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Apple fruit quality: Overview on pre-harvest factors

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ABSTRACT

Apple is the fourth most important fruit produced and eaten around the world with a production of 84 million tonnes in 2014. The modern cultivated apple (*Malus* × *domestica* Borkh) is probably the result of interspecific hybridization and, at the moment, ten thousand or more apple cultivars are listed in the European Apple Inventory. The large number of cultivars reflects also a broad range of variability in the quality traits. “Fruit quality” is a dynamic concept changing on the basis of the consumer needs and perceptions that reflect socio-cultural evolution. Almost all the characteristics determining apple quality can be measured or classified. Consumers assess apples by its appearance (colour, size, shape, absence of defects) and then by its eating quality, although the latter may determine the willingness to buy the product again. Furthermore, the high level of polyphenols confer apples relevant nutraceutical properties. Apple consumption has been deeply encouraged and a broad range of varieties are competing in the market, but the indisputable quality of a commodity is proved by the repeating purchase by consumers. In this review, the most common worldwide utilized external and internal quality parameters (i.e. firmness, starch, soluble solid content, titratable acidity) and conventional techniques as well as some new approaches to assess them are explored. New quality metrics recently developed, like I_{AD} and dry matter, are discussed too. The current review discusses the impacts and potentials of both environmental conditions, and agronomic factors. Environmental and agronomic factors along all the growing season strongly affect the final apple quality including the nutraceutical aspects. Temperature and light contribute to several modifications of external and internal apple quality like red overcolor and dry matter accumulation, but also can trigger unwelcome disorders like sunburn. Orchard design, training system and pruning can dramatically impact the skin overcolor and the maturity of the fruit. Crop load and thinning can determine physiological adjustments that benefit the dry matter accumulation in the fruit. Irrigation and nutrition can modified the overcolor and the chemical composition of the flesh.

1. Introduction

The apple belongs to the Rosaceae family. Apple, pear, quince, medlar and a few other species have been classified into the subfamily of Pomoideae. The pome fruits are characterized by two to five carpels enclosed in a fleshy covering. The center of origin for apples is Asia (Forsline et al., 2003), particularly the Republic of Kazakhstan (Dzhangaliev, 1977). The modern cultivated apple is probably the result of interspecific hybridization and the scientific name *Malus* × *domestica* Borkh. is generally accepted, replacing the previous name of *Malus pumila* (Korban and Skirvin, 1984). *Malus sieversii* Lebed., a wild apple species native to Central Asia, is recognized as a major progenitor of the domesticated apple (Way et al., 1991; Ponomarenko, 1987, 1992; Morgan and Richards, 1993; Juniper et al., 1999; Forsline et al., 2003; Forsline and Aldwinckle, 2004; Hancock et al., 2008). The number of species in the genus *Malus* Mill. is uncertain and not completely defined (Pereira-Lorenzo et al., 2009). Harris et al. (2002) identified 55 species, Zhou (1999) reported 30–35

Abbreviations: 1-MPC, 1-methylcyclopropene; ABA, abscisic acid; ACO1, 1-aminocyclopropane-1-carboxylate oxidase; ACS1, 1-aminocyclopropane-1-carboxylate synthase; AM, amylose; ANS, anthocyanidin synthase; ASE, artificial spurs extinction; AP, amylopectin; BA, 6-benzyladenine; C, chroma; CHI, chalcone isomerase; CHS, chalcone synthase; DAFB, day after full bloom; DFR, dihydroflavonol 4-reductase; DM, dry matter; DMC, dry matter concentration; DW, dry weight; EPT, electronic pressure tester; F3H, flavanone 3-hydroxylase; FW, fresh weight; GA, gibberellic acid; GC, gas chromatograph; GMO, genetic modified organism; h, hue angle; ha, hectare; HDP, high density planting; IAA, indole-3-acetic acid; I_{AD}, index of absorbance difference; IEC, internal ethylene concentration; JFC, juicy firm and crisp; L/D, length/diameter; LDP, low density planting; LAI, leaf area index; NAA, 1-naphthaleneacetic acid; NIR, near infrared; PAL, phenylalanine ammonia lyase; PG, polygalacturonase; PGRs, plant growth regulators; QC, quality control; RI, refractive index; RT-PCR, real time polymerase chain reaction; SIV, starch index value; SPI, starch pattern index; SSC, soluble solids content; TA, titratable acidity; TCSA, trunk cross sectional area; TSS, total soluble solid; UFGalT, UDP-galactose flavonoid-3-*o*-glucosyl transferase; WC, water content; WUE, water use efficiency; ΔE*ab, colour difference; ΔH*ab, hue difference

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species, Robinson et al. (2001) listed 25–47 species, Janick et al. (1996) reported 37 and Forsline et al. (2003) reported 27 primary apple species.

Apples are worldwide cultivated in temperate, subtropical and tropical environments. The commercial production is limited to latitudes ranging from 25° to 52° (Palmer et al., 2003). Over 63 countries produce apple with a great variability of growing conditions and utilize a large number of cultivars (Way et al., 1991). According to FAOSTAT (2014), apple consumption per capita in the world reached 9.2 kg per person in 2013. Apples are the fourth most important world fruit crop following all citrus types, grapes, and bananas (Forsline et al., 2003). In 2014, the annual average apple production reached 84.6 million tons worldwide (FAOSTAT, 2014). The largest producer is China, representing around 48% of the world's total production. The US is the second largest producer with 6.1% followed by Poland (3.8%), India (2.9%), Turkey (2.9%) and Italy (2.9%).

Ten thousand or more apple cultivars are listed in the European Apple Inventory (Watkins, 1985). The large number of cultivars exhibits a broad range of variability in the quality traits (Way et al., 1991). For many years, breeding and management techniques in agriculture have aimed at increasing yields to meet growing food needs. Thanks to these breeding activities, more genotypes are available to pursue the activity of increasing fruit quality (Laurens, 1999).

Sansavini et al. (2004) identified four groups of apple fruit ideotypes corresponding to different consumer preference profiles: "American/European dessert apples" characterized by a nice shape, appearance and colour (generally solid coloured), large size and sweet-tart-aromatic content; "European refreshing apples" that present an elevated juiciness, tartness with a solid colour or two-tone skin colour; "Asian dessert apples" are defined by high sweetness, firm flesh, high juiciness, low tartness, and long storability; "Juicy Firm and Crisp (JFC) high quality apples" present an excellent combination of juiciness and crispness with genotypes presenting high sugar and acid content.

Apple represents one of the most nutritional food in a healthy diet for its content in water (> 80%), sugars (fructose > glucose > sucrose), organic acids (0.2–0.8%), vitamins (mainly vit. C, 2.3–31.1 mg/100 g DM), minerals (= ash 0.34%–1.23%) and dietary fibres (≈ 2–3% and pectin < 50% apple fibres) (Kiczorowska and Kiczorowski, 2005; Cannella, 2008; Karakasova et al., 2009). Apples are known to have high polyphenol antioxidants (only second after cranberries) representing 20–25% of total fruit polyphenols consumed in the US as well as 10–30% of daily assumption of fiber and potassium (Aprikian et al., 2003; Boyer and Liu, 2004; Drogoudi et al., 2008). The main phenolic compounds reported in apple are chlorogenic acid, epicatechin, procyanidins, phloretin and quercetins and their profile depends on the variety, environmental conditions, cultural practices, maturity stage and storage time (Pissard et al., 2013). The allergenic potential depends on the variety – low allergenic cv will be preferred for breeding purposes (Botton et al., 2008).

Quality is one word with different meanings and this concept resounds with terms like genuineness, typicality and freshness of the product (Eccher Zerbini, 1989). Schreiner et al. (2013) outlined quality "as the sum of all characteristics, properties and attributes of a product or commodity which is aimed at fulfilling the established or presumed customer requirements" (by the International Organization of Standardization, ISO 8402, 1989). A new definition of quality of fruits and vegetables has been proposed by Kyriacou and Rouphael (2018) as a dynamic synthesis of their physicochemical properties and related to consumer perception. The first important publication about fruit quality was written by Schuphan in 1961. He published a book about the quality of the products focused on nutritional aspects and the risk of applying pesticides. Schuphan (1961) defined quality as a set of factors consisting of external characteristics (market value), technological characteristics (transformation value), internal characteristics (nutritional value), value of image (based on a psychological and irrational concepts) and sensory value (organoleptic traits). Expectations differ depending on the point of view along the supply chain (Eccher Zerbini, 1989; Barman et al., 2015). In fact, fruit quality can be defined in multiple ways reflecting the subjectivity of the matter as "degree of excellence" (Abbott, 1999), "degree of fulfilment of a number of conditions that determine its acceptance by the consumer" (Akhtar, 2015; Barman et al., 2015), "fitness for purpose" (Juran, 1989; Hewett, 2006) or when the product meets the standard for its specific use ("industrial quality", "nutritional quality", "export quality", "edible/consumer quality"). In general, fruit quality includes a wide group of external and internal traits. External fruit quality includes colour, shape, size and absence of defects, while the internal quality (determining the eating quality) consists of taste, texture, aroma, nutritional value, sweetness, acidity (contributing to flavour), shelf life and lack of defects (Kingston, 1992; Shewfelt, 1999). Initially, the consumer judges the product by its appearance (colour, size and shape) and then, by its eating quality, although the latter may determine whether or not a customer will buy the product again (Vanoli and Buccheri, 2012).

Harvest time becomes a fundamental decision in order to guarantee a final high fruit quality for the consumers, both early or late harvest can lead to several negative aspects decreasing the fruit quality (Vanoli and Buccheri, 2012). Variability among tree in the same orchard can influence the final quality of the product. Especially different crop load levels can severely affected the fruit quality and maturity (Serra et al., 2016). Variability within the same tree has been described in pear by Zhang et al. (2016). In fact, large canopy provides a broad range of quality trait changes inducing more variability compare to a small size tree (Rudell et al., 2017). Quality is also affected by planting density and is cultivar dependent (Costa et al., 1997). Almost all the characteristics determining the fruit quality can be measured. Some of the fruit quality parameters are usually determined through destructive methodologies, but in the last decade the onset of non–destructive strategies enriched the quality assessment possibilities and potentials, thanks to the development of new instruments to estimate fruit quality and maturity available for fruit industry and research sector (Betemps et al., 2012; Costa and Noferini, 2013).

In Europe and US, commercial standards define the quality of apples. The most important aspects are size, colour, integrity, presence of a smooth skin and absence of russet. European Union (EU) countries have standards about apple classification defined by Regulation CE No 1238/2005 (Doue, 2005) and it is possible to identify three main commercial categories: Extra, Class I and Class II. US classifies apples in four categories: US Extra Fancy, US Fancy, US N. 1 and US Utility.

This review provides a summary about the state of the art of research on apple quality and the environmental factors and agronomic practices that affect and manipulate fruit attributes before harvest (Fig. 1). More in details, additional factors impacting fruit quality are analysed shedding light on interactions with genetic material, climatic factors, agronomic practices and physiological mechanisms affecting apple fruit quality.

2. Cultivar and rootstocks

2.1. Cultivar

Quality is strictly linked to cultivar and many quality traits are polygenic (Iglesias et al., 2012). In the case of some important cultivars like 'Delicious', 'Gala', 'Fuji', 'Golden Delicious', 'Jonathan', 'Rome Beauty', and 'Stayman' we continually observe that the spur mutations frequently deviate significantly from the original cultivar in many ways (Gorini, 1982; Iglesias et al., 2012). Spur mutation of 'Granny Smith' and 'Golden Delicious' generally provides fruit with more colour, but also lower levels of dry matter and less acidity than the standard clone (Gorini, 1982). Some clones of 'Golden Delicious' produce fruits with less russet, more elongated and greener. Different susceptibility to russet was observed by Eccher and Hajnajari (2006) in strains of 'Golden Delicious' clones. 'Clone B', the most diffused one, is more