Factors affecting postharvest quality of fresh fruits

A ripened ovary of a flower together with any accessory part associated with, is referred to as fruit (Lewis & Robert 2002). In non-technical usage the term fruit normally means the fleshy seed-associated structures of certain plants that are sweet and edible in the raw state, for example apples, oranges, grapes, strawberries and bananas (Mauseth & James, 2003).

Fresh fruits and vegetables are living tissues which undergo continuous changes after harvest. Some of these changes are desirable, but from consumer’s point of view most of them are undesirable. It is not possible to stop the postharvest changes in fresh produce, but they can be retarded within certain limits (Kader, 2002).

There are several atmospheric factors which affect the postharvest life of fresh fruits. Climatic conditions, specially temperature and light have a significant effect on the nutritional quality of fresh fruits and vegetables (Kader, 2002).

FACTORS AFFECTING THE POSTHARVEST LIFE OF FRUIT

RESPIRATION

Respiration is the process by which stored organic materials are broken down into simple end products with a release of energy. During this process oxygen (O2) is consumed while carbon dioxide (CO2) is produced. All living organisms must carry out respiration at all times (Kader, 2002).

Respiration Metabolism

Even after the harvest, fruits and vegetables remain as living organs. Like all living tissues, harvested produce continues to respire throughout its postharvest life. The main purpose of respiration is to maintain sufficient supply of adenosine triphosphate (ATP). The process of aerobic respiration involves the regeneration of ATP from ADP (adenosine diphosphate) and Pi (inorganic phosphate) with the release of CO2 and H2O. In case of hexose sugar the overall reaction can be written as (Kader & Saltveit, 2003)

The different components in this reaction have different sources of destinations. The 1 mole of glucose (180g) can come from stored simple sugars (glucose, sucrose) or complex polysaccharides (starch). The 6 moles of O2 (192g) used to oxydize the 1 mole of glucose diffuses into the tissue from the surrounding atmosphere, while the 6 mole of CO2 (264g) diffuses out of the tissue. The 6 mole of water (108g) produced is simply incorporated into the aqueous solution of the cell.(Kader & Saltveit, 2003)

Aerobic respiration involeves a series of three reactions, each of which is catalyzed by a number of specific enzymes that either (i) add a phosphate group to a molecule, (ii) rearrange the molecule, or (iii) break down the molecule to a simpler one ((Biale, 1960);(Davies, 1980)). The three interconnected metabolic pathways are glycolysis, the tricarboxylic acid (TCA) and the electron transport system.

Glycolysis

The breakdown of glucose occurs in the cytoplasm, which produce two molecules of pyruvate. 10 different sequential reactions are catalysed by one enzyme. Phosphofructokinase (PFK) is the main enzyme in Glycolysis, which cleaves fructose 1, 6-diphosphate into two triose phosphate molecules. By controlling PFK activity of Glycolysis, cell can control their rate of energy production. ATP is used as a negative feedback inhibitor to control the activity of PFK (Davies, 1980). Besides pyruvate, Glycolysis also produces two molecules of ATP and two molecule of NADH (reduced nicotinamide adenine dinucleotide) from the breakdown of each molecule of glucose.

Tricarboxylic Acid (TCA) Cycle

The TCA cycle occur in mitochondrial matrix, involves in the breakdown of pyruvate into CO2 in nine sequential enzymatic reactions. Pyruvate is decarboxylated to form acetate, which condenses with a co enzyme to form Acetyl CoA. This compound then enters the cycle by condensation with oxaloacetate to form citric acid. Citric acid has three carboxyl groups, from which the cycle derives its name (Kader & Saltveit, 2003). Through a series of seven successive rearrangements, oxidations and decarboxylations, citric acid is converted into oxaloacetate, which is then ready to accept another acetyl CoA molecule. The TCA cycle also produces one molecule of FADH2 (reduced flavin adenine dinucleotide) and four molecules of NADH for each molecule of pyruvate metabolism.

Electron Transport System

The electron transport system occurs in the cristae of mitochondria, results in the production of ATP from the FADH2 and NADH. The energy produced is more than the cellular process requirement. In a series of reactions, one NADH molecule produces three ATP molecules and one FADH2 molecule produces two ATP molecules, but the exact number of ATP produced during electron transport depends not only on the energy of NADH and FADH2 but also on the chemical environment within the cell and mitochondria.

In the absence of O2, NADH and FADH2 accumulates, the TCA cycle stops and Glycolysis become the only source of ATP production. In anaerobic respiration hexose sugar is converted into alcohol and CO2 in the absence of O2. Pyruvate produced in Glycolysis is decarboxylated by the enzyme pyruvate carboxylase to form CO2 and acetaldehyde. The acetaldehyde is converted by the enzyme alcohol dehydrogenase to ethanol with regeneration of NAD+. Two moles of ATP and 21 kcal of heat energy are produced in anaerobic respiration (alcoholic fermentation) from each molecule of glucose (Kader & Saltveit, 2003).

Respiration Quotient (RQ)

The respiration quotient (RQ) determines the amount of substrates utilized in the respiration process. In other words RQ is the ratio of CO2 produced to O2 consumed measured in mole or volumes. In the aerobic respiration of carbohydrates the RQ is near 1, while is < 1 for lipid and > 1 for organic acids. Very high RQ values usually indicate anaerobic respiration in those tissues which produce ethanol.

GAS EXCHANGE

Barrier to Diffusion

Gas exchange between a plant organ and its environment follows Fick’s first law of diffusion. The sequential steps are (i) diffusion in the gas phase through the dermal system (i. e. cuticle, epidermis, stomata etc.); (ii) diffusion in the gas phase between the intercellular spaces; (iii) exchange of gases between the intercellular atmosphere and the cellular solution (cell sap) and (iv) diffusion in solution within the cell to centres of O2 consumption and from centers of CO2 production. This exchange is a function of the resistance of the dermal system to gas diffusion, the surface area across which diffusion can take place etc.

CO2 produced within each cell will raise the local concentration and this will drive diffusion of CO2 outward, toward the lower concentration near the cell-wall surface adjacent to the intercellular space. Diffusion of CO2 into intercellular space continues toward regions of lower concentration until it reaches the intercellular space below the dermal system. From there, CO2 moves through the cuticle or openings in the commodity’s surface to the air (Burton, 1982).

Movement of O2 within plant tissue is in a reverse but similar process to that mentioned above for CO2. In senescent tissue, O2 diffusion may be slowed down if the intercellular spaces become filled with cellular solution that anaerobic conditions develop within tissues. The rate of gas movement depends on the properties of gas molecule and the physical properties of the barriers (thickness, density etc.). Solubility and diffusivity of each gas are important for its diffusion across barrier. CO2 moves more readily than O2, while diffusion rate of C2H4 and CO2 are similar.

Internal concentration of CO2 and O2 in plant organs depend upon the maturity stage at harvest, the current organ temperature, the composition of external atmosphere and any additional barrier. Maturity stage influences the dermal system that effects gas diffusion. Increased temperature results raised rate of respiration as a result internal CO2 level increases as the O2 level decreases. If all other factors are held constant and the movement in the gas concentrations is the driving force for diffusion, then the concentration of O2 and CO2 within the tissue will fluctuate according to the fluctuation in the external atmosphere.

Methods to Alter rates of Gas Exchange

There are three types of barriers to gas exchange that affect the postharvest handling of fresh produce (Fig. 1). These are (i) the structure of the dermal system such as thickness of cuticle, number and distribution of stomata and breaks in epidermis etc. Resistance to gas diffusion can be increased by adding barrier such as wax coating or covering produce with polymeric films. (ii) The package in which the commodity is shipped can be additional barrier to gas diffusion. (iii) The degree of gas tightness of the transit vehicle or storage room will also affect gas exchange with outside air.

Schematic model of a commodity and its environment with three levels of gas exchange: B1= structure of dermal system and added barriers (waxing and film wrapping), B2= Permeability of package to gas diffusion, and B3 = gas tightness of the storage room Source: (Kader & Saltveit, 2003)

Fick’s first law of diffusion states that the movement or flux of a gas in or out of a plant tissue depends on the concentration gradient across the barrier involved, the surface area of the barrier and the resistance of the barrier to the diffusion. Fick’s law can be written as follows:

J = A. Î” C/R

Where

J = Total flux of gas to be diffused (cm3. s-1)

Î” C= Concentration gradient across the barrier

A= the surface area of the barrier

R= Resistance to diffusion

If the production or consumption rate of the gas by the organ and the concentration of the gas in the internal and external atmosphere is known, then the resistance is calculated as follows:

R = Concentration gradient/ Production or consumption rate

Different harvested fruits and vegetables have different rates of respiration; some respire at a faster rate (more perishable), while some respire at a relatively slow rate (less perishable vegetables) (Table 1).

Table 1: Classification of Sample Horticultural Commodities According to Respiration Rates (Wilson, 1999).

Respiration Rates

Types of Fruits and Vegetables

Very Low

- Dried fruit and nuts

Low

- Apples, garlic, grapes, onions, potatoes (mature), sweet potatoes

Moderate

- Apricots, cabbages, carrots, figs (fresh), lettuce, nectarines, peaches, pears, peppers, plums, potatoes (immature), tomatoes

High

- Artichokes, Brussels sprouts, cut flowers, green onions, snap beans

Extremely High

- Asparagus, broccoli, mushrooms, peas, sweet corn

The process of respiration is very important during ripening of fruit. In general there is an inverse relation between the rate of respiration and the postharvest life of fruit. Postharvest produce are classified according to their respiration rate as climacteric or non- climacteric. The rate of respiration increases in climacteric fruits during ripening while non-climacteric fruit shows no change in their low CO2 and ethylene production rates during ripening (Kader, 2002).

If prevention or decrease in respiration is achieved, this will prolong post-harvest storage life. Ethylene causes the increase in respiration, so decreasing ethylene is also a strategy used to increase post-harvest storage life.

Factors affecting respiration rate

Environmental Factors

Temperature

Temperature is important environmental factor in the postharvest life of fresh produce due to its outstanding effect on rates of biological reactions, including respiration. Within the physiological temperature range, the velocity of biological reaction increases two to threefold for every 10 °C rise in temperature (Van’t Hoff rule).

The ratio of reaction rates at two dissimilar temperatures is called the temperature coefficient (Q10) if the interval between the two temperatures is 10oC. If the temperature interval of Q10 is not exactly 10o C then it can be determined by the following equation:

$Q10 = (R2/ R1)\ 10/T2-T1$

Where R2 = rate of respiration at T2

R1 = rate of respiration at T1

T1 and T2 = temperature in °C

Scientists have found that Q10 is not constant for most biological processes over a wide range of physiological temperatures. Usually Q10 ranges from 1 to 5, although higher value may occur. For most biological reaction the Q10 is between 2 and 3 for temperature between 10 to 30 °C that means the reaction rate will be double or triple with every 10 °C increase.

O2 and CO2 Concentration

Practically, respiration can be controlled by either increasing carbon dioxide or decreasing oxygen. Decrease in oxygen near to zero is not desirable, though the O2 concentration reduces below that in air (20. 9%) and especially below 10%, a significant reduction in respiration rate is observed (Gorny, 2001). However when O2 concentration drops to less than 2 %, anaerobic respiration rate become predominant and CO2 production increases. (Figure 2) (Kader & Saltveit, 2003).

Ethylene Concentration

Exposure of climacteric tissues during their pre-climacteric stage to ethylene raises the rate of respiration. Once the respiration rise has begun, the endogenous rate of ethylene production increases and the internal ethylene concentration also increases, reaching levels that saturate its biological activity. However, unlike the case in climacteric tissues in non-climacteric tissues endogenous ethylene production remains unaffected (Kader & Saltveit, 2003).

Internal factors

Type of Commodity

Fruits and vegetables vary greatly in their respiration rate (Table. 1). Differences among plant parts and in the nature of their surface coatings (e. g. cuticle thickness, stomata, lenticels) influence their rate of diffusion characteristic and consequently their respiration rates.

Stage of development at Harvest

The respiration rate is usually high at early stages of development and decreases as plant organs mature. Thus fruits and vegetables harvested during the active growth phase have high respiration rates.

Chemical Composition

Respiration rate decreases with a decrease in water content of the tissue. The value of Respiration Quotient (RQ) is usually controlled by the rate of utilization of carbohydrates, proteins, lipids etc.

ETHYLENE PRODUCTION

Ethylene (C_2H_4) is a gaseous hormone produced from bacteria, fungi and all parts of higher plants such as shoots, flowers, seeds, leaves, roots, and fruits (Pech et al., 2003). It is a flammable and colourless gaseous compound (Arshad & Frankenberger, 2002).

Being a ripening hormone ethylene play a very important role in the postharvest life of many horticultural products, like increasing senescence speed and reducing shelf life but beneficially it improves the quality of the fruit and vegetables by manipulating uniform ripening process (Reid, 2002, p. 149). Because of the enormous influence of ethylene on the physiological development and postharvest life of fruits and vegetables, its biosynthesis, action, and control have been intensively investigated (Reid, 2002; Pech et al., 2003).

The biosynthetic process of ethylene is usually completed in three major steps. The ethylene biosynthetic pathway is given in the figure 3.

Step I:

The biosynthesis of ethylene hormone is started by the conversion of Methionine (MET) to S-adenosyl-L-methionine (SAM) by the enzyme methionine adenosyltransferase (Pech et al., 2003). However, methionine adenosyltransferase is thought to consider as a rate limiting enzyme in ethylene biosynthesis because formation of SAM depends on the activity of this enzyme and SAM levels may indeed regulate ethylene production. Therefore, the sensitivity or importance of methionine adenosyltransferase to SAM implies that this enzyme may play a regulatory role in ethylene biosynthesis (Arshad & Frankenberger, 2002, p. 13).

Step II:

SAM is consequently converted to 1-aminocyclopropane-1-carboxylic-acid (ACC) by a pyridoxal enzyme ACC synthase (ACS) (Figure 1). Actually, before the discovery of ACC, as intermediate, immediate precursor in MET dependent ethylene production process, the ethylene biosynthetic pathway was intangible (Arshad & Frankenberger, 2002, pp. 11-50). The conversion of SAM to ACC by ACS is another rate-limiting step in the biosynthetic pathway of ethylene. ACS is a cytosolic enzyme (found in the cytoplasm of plants) (Paliyath & Murr, 2008b) and its activity is strongly inhibited by aminoethoxyvinylglycine (AVG) (a competitive inhibitor) and aminoisobutyric acid (AIB) (an inhibitor of pyridoxal phosphate-mediated enzyme reactions) (Arshad & Frankenberger, 2002, pp. 11-50). Moreover, the activity of ACC synthase is also influenced by factors such as fruit ripening, senescence, auxin levels, physical stresses, and chilling injury. The synthesis of this enzyme increases with an increase in the level of auxins, indole acetic acid (IAA) and cytokinins (Wills et al., 1998, p. 42).

Step III:

At last the ACC converts into ethylene by the action of ACC oxidase (known as ‘ ethylene forming enzyme’ or EFE) (Arshad & Frankenberger, 2002, pp. 11-50; Pech et al., 2003). However, ACC oxidase is a bi-substrate enzyme as it requires both oxygen and ACC. Moreover, this enzyme also requires Fe2+, ascorbate and CO2 for its activity. Activity of ACC oxidase is inhibited by cobalt ions, and temperatures higher that 35oC (Wills et al., 1998, p. 42).

The sub cellular position of ACC oxidase is still a point of controversy because there is a large number of data is available showing that this enzyme is associated with plasma-membrane or with apoplast or tonoplast. The activity of this enzyme (ACC oxidase) has been studied in many horticultural crops like melon, avocado, apple, winter squash, pear and banana. The activity of ACC oxidase is not highly regulated as ACS. It is constituted in most vegetative tissues and it is induced during fruit ripening, wounding, senescence and fungal elicitors (Arshad & Frankenberger, 2002, pp. 11-50).

In fruits and vegetables several metabolic reactions starts after harvesting. In most cases, an increase in biosynthesis of gaseous hormone like ethylene serves as the physiological indication for the ripening process. During ripening process, in some fruits large amount of ethylene is produced which is usually referred as ‘ autocatalytic ethylene’ production response. However, fruits are divided into two main categories on the basis of ethylene production, i. e. climacteric (those produce large amount of ethylene) and non-climacteric fruits (those produce smaller amount of ethylene). In climacteric fruits like apple, pear, banana, tomato and avocado, ethylene production usually ranges from 30-500 ppm/(kgh) during ripening. While non-climacteric fruits like orange, lemon, strawberry and pineapple, produce 0. 1-0. 5ppm/(kgh) of ethylene (Paliyath & Murr, 2008) (Table 2). Therefore application of even a very low concentration of ethylene (0. 1-1. 0 Î¼L/L) is sufficient enough to accelerate full ripening of climacteric fruits; however, the magnitude of the climacteric rise is not dependent on the amount of ethylene treatment. On the contrary, application of ethylene causes a temporary rise in the rate of respiration of non-climacteric fruits and the degree of increase depend upon the amount of ethylene (Wills et al., 1998).

Moreover, the difference in the respiratory patterns of climacteric and non-climacteric fruits is associated with the different behaviour in terms of the production and response to ethylene gas (Burton, 1982). The increase in respiration, as influenced by ethylene application, may happen several times in non-climacteric fruits, but only once in climacteric fruits (Wills et al., 1998).

Indeed, ethylene is produced by all parts of the plant but the magnitude of ethylene production varies from organ to organ and also depends on the stage and type of growth and developmental process. In fact, recent ethylene based research findings have increased the understanding of biosynthetic pathways and enzymes involved in ethylene production, as well as the development of several ways to manipulate ethylene production e. g. by genetic alteration of plants (Arshad & Frankenberger, 2002). Ethylene is produced by various plant parts growing under normal conditions however, any kind of biological, chemical or physical stress (e. g. wounding) strongly promotes endogenous ethylene synthesis by plants. Among stress induced ethylene production, pre-harvest deficit irrigation is one of the most important factor causing higher ethylene production rates in fruits like avocado (Adato & Gazit, 1974) and tomato (Pulupol et al., 1996).

REGULATION OF ETHYLENE BIOSYNTHESIS

In plants, ethylene itself stimulates the ability of the tissue to convert ACC into ethylene, which is also regarded as phenomenon of ‘ auto-regulation’. In ripening fruits, regulation of ethylene biosynthesis is a characteristic feature and is triggered by the exposure to exogenous ethylene by the activation of ACC synthase and/or ACC oxidase (Arshad & Frankenberger, 2002, pp. 25-27).

On the other hand, sometimes ethylene inhibits its own synthesis, as negative feedback has already been recognised in a number of fruits and vegetable tissues. In such cases, exogenous ethylene significantly inhibits the production of endogenous ethylene, induced by ripening, wounding and/or treatment with auxins. Moreover, this auto inhibitory effect seems more directed towards limited availability of ACC in the presence of AVG, an inhibitor of ACC synthase (Arshad & Frankenberger, 2002, pp. 25-27). Scientists have also revealed that the inhibition or negative regulation of ethylene synthesis is the result of activity of a gene, E8 whose expression leads to the inhibition of ethylene production in tomatoes (Arshad & Frankenberger, 2002, pp. 25-27).

MECHANISM OF ACTION

The response of ethylene action can be classified into two categories namely concentration response and sensitivity response. The concentration response involves the changes in concentration of cellular ethylene while the sensitive response involves the increase in tissue sensitivity to ethylene. Moreover, both of these responses involve the binding of ethylene to some components of the cell to mediate the physiological effects (Arshad & Frankenberger, 2002, pp. 28-36).

Wills et al. (1998, pp. 42-45) likewise explained that plant hormones control the physiological processes by binding to specific plant or fruit receptor sites, which trigger the succession of events leading to visible responses. In the absence of ethylene, these receptor sites are active, allowing the growth of plant and fruit to proceed. During fruit ripening, ethylene is produced naturally or, if it is artificially introduced in a ripening room, it binds with the receptor and inactivates it, resulting in a series of events like ripening or healing of injuries in plant organs. Ethylene action can be controlled through modification of the amount of receptors or through disruption of the binding of ethylene to its receptors. Binding of ethylene is believed to be reversible at a site which contains metal like copper, zinc, or iron (Burg & Burg, 1965, as cited in Burton, 1982). The affinity of receptor for ethylene is high in the presence of oxygen and decreases with carbon dioxide.

Changes in the pattern of ethylene production rates and the internal concentrations of ethylene associated with the onset of ripening have been studied in various climacteric fruits. For instance, tomato and honeydew melon exhibited a rise in ethylene concentration prior to the onset of ripening, determined as the initial increase in respiration rate. On the other hand, apple and mango did not show any increase in ethylene concentration before the increase in respiration (Wills et al., 1998, pp. 42-45).

Ripening has been associated with senescence as it leads to the breakdown of the cellular integrity of the tissue. It is part of the " genetically programmed phase in the development of plant tissue with altered nucleic acid and protein synthesis occurring during the onset of the respiratory climacteric resulting in new or enhanced biochemical reactions operating in a coordinated manner" (Wills et al., 2007, p. 40). These concepts confirm the known degradative and synthetic capacities of fruit during the ripening process. The ability of ethylene hormone to initiate biochemical and physiological events leads to the theory that ethylene action is regulated at the level of gene expression (Pech et al., 2003; Wills et al., 1998, pp. 45-46).

TRANSPIRATION/ WATER LOSS

Plants depend more on the availability of water than any other single environmental factor (Kramer and Boyer, 1995). Water loss is very important in determining the shelf life and quality of harvested plant organs. As long as the harvested produce retains water, it remains fresh. Transpiration is one of the main processes that affect postharvest life of the fruit (Ben-Yehoshua & Rodov, 2003)

Most fresh produce contains from 65 to 95 percent water when harvested. Within growing plants there is a constant flow of water. Fresh produce continues to lose water after harvest, but contrary to the growing plant it cannot replace lost water from the soil and so must use up its water content remaining at harvest (Gustavo et al., 2003). This loss of water from fresh produce after harvest is a serious problem, causing shrinkage and loss of weight. When the harvested produce loses 5 or 10 percent of its fresh weight, it begins to wilt and soon becomes unusable. To extend the usable life of produce, its rate of water loss must be as low as possible (Wilson et al., 1995). Although temperature is the prime concern in the storage of fruits and vegetables, relative humidity is also important. The relative humidity of the storage unit directly affects water loss in produce. Water loss means salable weight loss and reduced profit (Wilson et al., 1995).

Transpiration of fresh fruits is a mass transfer process in which water vapor moves from surface of the plant organ to the surrounding air. Fick's law of mass transfer explains this process as follows:

J = (Pi-Pa) At / (RDT)r

Where Pi and Pa are the partial gas pressures in intercellular spaces and in the ambient atmosphere respectively; At is surface area of fruit; RD is the gas constant per unit mass; T is the absolute temperature; r is the resistance; and J is the gas flux. According to Fick's law, the movement of any gas in or out of the plant tissue is directly proportion to the partial pressure gradient (Pi-Pa) across the barrier involved and the surface area of the barrier and is inversely proportion to the barrier to diffusion. Therefore the driving force of transpiration is the difference of water vapor pressure (WVP) between the tissue and the surrounding air. While the water vapor pressure deficit (VPD) of the air is difference between the WVP of air and that of saturated air at the same temperature. Relative Humidity is the most popular term for expressing the water content of air. It can be defined as the ration of actual WVP in the air to the saturation WVP at a given temperature.

Water loss depends on the difference between the water vapour pressure inside the fruit and the pressure of water vapour in the air. To control water loss in fresh produce as low as possible, it must be kept in a moist atmosphere. Air movement also plays a vital role in the water loss from the fresh produce. Water loss is directly proportion to the air movement in the surrounding. Though air movement through produce is also indispensable to remove the heat of respiration, but the rate of movement must be kept as low as possible (Gustavo et al., 2003).

ROUTES OF WATER TRANSMISSION

As the harvested fruits and vegetables are detached from plant, the xylem vessels are blocked with air and their operation is stopped (Burton, 1982). Therefore, water has to use different routes to move through the tissue. Following are the major potential pathways for water movement in harvested produce.

Symplast

The cytoplasm of connected cells is interconnected by plasmodesmata, filled with protoplasm and lined with the plasmalemma. Therefore symplast is formed throughout the interior of a plant organ. Water and dissolved solutes move through the symplast system from cell to cell by diffusion (Ben-Yehoshua & Rodov, 2003).

Apoplast

The cell wall surrounding symplast also form a continuous system, termed as apoplast. The apoplas provide an alternative avenue for liquid water movement by hydrostatic pressure through the interfibrillar spaces in the cell wall (Woods, 1990).

Intercellular Atmosphere

The plant also contains a system of intercellular gas-filled spaces that form a continuous network and serve as main pathway for O2 and CO2 transport.

This field of air space provide adequate gas exchange in bulky organs (Ben- Yehoshua. S, 1969).

MAJOR EVAPORATION SITE: COMMODITY SURFACE

There are three major routes for moisture loss from harvested commodities to the atmosphere: (a) through outer layer that forms a surface for evaporation (cuticle and epicuticle wax; periderm) resistance for water movement through (b) the apertures in the surface connecting the internal and external atmosphere (stomata, lenticels) and (c) through the stem scars or pedicel.

Cuticle and Epicuticular wax

This layer, which lines all interfaces between the plant and the atmosphere, protects the plant from its relative dry environment. Resistance to water movement is derived from cuticular layer (Ben- Yehoshua, 1969; (Burg & Burg, 2006). The cuticle cosntains a matrix of cellulose, polyuronic acids, proteins and phenolic compounds. These are combined with variation of amount of waxes embedded over its surface (Kolattukudy, 1980). Permiability to water usually depends more on amount of waxes than on the thickness of cuticle (Kramer & Boyer, 1995).

Periderm

Periderm is a corky peripheral tissue. This tissue consists of several layers of cells that become corky as a result of deposition of waxes on their cell walls, and they lose their living contents. The periderm is not readily permeable to water and is permeable to gases only through lenticular pores, which replace the stomata of the original epidermis. About 97% of the total water lost from the potato tubers migrates through cell walls to the periderm, where it evaporates (Burton, 1982).

Trichomes and Hairs

Unicellular or multicellular projections develop on the epidermis of all parts of plants. Their exact function is still vague, but they are considered to reduce water loss (Cutter, 1976). The presence of trichomes can decrease the driving force of transpiration by reducing the surface temperature and increasing the boundary layer resistance.

Stomata

Before harvest, most of the evaporation occurs from undersides of leaves via stomatal guard cells and adjacent cells (Kramer and Boyer, 1995). Stomata occur in many fruits at early stages of development, but sometimes they are not found in mature fruits of some species, for example, in the grape berry (Possingham et al., 1967). Orange has greatest stomatal density reported so far for any fleshy fruit (Banks, 1995). Stomata usually function less effectively in mature fruit (Blanke and Leyhe, 1988). In most cases it is reduced with maturation and usually of minor importance for fruit water loss during postharvest period (Ben-Yehoshua & Rodov, 2003).