Fruit Quality Parameters in Apple 
(Malus × domestica Borkh.)

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Summary

Apple is the fourth important temperate fruits crop of the world after citrus, grapes and banana and is presently grown in many countries with a total world production of more than 71 million tonnes. Apples are consumed fresh, directly after harvest or after a storage period for up to 6 months or even longer. Apples can also be processed into juice, sauce, slices, vinegar and cider. Most of the cultivated apples belong to the species *Malus × domestica* Borkh. in the Rosaceae family. More than 7500 apple cultivars have been described from different countries. However, only a few of them have achieved commercial success in the international market. The commercial success of any apple cultivar depends upon various quality traits such as fruit size, colour, taste, acidity, shelf life, disease resistance, pre and post harvest changes etc. None of the apple cultivar has all these good qualities but the commercially successful cultivars have optimum level of one or more of these traits. Consumers from different geographical regions prefer different quality traits which in turn determine the success of an apple cultivar in that region. The attractiveness of fruit to consumers is determined by visual attributes that include appearance, size, uniformity, colour, storability and shelf-life as well as non-visual attributes such as taste, aroma, flavor, firmness (texture), nutritional value and healthiness. Golden Delicious and Delicious strains are preferred in USA, Cox’s Orange Peppin in England, Grainy Smith in Australia, McIntosh in Canada, Breaburn in New Zealand, Fuji in Japan and Red Delicious and its sports in India. Consequent upon this, most of the orchids in these countries are occupied by their respective dominant cultivars resulting into monoculture of apple and subsequent germplasm depletion. Understanding of fruit quality parameter in apple may help in organizing such apple breeding programmes, wherein, the otherwise, commercially less important cultivars could be exploited for their genetic improvement so as to bring them at par with existing successful cultivars. In this backdrop, a detailed understanding of fruit quality traits in apple has been presented in this chapter.
Introduction

Apple (*Malus × domestica* Borkh) is one of the leading temperate fruit crops of the world and has high market value for its beautiful appearance, crispy flesh, pleasant flavor and sweet taste (Asif Ali et al., 2004). In general apple fruit has multiple uses, preferably consumed as fresh and also processed into juice, sauce, slices, vinegar and cedar (Folta and Gadiner, 2009). It is believed that more than 7500 cultivars exist in the world that have originated from different countries. Many cultivars have desirable characteristics which make them suitable for cultivation under specific conditions, but only a few dozen of these are grown commercially on a worldwide scale (Moore et al., 1991). In early times the apple cultivars have been selected in or around established orchards as chance seedlings whereas more recent cultivars generally are derived from breeding programs or have been selected as sports (mutants) from other cultivars (Janick et al., 1996; Brown et al., 2005). An apple cultivar is thus either a hybrid or a sport (mutant) and does not propagate true to seed. It must be propagated asexually by cuttings, grafting, budding, tissue culture etc. Thus, all trees of a particular type are clones of a single original tree. Development of new apple cultivars depends on improvement of several good characteristics such as uniform and consistent yield, commercial fruit quality, good post-harvest storability and shipping quality, high consumer demand and finally resistance against diseases, pests and storage disorders (Ferree and Warrington, 2003). Although transgenic plants have been produced for a number of apple cultivars (Seong et al., 2005; Chevreau et al., 2011; Wu et al., 2011), but these are yet to be released for cultivation. Apples generally require a certain amount of chilling accumulation during the winter to break bud dormancy before active shoot growth in the spring and are therefore suitable for growing mainly in areas with a temperate climate (O’Rourke, 2003). However apples can also be grown in other climates, like subtropical and even tropical areas at high altitudes, where sometimes two crops can be produced per year (Pereira-Lorenzo, 2009). The major apple producing countries are China, USA, Turkey, France, Germany, Italy, Poland, Russia and India (Table 1) but its cultivation has also been reported from countries like South Africa, Kenya, Ethiopia, Uganda and Zimbabwe etc. (Wamocho and Ombwara, 2001; Ashebir et al., 2010). In 2010, about 69 million tones of apple were produced worldwide with China producing half of it. The US is the second largest producer with more than 6% of world production. In India, apple is grown mainly in Jammu and Kashmir, Himachal Pradesh and
Uttaranchal. The Jammu and Kashmir state owing to its suitable climate, contributes 60-65% of apple to the total produce of the country. Some of the major apple cultivars grown in India include, Red Delicious, Royal Delicious, Simla Delicious, Golden Delicious, Ambri, Granny Smith, American Trel etc. The total area under apple cultivation in our country is 2.31 lakh ha with a total production of 13.80 lakh tones and a productivity of 6.0 tones/ha. A list of some major world cultivars with region of their preference is presented in Table 2.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Country</th>
<th>Production Million tonnes</th>
<th>S.No.</th>
<th>Country</th>
<th>Production Million tonnes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>China</td>
<td>33.27</td>
<td>7.</td>
<td>France</td>
<td>1.71</td>
</tr>
<tr>
<td>2.</td>
<td>USA</td>
<td>4.21</td>
<td>8.</td>
<td>Iran</td>
<td>1.66</td>
</tr>
<tr>
<td>3.</td>
<td>Turkey</td>
<td>2.60</td>
<td>9.</td>
<td>Brazil</td>
<td>1.28</td>
</tr>
<tr>
<td>4.</td>
<td>Italy</td>
<td>2.20</td>
<td>10.</td>
<td>Chile</td>
<td>1.10</td>
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<tr>
<td>5.</td>
<td>India</td>
<td>2.16</td>
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<tr>
<td>6.</td>
<td>Poland</td>
<td>1.86</td>
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<td><strong>World</strong></td>
<td></td>
<td><strong>69.57</strong></td>
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Source: [Wikipedia]

Table 2: List of major world apple cultivars and their region of preference.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Cultivar</th>
<th>Country/Region of preference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Red Delicious</td>
<td>United States, India</td>
</tr>
<tr>
<td>2.</td>
<td>Golden Delicious</td>
<td>Europe</td>
</tr>
<tr>
<td>3.</td>
<td>McIntosh</td>
<td>North Eastern United States and Eastern Canada</td>
</tr>
<tr>
<td>4.</td>
<td>Jonathan</td>
<td>Mid West</td>
</tr>
<tr>
<td>5.</td>
<td>Granny Smith</td>
<td>Australia, New Zealand, Argentina</td>
</tr>
<tr>
<td>6.</td>
<td>Cox-Orange Pippin</td>
<td>England</td>
</tr>
<tr>
<td>7.</td>
<td>Belle de Boskoop</td>
<td>The Netherlands</td>
</tr>
<tr>
<td>8.</td>
<td>Fuji</td>
<td>China, Japan</td>
</tr>
</tbody>
</table>
Fruit Quality Traits

Fruit quality is defined as the degree of excellence of fresh fruits and it is a combination of different characteristics and properties. These characteristics are usually attractive to consumers in terms of market acceptability or human health improvement (Kader, 1999). The attractiveness of fruit to consumers is determined by visual attributes that include appearance, size, uniformity, colour and freshness, as well as non-visual attributes such as taste, aroma, flavor, firmness (texture), nutritional value and healthiness (Nour et al., 2010). According to Pereira-Lorenzo (2009), important quality traits to consider are fruit size, shape, color, acidity, sweetness, flavour, resistance to diseases and abiotic stress, harvest time, storability and shelf-life. Nowadays, almost all commercially grown apples are stored for some times before being sold, and therefore cultivars need to have good storage ability (Ferguson and Boyd, 2002). Several other factors that determine the fruit quality include ethylene production level, antioxidant content, phenol content, harvest time and fruit maturity (Jenks and Bebeli, 2011). These fruit quality parameters are affected by many factors including genetics, soil properties and weather conditions and thus vary from cultivar to cultivar and even year to year in the same cultivar.

Many apple cultivars especially those which are not produced through planned breeding programs are characterized by quite their unusual pomological traits with a poor external appeal as compared to commercially successful cultivars which have arisen either through a planned breeding or have been maintained through skilled agricultural/agronomic practices. Low external appearance, biennial bearing, too bitterness or too sweetness, short shelf life etc. are some of the main reasons for loss of interest among orchardists to grow such cultivars. This in turn has led to monoculture of a specific group of cultivars. At present almost every country is practicing monoculture of a particular cultivar due to their commercial success based on fruit quality parameters. In Italy, 70% orchards are planted with cv. Golden Delicious (Donno et al., 2012), where as Red Delicious and its Sports are cultivated in major part of Indian orchards. Similarly
Grainy Smith is preferably grown in Australia, Breaburn in New Zealand, Fuji in Japan and McIntosh in Canada. The monoculture of apple has in turn led to genetic erosion and loss of many local cultivars. Increased knowledge of fruit quality traits in apple and methods of quality assessment that should correlate with consumer preference are thus two important factors in apple breeding programs that may help in evaluation of apple germplasm and selection of new cultivars other than already successful ones. According to Janick et al., (1996), the fruit quality can be judged by many criteria such as fruit size, shape, colour, flavor, texture, post-harvest storage etc. The commercially successful cultivars possess optimum range of most if not all of these quality traits, although the optimum range preference lies in the hands of a consumer. Descriptor lists for evaluating fruit morphology are available (Whatkins and Smith, 1982). Selection indices based on a number of characters have been proposed by Blaze and Paprustein (1988). Some of the fruit quality traits in apple are discussed below.

(i) Fruit Size

Fruit size is one of the most important traits in apple which varies among cultivars and even between trees of a single cultivar. According to Janick et al., (1996), there are many ways of expressing fruit size, the most common being diameter. The best way to determine fruit volume is given by the formula \[ \text{Height (mm)} \times \text{Radius (mm)}^2 \div 1000 \times 2.7 \] (Brown, 1960). The generally accepted minimum diameter in apple is 65mm. The number of cells, size of each cell, and the air spaces between cells all play important role in determining fruit size in apple. Some apples achieve their larger size by having larger number of cells, and some achieve their larger size by having larger sized cells. Factors that affect fruit size include genetic, cultural and environmental (Jemric et al., 2013). It has been established that genetic factors have a stronger influence on fruit mass than ecological conditions, rootstock and cultural practices. Some apples like crab apples are genetically small, whereas others like red delicious and its sports are genetically larger. In such cases both cell number and cell size may be genetically controlled.

Among cultural factors, crop load (number of fruits per tree in relation to size of the tree) is the most important factors that affect fruit size. Apples from trees with a heavy crop load tend to have smaller sized fruits, whereas, trees with moderate to standard crop load yield larger sized fruits. Reducing the crop load (also called thinning) is a general practice employed by growers to achieve suitable fruit size (Williams, 1985). Thinning increases fruit size largely by providing
resources for increasing the cell number of the remaining fruit. Other cultural factors that can affect fruit size are pruning, pollination, nutrition, and soil management.

The most important environmental factors influencing fruit size are temperature and light. At early stage, fruit growth occurs by cell division, whereas at later stage towards maturity, fruit growth occurs by cell expansion. The critical time period for fruit growth is the first five weeks or so following bloom. Bright sunny days and warm temperatures during early spring favor larger fruit size, than cool and cloudy weather in this period. Warm temperature increases fruit size primarily by providing conditions that increase cell size. In order to assess whether smaller size is correlate with poor fruit quality, De Salvaor (2006) studied relationship between fruit size and other quality parameters in Golden delicious and Red Chief cultivars under heavy and standard crop load conditions. A negative correlation was found between fruit size/TSS content and fruit weight/flesh firmness in both the cultivars. On the other hand a strong positive correlation was found between fruit size and fruit weight. Fruits from heavy cropping trees were found smaller, firmer and with higher TSS content indicating that a moderate increase in crop load does not affect fruit quality. There are, however, other observations that confirm that heavy crop load lowers TSS content and titrable acidity, reduces flesh firmness and alters background colour (Greene et al., 1989; Johnson, 1992; Gottfried, 2000).

In general, it is comparatively easy to achieve larger fruit size in cultivars having high genetic potential for this trait. However, larger sized fruits too have certain problems. They are softer than smaller fruits both at harvest and after storage (Siddiqui and Bangerth, 1995; Harker et al., 1997). The present day fruit size in apple has been achieved through a continuous selection process over the years from small wild types and their hybrids. According to Janick et al., (1996), for breeding programmes, it is advisable to select very large fruited seedlings as parents to ensure an increase in the proportion of seedlings with good fruit size from which selection for other desirable characters can be made.

(ii) Fruit Shape

Fruit shape is one of the important characteristics used by growers and consumers to identify apple cultivars. A mature apple fruit can be cut longitudinally in half through the core to
determine the fruit shape. Hedrick (1924) has classified fruit shapes of apple into round, conic, oblate, oblique, oblong, ovate and some intermediate forms (Fig.1).

![Fruit shapes in apple](https://www.google.co.in/search?q=Fruit+shape+apple+cultivars&espv) / www.ars.usda.gov / [http://www.extension.org/pages/66368/apple-fruit-shapes](http://www.extension.org/pages/66368/apple-fruit-shapes)

Fruit shape varies from cultivar to cultivar and may differ within a cultivar depending upon the growing location and the environmental conditions.

### (iii) Fruit Color

The peel or skin color of apple is an important quality attribute for growers as well as consumers. The consumers generally prefer either clear yellow, bright green or from complete red to striped red. In apple, fruit color is primarily determined by the ground color of the skin and secondly by the superimposed anthocyanin pigmentation. The ground color of an immature fruit is dark green and as the fruit matures, it may turn to green, greenish-yellow, creamish-yellow or yellowish-green (Janick et al., 1996). In absence of anthocyanin development, the fruit remains green or yellow at maturity. In presence of this pigment, however, the fruit takes several forms of
color development (red stripes, red blushes, solid red, etc.). The intensity of color as well as the colored area covered on the fruit shows great variations among cultivars and within a cultivar depending upon the amount of anthocyanin and the number of cells containing this pigment in the epidermal and sub-epidermal layers (Dayton, 1959). According to Janick et al., (1996), fruit color is a very complex character affected by the stage of maturity, general environment, nutritional factors and cultural practices and by the micro-environment within the area of the tree. The anthocyanin production is absolutely light and temperature dependent. Not only, the intensity, but also the quality of light influences anthocyanin formation. Low temperatures increases and high temperature reduces anthocyanin concentration in apple peels. The coloring, thus generally takes the shape of either stripes alone, stripes on a blush or blush alone. The ground color of the fruit has a direct impact on the color development in apple. The most brilliant color is produced when the ground color is almost white and the dullest brown, when the ground color is green (Janick et al., 1996). The consumer preference for fruit color varies from country to country and region to region. e.g. Red stripped apples are preferred in New Zealand, blushed apples in Canada and overall red in India. Since red color and its varied forms (red stripes and blushes) are a desirable character in apple, the cultivar Red Delicious and its red sports are the most dominant group of apple cultivars grown all over the world.

The flesh color of apple is also an important quality trait which varies from white through cream to pale yellow. In some cases it may be greenish white or tinged with red. For consumers as well as fruit processors, the preferred color is clear yellow. White flesh is also acceptable but red flesh is unacceptable (Janick et al., 1996).

(iv) Fruit flavor / aroma

Fruit flavor is an important trait determining the commercial success of an apple cultivar. Apple is a climacteric fruit meaning that a mature apple will experience a dramatic rise in respiration when ripening is initiated. Many other changes such as softening and increase in the concentration of flavor volatiles occur during the ripening process. Most importantly, the organic acids especially malic acid together with soluble sugars and volatile substances contribute to the flavor quality of apple fruit. More specifically, the sugar-to-acid ratio is an important aspect of apple flavor. It increases dramatically during ripening and is also a major distinguishing characteristic among varieties. A “sweet” apple has a high sugar-to-acid ratio, and a tart apple
has a low sugar-to-acid ratio. Fruits with little acid are very sweet in taste and hence are unacceptable in the market. An ideal apple should be sub-acidic with a pleasant flavor. Since there is a post harvest storage period in apple before it reaches to the market, the flavor development during or after storage is very important. Post storage apple taste is generally affected by development of an aldehyde or decrease in acidity.

Apples contain a large concentration of flavonoids, as well as, a variety of other phytochemicals. The concentration of these physico-chemicals may depend on many factors, such as cultivar, harvest, storage and processing (Lee et al., 2003; Nour et al., 2010). Until the late 1970’s, most research on apple aroma and flavor concentrated on identifying volatiles produced by ripening fruit (Tressl et al., 1975). Subsequently the biochemical origin of aroma volatiles and improvements in methods of separation and identification of volatiles have been reviewed (Dimick and Hoskin, 1983; Yahia, 1994; Sanz et al., 1997). These new methods have resulted in better understanding of biosynthetic pathways and control mechanisms in the synthesis and subsequent accumulation and release of volatiles from apples (Dixon and Hewett, 2000). The aroma profile of apple has revealed the presence of over 300 volatile compounds which include alcohols, aldehydes, carboxylic esters, ketones and others (Dixon and Hoskin, 1983; Paillard, 1990; Yahia, 1994; Mahinagic et al., 2006). According to Dixon and Hewett (2000), about 20 of these chemicals are the “Character Impact” compounds which predominantly contribute to aroma/flavor quality and intensity of apple. Volatiles important for flavor and aroma are synthesized from amino acids, membrane lipids and carbohydrates during ripening period (Sanz et al., 1997). The volatile production in apple has been categorized according to the type and quantity of esters or alcohols, aroma production pattern, skin color and C6 aldehydes (Dirink and Schamp, 1989; Paillard, 1990; 1996). Yellow skin cultivars have been reported to produce mainly acetic acid esters, whereas, red skinned cultivars produce butyric acid esters (Paillard, 1979). Rowan et al., (2009) while studying the heritability of volatiles which contribute to apple flavor found a genetic basis of complex and variable nature of apple volatiles.

(v) Fruit Taste/ Soluble Solids Content (SSC)

The basis of apple taste is acidity and sweetness. In fact, it is the balance between these two traits, irrespective of aroma, that primarily determines the acceptability of the fruit. Apples that are high in acid and low in sugar are quite unpalatable, being too acidic. Similarly apples
high in sugar and low in acid are too sweet and insipid (Janick et al., 1996). The acid in the mature fruit is almost malic acid, and is measured either as percentage of malic acid in the fruit juice or as pH of the juice. The main sugars are fructose, sucrose and glucose conventionally measured by refractive index as percentage of total sugars in the fruit juice (Brown and Harvey, 1971). According to Janick et al (1996), majority of the successful desert apples are in the groups of medium acid/medium sugar, medium acid/high sugar, and low acid/medium sugar. Very sweet type of cultivars generally have malic acid in the range of 0.1 to 0.3% in the fruit.

Soluble solid content (SSC) is a good indicator of sugar content of fruits like apple (Hoehn et al 2003). According to kvikliene et al., (2006), SSC varies from year to year and is dependant more on weather conditions than on any other factor. Jemric et al., (2013) are of the view that high SSC values in apple may be attributed partly to low crop load, but mainly as a result of genetic differences. High values of SSC due to low crop load have also been reported earlier (Wunshe et al., 2005; Sai et al., 2011). Nour et al., (2010) observed variations in soluble solid content in different apple cultivars ranging from 10.8% to 16.5%. All these cultivars having high SSC content also displayed high sugar content. Some other workers reported moderate values of SSC with no significant difference among old or local cultivars (Mratinic and Fotinic-Aksic, 2011; 2012, Jemric et al., 2013).

Titatable acidity is another important tool in predicting taste of apples (Harker et al., 2002). Nour et al., (2010) recorded titatable acidity in different apple cultivars ranging from 0.101% to 0.771% with an average value of 0.265%. Some other workers have also reported a wide range of titatable acidity values among apple cultivars (Mratinic and Fotiric-Aksic, 2011; Jemric et al., 2013). In general fruits from light cropping trees have higher titatable acidity values (Saei et al., 2011). According to Lex (1995), the apple cultivars with SSC:TA ratios lower than 20 are suitable for processing and cider production, while others are more suited for direct consumption.

(vi) Fruit harvest and storage

Maturity at harvest is the most important factor that determines storage life and final fruit quality. Horticultural maturity is defined as the stage of development at which horticultural crops are harvested to meet consumer requirements (Watada et al., 1984). Apples should be harvested
at an optimum time to maximize storage length and fruit quality. The optimum harvesting time in turn depends upon the climate of the growing season, time of bloom, fruit flavor, soluble solids content, flesh firmness and skin color. These parameters are routinely measured in apple to determine relative conditions of time of harvest. The measurements, however, do not necessarily characterize the quality of apple. Apples picked too early or too late in their season lose more mass and are subject to post harvest physiological disorders than fruits picked at optimum stage of ripeness (Kader, 1999; Kvikliene et al., 2006). All fruits with a few exceptions (pears, avocados and bananas) reach their best eating quality when allowed to ripen on the plant. However, some fruits are usually picked mature but unripe so that they can withstand the post harvest handling for long distance transportation.

Ripening is a process of physiological, metabolic and biochemical changes, initiated and/or coordinated by ethylene, either on or off the tree and includes loss of background green color, softening of fruit tissue and development of background characteristic aroma and flavor (Wills et al., 1997). According to Kader (1999) fruits like berries, cherry, citrus, grape and pineapple are not capable of continuing their ripening process after harvest. Such fruits produce very small quantities of ethylene and do not respond to ethylene treatment and thus should be picked when fully ripe to ensure good fruit quality. On the other hand fruits like apples, apricot, avocado, banana, mango, papaya and pear produce very high quantities of ethylene during ripening and application of ethylene following harvest will result in faster and more uniform ripening. Such fruits can be harvested mature but unripe as they continue to ripe even after harvest. Apples are classified as having climacteric ripening pattern which is rapid increase in production of ethylene and/or respiration rate to a maximum after which the rate declines. Physiologically mature pre-climacteric apples have the greatest storage potential (Lelievre et al., 1997). Thus to ensure maximum storability, apples should be picked when ripe, but not fully ripe (Ingle et al., 2000).

Two basic requirements for maintaining fruit quality during post harvest storage in apple include temperature and humidity. Storage temperature should be as low as possible without freezing the fruit. Due to the presence of sugar content, apples do not actually freeze until the temperature reaches 28 to 30 degrees F. Thus storage temperature should ideally be around 32 degrees F. Humidity should be as high as possible but less than 100%. In general 95% relative humidity is recommended. Storage at low temperature and/or in a modified atmosphere with ultra low
oxygen concentration (Wills et al., 1997; Dixon and Hewett, 2000; Aaby et al., 2002) is generally practiced to ensure good fruit quality and extended shelf life. For longer storage life (as long as 6-7 months), and to maintain higher fruit quality, controlled-Atmosphere (CA) storage is used by larger growers or traders. CA storage rooms have reduced oxygen levels (3-5% vs. 21% in a normal atmosphere), which slows down respiration and hence ageing. A CO2 concentration of 2-3% has been found sufficient to retard fruit ripening and ageing processes (Viskelis et al., 2011).

Apples are harvested at different stages of maturity depending on how long they will be in storage before marketed. Apples to be used shortly after harvest are tree ripened and picked at a much later stage of maturity than apples that will be stored for 6-9 months or more. Although flesh firmness is one criterion that is used to determine the maturity and quality of apples, but it does not help in making any decision about the harvesting time? For this the best indicator is starch index (or starch level). A young developing fruit is composed of starch and as the apple matures, the starch is converted to sugars. A fully mature apple has no starch but all sugars, at this stage apple begins to senesce. So apples picked at an early stage of maturity will have more starch than those picked later. The starch-iodine index is evaluated by cutting an apple in half and covering the cut surface with a potassium iodide solution for several minutes. The areas of starch in the apple will appear black; the level of staining will determine the amount of starch.

(vii) Fruit Firmness

Firmness and sugar content are important quality attributes that directly influence consumer preference in purchasing fresh fruit. Considerable research has been done to understand the physiology and physical mechanisms involved in fruit softening. A number of studies have concluded that apple softening is mediated by loss of cell to cell adhesion (Harker and Hallett, 1992; De Smedt et al., 1998). Some worker believe crop load as main factor (Desalvadov et al., 2006; Saei et al., 2011), whereas, Jemric et al., (2013) reported genetic factors for variations in fruit firmness. A comprehensive review by Johnston et al., (2002) describes the pattern of softening in apple and how it is influenced by different pre-harvest, at harvest and post harvest factors. Several authors advocated that apples soften only by 25-50% to a final firmness of 35-50N compared to other crops (melon, tomatoes, kiwi etc.) which soften by 75-100% during ripening to a final firmness of 0 – 10N (Bourne, 1979; Johnston et al., 2002).
According to Johnston et al., (2002), softening in apple takes place in a non-linear manner with a slow initial phase followed by a rapid second phase and then again a slow final phase. Further, since phase second is difficult to control once it is initiated; hence phase 1st softening needs to be prolonged if firmness is to be maintained long term in storage. The early season cultivars tend to soften more rapidly than late season cultivars. This is probably due to the fact that early maturing apple cultivars have larger cells, larger intercellular spaces and are less dense than late maturing cultivars (Kahn and Vincent, 1990). Ethylene is considered a major fruit ripening hormone and its role in fruit softening has been established through several approaches (Watkins et al., 1989; Mir et al., 2011; Sisler and Sevek, 1999). Although the exact role of ethylene in softening process is yet unclear, but it is argued that this hormone induces softening by regulating expression of cell wall modifying enzymes (Pech et al., 1999; Atkinson et al., 1998).

(viii) Fruit skin and Russetting

The fruit skin in apples consists of cuticle, epidermis and several layers of hypodermis (Babos et al., 1984). The skin thickness considerably varies between cultivars (Babos et al., 1984; Homutova and Blazek, 2006) and is of significant importance during storage and transportation. In apple, the skin is thicker at the stem end of the fruit than at the stylar end, whereas, the thickness is intermediate at the point of maximum fruit diameter (Knuth and Stosser, 1987; Homutova and Blazek, 2006). The late ripening cultivars have in general thicker skin than earlier ripening types (Kumachova, 2003). It has been argued that the skin characteristics in apple influence bruising, (Garcia et al., 1985), calcium penetration (Glenn et al., 1985) and also the infection by fungal pathogens (Mourichon and Bompeix, 1979).

Russetting is found in many apple cultivars and can vary from zero to 100 percent with all gradations in between. According to Brown (1975), russetting can be slight (confined to stalk cavity or calyx only), moderate (in patches over the fruit) and complete (entire on the fruit). In some countries, russetting is preferred, because it is associated with increased aromatic flavor (Janick et al., 1996). Although russetting is a genetically controlled phenomenon but it can also be influenced by external factors such as low temperature, high humidity and excessive spraying etc.
(ix) Apple fruit quality and disease resistance

Although it has been reported that consumers generally prefer apple fruits that are juicy, crisp and sweet, there are several other factors that determine the fruit quality and some of these may be associated to disease resistance, e.g., hardness, acidity, ethylene production level, flesh texture, antioxidant content, phenol content, harvest time and fruit maturity (Jenks and Bebeli, 2011). Several chemical constituents in the fruit can probably play an important role in resistance to fungal diseases, especially storage diseases. For example total phenol content is one of the factors affecting the apple storability and disease resistance. Similarly a large number of volatile compounds such as alcohols, aldehydes, carboxylic esters and ketones are important in disease resistance of apple. In resistant cultivars, phenolic components accumulate at a higher rate than in susceptible cultivars (Usenik et al., 2004; Treutter, 2005; Lattanzio et al., 2006). Among phenolic compounds, the flavonoid quercetin has been considered the most important agent for controlling blue mould and patulin accumulation in ‘Golden Delicious’ (Sanzani et al., 2009a). Subsequent studies have demonstrated that this control is achieved through an increased transcription of genes involved in the quercetin biosynthetic pathway (Sanzani et al., 2009b; Sanzani et al., 2010). In a wide variety of plants, organic acids and nutritional compounds such as vitamin C and glutathione associated with fruit taste and quality and are also related to the level of disease resistance (Ferguson and Boyd, 2002). The relationship between harvest day and vitamin C content of apple fruits has been investigated by Davey et al., (2007). Low pH can enhance \textit{P. expansum} colonization, which means that cultivars with a lower pH in their fruits are more susceptible to fungal attack (Prusky et al., 2004). Apple peel is considered as the main defense mechanism against fungal infection. Most of the apple phytochemicals such as ascorbic acid, glutathione, antioxidative enzymes, phenols and cuticular waxes like ursolic acid, are mainly localized in the peel. Among these, ursolic acid is considered as the main cuticular waxes that reduces shelf life diseases (McGhie et al., 2005; Frighetto, et al., 2008).

(x) Miscellaneous

The commercial success and consumer acceptability of any apple cultivar is based on the aforementioned quality traits and hence can be considered as major parameters for its improvement in all apple breeding programmes. However, some fruit defects exist in nature
which may affect the market value of any good quality apple and hence its commercial success. According to Janick et al., (1996) a number of fruit and flesh defects which have an important effect on fruit quality in apple include fruit cracking (Opara et al., 1996), calcium defects such as bitter pit (Ferguson and Watkins, 1989) and flesh disorder water core (Marlow and Loescher, 1984).

**Fruit cracking:** Fruit cracking ranges from cuticle cracks to those that penetrate deep into the flesh. The intensity and type of cracking may vary depending upon the genotype and water status of the plant. Severe cracking of susceptible cultivars may lead to huge economic losses (Opara et al., 1996).

**Calcium defects:** Ca defects can cause a serious loss in susceptible cultivars. These can be controlled by Ca sprays or sometimes by fertilization. Bitter pit resistant cultivars have higher levels of Ca and B and lower levels of Mg and K in their fruit and leaf (Janick et al., 1996).

**Water core:** Water core is a glassy appearance in fruit flesh and appears due to change in membrane integrity associated with maturation and ripening and resulting in the accumulation of fluid in the intercellular spaces and elevated sorbitol concentrations. It is associated with the elevated sweetness in the fruit and is thus preferred by some consumers. Severe water core may lead to storage breakdown resulting in huge economic losses. Most cultivars are susceptible to water core with varying degree (Janick et al., 1996).

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**References**


Hoehn E., Gasser F., Guggenbuhl B. and Kunsch U. (2003). Efficacy of instrumental measurements for determination of minimum requirements of firmness, soluble solids,


