



Review Article

Review on postharvest quality and handling of apple

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Abstract

Apple is a climacteric temperate fruit with high market demand providing essential components to the body. Nowadays, apple production is increasing every year especially in EU member countries are the highest producer. Hence, this paper reviews the postharvest quality and associated changes during handling. Usually, farmers face difficulty in estimating the right harvesting time though Different methods exist to test the maturity stage such as counting the days after full bloom, color change, firmness test, measuring soluble sugar, starch iodine test and Streif index. Depending on different factors, farmers can choose the best maturity estimation method in various locations. Postharvest diseases of apples makeup a major part of the economic losses incurred during apple production. Annual losses of many fruits, including apple, vary from 5 to 35% and for developing countries, it ranges between 20%-50%. The most common causes are poor harvesting methods, transportation and storage methods which can open access for fungal growth species such as *Botrytis* species. *B. cinerea* is one of the most important of the species with unique characteristics causing the highest losses.

Introduction

Apple (*Malus domestica*) is a temperate fruit adapted to the temperate zone of latitude varying between 35 and 50° (Kellerhals, 2009). It consists of various biologically active compounds and certain phenolic compounds that are recognized to act as antioxidants. Apple is available throughout the year and consumed as fresh or after being processed in to juice, slice or other products (Wu, *et al.* 2007).

The current production of apple worldwide is exceeding 50 million tons each year. EU member states are among the highest producers of apple with high consumption. Jonagold, Jonagored and Golden Delicious are the most widely grown apple cultivars in Belgium for both local consumption and export (Kellerhals, 2009).

Postharvest diseases of apples makeup a major part of the economic losses incurred during apple production. Annual

losses vary from 5 to 35% and for developing countries, it ranges between 20- 50% losses before it reaches the consumers [1].

A variety of bacterial and fungal species are responsible for postharvest losses. The most common fungal pathogens are *Botrytis cinerea*, *Penicillium expansum* and *Mucor piriformis* (Elad, *et al.* 2007). Among these fungal pathogens, *Botrytis* species are the most threatening pathogens of many agricultural commodities including ornamentals and field crops (Elad, *et al.* 2004). *B. cinerea* is one of the most important of the *Botrytis* species with unique characteristics. It can live both pathogenically and endophytically [2].

Harvest date prediction and maturity monitoring

The most vital concern in the harvesting procedure is to select the ideal harvesting time. The fruit maturity at harvest directly affects quality and storability of the apple fruit [3,4]. For long-term storage, fruits have to be harvested at earlier maturity stage. Different methods are used to test the maturity

stage such as counting the days after full bloom, color change, firmness test, measuring soluble sugar, starch iodine test and Streif index.

Streif index, (firmness/(TSS × starch index)), is used most often in determining apple maturity stage because of its reliability and it is not sensitive to location variation and year [5]. These measurements are easy, rapid and inexpensive. Starch level decreases as the maturity stage of the fruit increases because of the conversion of starch to sugar. It starts to decline before the onset of ripening and this helps to predict the maturity level of the apple. Starch-iodine chart picture is a very simple, cost-effective and quick method to assess the maturity stage of the apple during a harvest and storage time [4-7].

Respiration and ethylene production rate of apple increases as it reaches to maturity. The climacteric minimum point is a good indicator of maturity stage before the onset of ripening. Monitoring respiration and ethylene production is usually done in the laboratories and are a good indication of maturity stage. This method is not feasible and practical for farmers to use them on the field due to the requirement of laboratory setup [8,9].

Postharvest change and apple quality

Fruit ripening is a period associated with physiological and structural changes: fruit softening, respiration, hydrolysis of starch, chlorophyll degradation and membrane changes. These physiological and structural changes after harvesting can be slowed down primarily by Controlled Atmosphere (CA) storage. Due to low concentration of oxygen and higher carbon dioxide, all biochemical processes are suppressed in CA storage [10]. Apple quality is a combination of parameters such as firmness, color, Total Soluble Solid (TSS), sugar content and titratable acidity. These parameters are important in determining apple maturity and consumer pleasure. Apple firmness is associated with texture while TSS, sugar and acidity are related to the taste characteristics of the apple [11].

Pectic substances are the main constituents of both middle lamella and cell wall matrix. They are key regulators of intercellular cell adhesion. Thus, pectic has been considered an important substance determining the fruit texture [12,13]. Various networks of pectin, cellulose microfibril, proteins (structural) and phenolics determine the firmness. Microfibrils are embedded between the matrix of polysaccharides and pectin forming stiff bonds.

Besides these bonds, links between various components such as between xylan and cellulose through hydrogen bond, rhamnogalacturonan attached together and homogalacturonans to each other by ionic calcium bond determines the firmness of the cell wall. Pectin to pectin through ester bond formation and linkage between rhamnogalacturonan and xyloglucan by covalent bond also contributes to the firmness of the cell wall [14].

Cell wall modification is the main reason for the softening during fruit ripening. This loss of firmness is due to change in

pectin polysaccharides [15]. Enzymes which are believed to be responsible for cell wall modifications are polygalacturonase, pectate lyase, methylesterases, β -galactosidases and α -L arabinofuranosidases. These enzymes causes debranching (side chain of the pectin), depolymerization and solubilization of the cell wall pectin [3,16]. Consequently, the fruit loses its firmness.

Color is an important quality parameter determining the visual quality and market acceptability by consumers. Color development is associated with ripening process due to associated physiological change. It is characterized by color evolution through breakdown of chlorophyll and other pigments [17]. Different factors influence their synthesis such as light energy and temperature [18]. Since color is the first sensation that consumers use to reject or accept a fruit, adequate storage throughout the postharvest chain is required [6].

During fruit ripening and storage, titratable acid content of the fruit declines gradually leading to reduced fruit flavor [11]. Consumer acceptability depends on the right sugar/acidity ratio of fruit. Soluble solid content of the fruit at maturity stage varies between seasons, cultivar, and chemical application. Soluble solid includes organic acids inorganic salts and sugars. Starch degradation as maturity progresses increases the concentration of soluble sugars leading to a sweet taste. Picking soluble solid content of Delicious apple can vary between 10.8%-12.2% [9].

Ethylene control

Ethylene regulates many plant responses such as senescence, ripening, growth and abscission. This response is controlled by regulation of either ethylene production or action. Usually controlling the activity of enzymes involved in ethylene biosynthesis, such as ACC synthase and ACC oxidase, are most effective (Figure 1). Amino-ethoxy-vinyl-glycine (AVG), Aminoxyacetic acid (AOA) acid and Naphthaleneacetic acid are used to control ethylene through inhibition of ethylene biosynthesis. 1-methylcyclopropene (1-MCP) completely arrests the action of the ethylene by binding with ethylene receptors[19].

During biosynthesis of ethylene, the conversion of ACC to ethylene requires both ACCase enzyme and oxygen. Thus, anaerobic condition favors the suppression of ethylene production due to the low or absence of oxygen. Storing apples under low oxygen conditions, in other words in CA storage plays an important role to inhibit ethylene biosynthesis.

Physical treatments including hot water dip can suppress ethylene biosynthesis by inactivating ACCase and ACCase enzymes which have an active role in ethylene synthesis. According to the review of Fallik [20]. Hot water immersion (43-53°C, 2 hours), ethylene production of an apple was significantly reduced. Bai, *et al.* [21]. Also observed reduced ethylene production after placing the apple in 38°C and >93% RH air for 4 days. Moreover, heat treatment also controls microorganisms and insects attack besides inhibiting ethylene production.

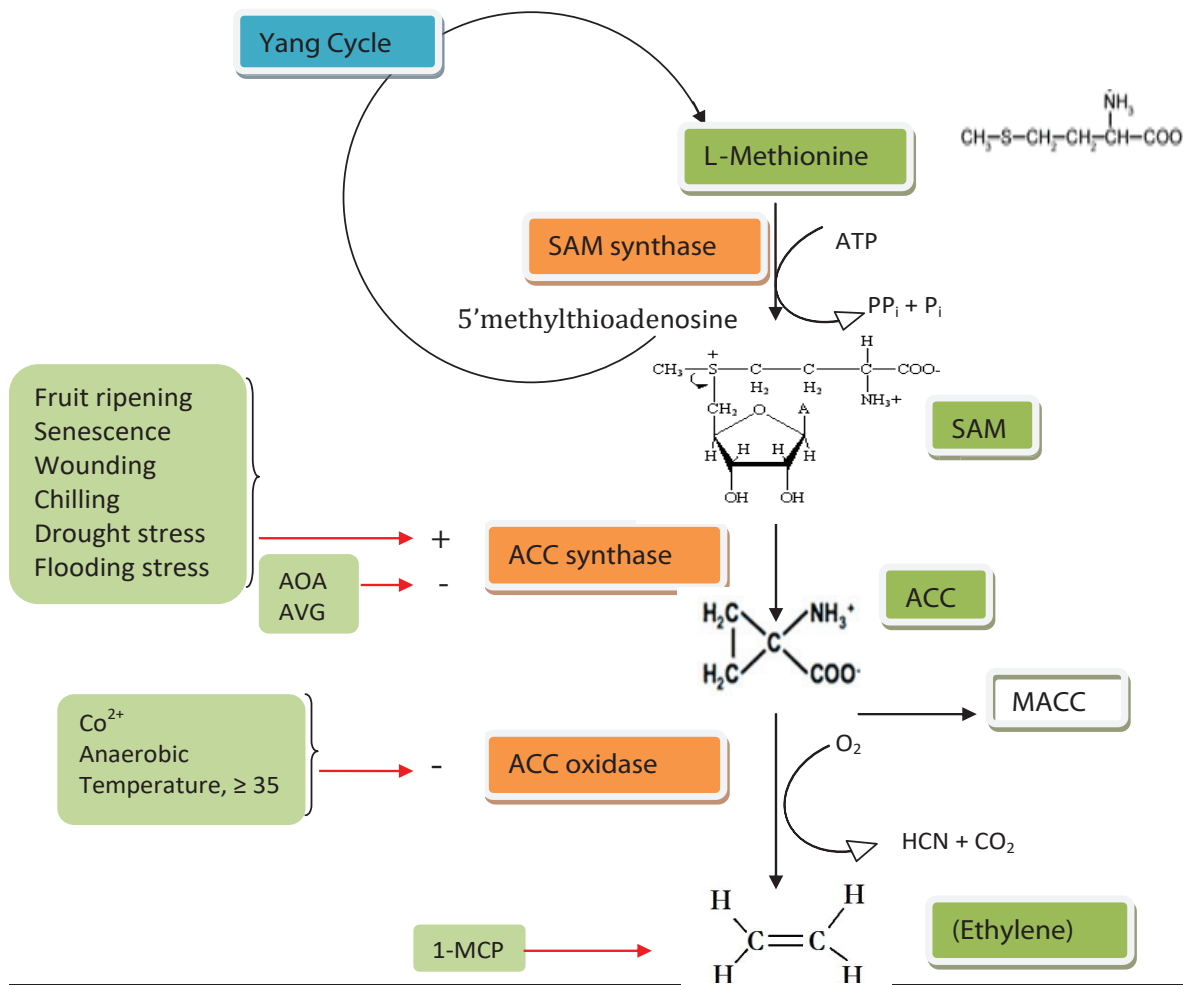


Figure 1: Schematic presentation of the ethylene biosynthesis pathway as well as ethylene inhibiting and/or promoting factors. Arrow with “-” sign are factors inhibiting ACS and ACO enzymes to suppress ethylene production; 1-MCP inhibit ethylene action by binding with ethylene receptors. Signs with “+” are factors that increase ethylene production by accelerating the conversion of SAM to ACC by triggering the expression of ACS [22].

Losses of apple

Losses of apple fruits are a major problem in the postharvest chain and are caused by a wide variety of factors, ranging from pre-harvest conditions to retailer and consumer level. Harvesting before optimal maturity stage is one of the factors. There are a number of reasons that farmers may harvest apples before optimal maturity. For example, early arrival of harvesting labors, incorrect prediction of harvesting date or different environmental factors may delay optimum maturity [23]. Consequently, the apple has less sensory qualities.

Apples undergo various loading actions that can lead to bruising and this at different stages of handling such as on the farm, during grading, storage and distribution. According to Yuwana & Duprat [24] and Gonzalez [25]. Between 20%-50% of the total apples get bruised during different handling steps. Bruise severity of apple mainly depends on the cause of the bruise, the variety and harvesting conditions [25].

In CA storage, optimizing the levels of gasses is essential to protect the fruit from atmospheric induced disorders such as low oxygen or high carbon dioxide injury [26]. Too low oxygen

level can result in alcoholic flavor produced through anaerobic fermentation. Too high carbon dioxide levels can induce rough fruit skin and internal browning. Apples are typically stored at 0°C and some varieties are susceptible to internal disorders and are often stored at temperatures above 0°C. This sensitivity of apples to low temperature injury is variety dependent [27].

Postharvest pathogens play a major role in causing losses in the apple production chain. More than 90 fungal species have been described that cause decay of apples during storage. The relative importance of each pathogen depends on climatic and storage conditions [28]. Cold storage temperature is vital for postharvest pathogen control because growth temperatures for these pathogens are much higher. Still, some fungi are able to grow at temperatures as low as -2°C. Consequently, they cannot be entirely controlled unless the storage time is limited [29].

Common fungi species that are responsible for the losses of stored apple fruits include *Botrytis cinerea*, *Penicillium expansum* and *Mucor piriformis* [30]. Diseases from these fungi occur regularly during storage and cause high yield and economic losses.

Botrytis cinerea

Botrytis cinerea is the most widely distributed necrotrophic fungal pathogen of fruits, vegetables, transported and stored plant commodities. Over 235 crop species can be affected by *Botrytis* species and some of the *Botrytis* species are host specific. Epidemics due to *Botrytis* species are economically damaging. For this reason, strong effort has to be invested before and after harvesting to protect against *Botrytis*.

B. cinerea is the most interesting and important *Botrytis* species with unique characteristics. It can live both pathogenically and also endophytically in the host [2,31].

Different stages of infections processes are distinguished in fungus *B. cinerea* species as indicated in Figure 2. Infection process of *B. cinerea* comprises major stages: conidium attachment, germination, penetration and killing of the host. Conidia are ubiquitous in the air and transported by different agents such as wind, insects and rain over distances to start a new infection. Once the conidium is attached to the host, it starts to germinate when conditions are good and produces germ tubes. At the tip of the germ tube, appressoria develop which assists penetration. Therefore, the cells are killed and necrotic lesion progresses [2].

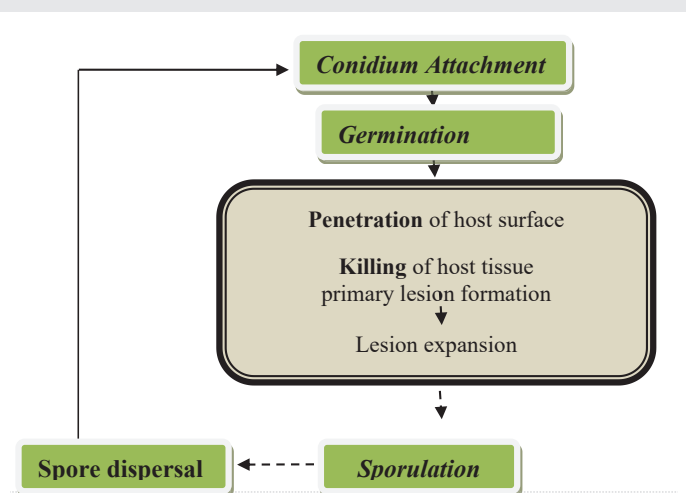


Figure 2: Different infection stages of fungus *B. cinerea* species. (The diagram is adapted from Jan & Kan 2006) [32].

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