target.

Nitrogen Flush

Flushing the storage room with N_2 is an excellent method for depleting O_2 in CA. This can be done using pressurized N2 gas cylinders. Alternately, liquid nitrogen (LN) also can be used by spraying the LN in front of evaporator blowers. Care must be taken to make sure too much LN does not enter the CA room as it can compromise temperature maintenance. An O_2 sensor is used to determine when to stop the LN addition.

Elevating CO_2 level

If not done by produce respiration, CO2 is increased by introducing a calculated volume of CO_2 to the CA room from CO_2 gas cylinders. Maintaining.

Maintaining CA

In order to maintain controlled atmosphere conditions, the exact amount of O2 required for respiration needs to be admitted into the CA room. This is done by calculating the oxygen consumption rate by the produce and the introduction of oxygen (air) into the room through a metering device. Alternately, an inlet device can be activated once the oxygen level reaches the low level target and until air admitted reaches the upper level set point. The on-off will be operated between the two limits. For CO2, the excess CO2 produced need to be removed. This is done likewise by activating a CO2 scrubbing device once the upper limit of CO2 is reached and scrubbed until it reaches the lower set point and stopped. Again, the on-off will be operated between these two limits. The following are available scrubbers for CO2.

Scrubbing of CO_2

Several methods have been used to scrub CO_2

a) caustic soda,
b) hydrated lime,
c) water,
d) activated charcoal and
e) Molecular sieves.

Monitoring of the atmospheric composition is necessary to control the scrubbing system. Caustic soda (NaOH) was one of the first reagents used commercially for CA storage applications and was used in mixture with water. The solution was circulated in open tubes and thus absorbed CO2, the residence time being controlled according to the required removal rate. Its use was discontinued due to its corrosiveness and potential danger in handling. However, dry caustic material has been proposed as a reasonable alternative. Perhaps the simplest method of controlling CO2 levels is through hydrated lime scrubbers (Ca(OH)2). The scrubber is an insulated and sealed plywood box usually containing between half to the total amount of lime required to remove the CO2 produced during the entire storage period. The box is connected to the CA room and air flow to it is left to natural convection or controlled by forced-air blowers and dampers. There are two types of water scrubbers for CO2. One is the brine scrubber in which brine is pumped into an aerator, which causes CO2 to escape to the atmosphere. Dry evaporators‘ coils are used to prevent corrosion. A modified system also is available using two aerators, one internal and one external. Activated charcoal and molecular sieve scrubbers are units filled with the respective absorbers, two blowers and four timer-controlled valves. Air from the CA room is circulated to the scrubber where CO2 is absorbed. The CO2-depleted air is returned to the storage room. When the absorbent is saturated, outside air is circulated through the scrubber and back to the outside to remove the CO2. If a molecular sieve is used, it is also heated to speed up the reactivation process.

Membrane system for CA/MA

Controlled and modified atmosphere (CA, MA) storage units are used in the same context and usually they mean the same in the context of a storage room. They both involve changing the storage atmospheric composition to a desired level. The controlled atmosphere refers to an atmosphere with a strict control of the gas concentrations of oxygen, carbon dioxide and nitrogen. Modified atmosphere (MA) is used more in situations where the produce is held under conditions where the atmosphere is modified by the produce, package, over wrap, box liner or pallet. Oxygen generally is reduced through respiration by the produce (passive system), and the carbon dioxide level is determined by the permeability of the film, respiration, temperature, gas barrier property and other factors. The concept of modified atmosphere was developed almost simultaneously as a packaging concept and extended to larger containers and small storage units. In MA designated systems, the carbon dioxide and oxygen levels are not strictly controlled to specific concentrations. The membrane system is a type of modified storage that has evolved as an extension of a modified atmosphere package (MAP). The MAP‘s commercial success and CA‘s scientific background provided the basis for the membrane system for CA generation and maintenance. It is based on selective diffusion of gases through the membrane material, which at a predetermined product loading will bring in enough oxygen for the aerobic respiratory need and at the same time help to remove the carbon dioxide produced by the respiratory process. It establishes a dynamic equilibrium between produce respiration and membrane permeation. The theory is that when the right film and right temperature are used, the membrane will help to maintain a theoretically correct and beneficial mixture of carbon dioxide and oxygen inside the chamber. The method was invented by two French investigators Marcellin and Leteinturier, and involves the use of elastomers of silicone (Smock, 1979) [15]. The membranes breathe in oxygen and breathe out carbon dioxide in synchrony with the produce respiration pattern and hence maintain a preset concentration of oxygen and carbon dioxide inside the room. Since most CA/MA systems operate at considerably reduced oxygen levels (e.g., 2%) and slightly elevated CO2 levels (e.g., 5%), the concentration gradient for these two gases across the membrane are very different (19% for O2 and 5% for CO_2 in the above assumption). Hence, the membrane has to have a selective differential permeability to these gases in order to maintain a set atmospheric composition in the storage room. The simplified concept is detailed below, and the complexity of the concept also is elaborated. A membrane system is based on the gas diffusion process. It uses special membranes with selective permeability. The gas diffusion occurs between the air from inside and outside the chamber across the semi-permeable special membrane. The extent of gas diffusion depends on the concentration gradient of the components (primarily O_2 and CO_2) and permeability of the membrane to these gases. The resulting concentration depends on:

a) Permeability of the gas through the membrane,
b) Concentration gradients,
c) Respiratory demand of the produce (respiration rate and quantity of the produce), and
d) Temperature.

Conclusion

About one -third of the fruits produced worldwide are never consumed by humans due to loss at various stages and the loses are generally more in developing countries in comparison with developed countries especially when compared between production and retail sites. Post-harvest physiology has direct applications to postharvest handling in establishing the storage and transport conditions that best prolong shelf life, for example 1- Methyl Cyclopropene (1-MCP) is an inhibitor of ethylene perception that can delay or prevent ripening and senescence processes in plant tissues. Pre-harvest factors also effect the post-harvest life of fruits and vegetables. Controlled atmosphere storage has been shown to be effective in reducing the post-harvest losses and prolonging the life of the produce by proper management of respiration via alteration in the gaseous composition and storage temperature. Proper understanding of the biochemistry and the underlying physiological factors will go a long way in minimising the post-harvest losses and thereby improving the socio-economic condition of the farmers particularly in the developing countries.

References

1. Chris B. Watkins Department of Horticulture, Cornell University, Ithaca, NY 14853 current and future research and uses of 1-MCP in apples.
2. El-Ramady HR. Faculty of Agriculture, Kafrelsheikh University, Kafr El-Sheikh, É. Domokos-Szabolcsy M. Fári Plant Biotechnology Department, Debrecen University, N. A. Abdalla H.S. Taha Plant Biotechnology Department, Genetic Engineering Division, © *Springer* International Publishing Switzerland 2015 E. Lichtfouse (ed.), Sustainable Agriculture Reviews, Sustainable Agriculture Reviews 15, DOI 10.1007/978-3-319-09132-7_2, Postharvest Management of Fruits and Vegetables Storage.
3. Friboulet A, Thomas D. Systems biology – an interdisciplinary approach. Biosens Bioelectron. 2005; 20:2404-2407.
4. Hertog MLATM, Rudell DR, Pedreschi R, Schaffer RJ, Geeraerd AH, Nicolai BM *et al*. Where systems biology meets postharvest. Postharvest Biol Technol. 2011; 62:223-237.
5. Hosahalli Ramaswamy S. PHD, FCSBE, FAFST (I) Professor Department of Food Science and Agricultural Chemistry McGill University, Post-harvest Technologies of Fruits & Vegetables, chapter, 7, 85-104

6. Hosahalli Ramaswamy S. PHD, FCSBE, FAFST (I) Professor Department of Food Science and Agricultural Chemistry McGill University, Post-harvest Technologies of Fruits & Vegetables, chapter. 8, 107-108.
7. Hosahalli Ramaswamy S. PHD, FCSBE, FAFST (I) Professor Department of Food Science and Agricultural Chemistry McGill University, Post-harvest Technologies of Fruits & Vegetables, chapter 9, 127-128.
8. Hosahalli Ramaswamy S. PHD, FCSBE, FAFST (I) Professor Department of Food Science and Agricultural Chemistry McGill University, Post-harvest Technologies of Fruits & Vegetables, chapter 10, 167-168, 174-177, 189-198.
9. Huber DJ. Suppression of ethylene responses through application of 1methylcyclopropene: A powerful tool for elucidating ripening and senescence mechanisms in climacteric and nonclimacteric fruits and vegetables. Hort Science. 2008; 43:106-111.
10. Kader AA, Barrett DM. Biology, principles and application. In: Processing Fruits: Science and Technology, (Somogyi, L.P. *et al*., Eds.). Technomic Publishing Co. Inc., Lancaster, Pennsylvania, USA, 2003, 1.
11. Norman Haard F. Department of Biochemistry. Memorial University of Newfoundland, St. John's, Newfoundland, Canada, Postharvest Physiology and Biochemistry of Fruits and Vegetables.
12. Pratt HK. The role of ethylene in fruit ripening. Facteurs et regulation de la maturation des fruits. Centre National de La Recherche Scientifique: Pairs, France, 1975, 153-160.
13. Salunkhe DK, Bolin HR, Reddy HR. Storage, Processing and Nutritional Quality of Fruits and Vegetables. Voll. Fresh Fruits and Vegetables, CRC Press, Boca Raton, 1991.
14. Sisler EC, Serek M. Compounds interacting with the ethylene receptor in plants. Plant Biology. 2003; 5:473-480.
15. Smock RM. Controlled atmosphere storage of fruits. Hort. Review. 1979; 1:301.
16. Sylvia Blankenship. Professor, Horticultural Science North Carolina State University, Raleigh, NC, Ethylene Effects and the Benefits of 1-MCP.
17. Vijay Paul. Indian Agriculture Research Institute. G.C. Srivastava, Amity University. Rakesh pandey, Indian Council of Agricultural Research. DOI:10.13140/RG.2.1.1606.8321. Post-harvest management of fruits: physiological inputs.
18. Watkins CB. The use of 1-methylcyclopropene (1-MCP) on fruits and vegetables. Biotechnology Advances. 2006; 24:389-409.
19. Watkins CB. Overview of 1-methylcyclopropene trials and uses for edible horticultural crops. Hort Science. 2008; 43:86-94.