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Tree ripening and postharvest firmness loss of eleven commercial nectarine cultivars under Mediterranean conditions

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ABSTRACT

On-tree and postharvest softening of 11 yellow flesh nectarine cultivars with different commercial harvest seasons (early, mid and late) were studied under Mediterranean conditions (Lleida, NE-Spain). Fruit were harvested weekly at five consecutive harvest dates (from H1 to H5) over three consecutive years (2009–2011). Diameter, percentage of skin overcolor (SC), flesh firmness (FF), I_{AD} index (the difference in absorbance between 670 and 720 nm), visible reflectance spectra, soluble solids content (SSC), titratable acidity (TA), ethylene synthesis, objective skin color and postharvest softening rate were measured. The decline in flesh firmness and the I_{AD} were both significantly affected by cultivar and ripening season. Low acid (TA < 6 g of malic acid L^{-1}) cultivars such as 'Big Top', 'Nectareine', 'Honey Royale', 'Big Nectared' and 'Nectalady', had a lower firmness decline than acid ones (TA ≥ 6 g of malic acid L^{-1}), both on-tree and during postharvest, resulting in a better commercial and postharvest performance. A high and significant positive correlation was found between I_{AD} and flesh firmness (r = 0.72, P ≤ 0.01). Early cultivars tended to lose flesh firmness and I_{AD} faster than mid and late cultivars. The softening rate during the postharvest period was mainly dependent on ripening season. Early ripening nectarines soften faster than mid and late ones.

1. Introduction

The peach [*Prunus persica* (L.) Batsch] is the second most important deciduous fruit crop in the European Union (EU), after the apple, reaching a total production of 3.568.000 t in 2015. Especially important are Italy and Spain, accounting together around 79% of the total EU production. Spain is currently the first producing country of the EU and the primary exporter in the world (Iglesias, 2013).

The most significant change in the peach industry in the last three decades has been the development and introduction of new cultivars with precocious and high overcolor, good size and in general a predominant sweet taste due to their low acidity (TA < 6 g of malic acid L^{-1}) (Iglesias, 2013). This change started with the introduction of the yellow flesh nectarine 'Big Top' (Zaiger Genetics Inc. California, USA) two decades ago, which has been very appreciated by European retailers and consumers, and has brought a significant advantage in terms of harvest and postharvest management (Iglesias and Echeverría, 2009) and fruit quality characteristics (Reig et al., 2016). However, some of these new cultivars were not well adapted to some growing conditions (Reig et al., 2015).

Peach is a climacteric fruit in which ripening starts with the rise of ethylene production (Tonutti et al., 1991), and involves many biochemical and physiological processes including the modification of the cell wall. This modification implies changes in the polysaccharide architecture which results in a very slow decline of firmness (softening), followed by a rapid and dramatic firmness decrease ('melting') late in ripening corresponding to the onset of ethylene climacteric (Borsani et al., 2009; Giovannoni, 2001; Hayama et al., 2006; Tonutti et al., 1996; Trainotti et al., 2003). Flesh texture and firmness at full ripening are commonly used traits to classify peach fruit into four different phenotypes: melting (MF), non-melting (NMF), stony hard (SH) and slow ripening (SR) (Bassi and Monet, 2008; Byrne et al., 2012). Most of the peach and nectarine commercial cultivars marketed worldwide belong to the MF phenotype, although the speed of softening greatly varies within this group (Byrne et al., 2012). Within the melting texture, Bassi

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and Monet (2008) reported an additional flesh texture ('very, very firm'), which resembles the SH flesh in firmness and crispiness, but becomes melting when fully ripe and shows a prominent delay in softening and ethylene production. This texture can be found in recently developed nectarines (e.g., 'Big Top') or standard peaches (e.g., 'Rich Lady' and 'Diamond Princess'). 'Big Top' is currently the indisputable melting cultivar reference and the most highly valued and widespread cultivar in Europe (Reig et al., 2016).

In order to monitor on-tree peach fruit ripening and determine the beginning of harvest, parameters such as flesh firmness, fruit size, background color and total soluble solids content (SSC) (Eccher Zerbini et al., 1994; Kader, 1999; Valero et al., 2007) are still being used. However, these parameters do not provide a complete view and the measurement of other physiological, biochemical or biomolecular parameters which are related to the progression of ripening, such as ethylene and aroma volatile compounds emission, respiration, soluble pectins, chlorophyll, carotenoid and/or flavonoid contents, and mRNA levels of ripening-related genes are usually needed (Carrari et al., 2006; Golding et al., 2005). Some of these assays are complex, costly and do not provide the real-time information needed in agronomic practice (Ziosi et al., 2008). Recently, a hand-held instrument (DA meter, Sinteleia, Bologna, Italy) was developed to allow an indirect and real-time non-destructive determination of the chlorophyll content in the fruit skin, by measuring the absorbance within the chlorophyll absorption range (I_{AD}) (Lurie et al., 2013; Nyasordzi et al., 2013; Ziosi et al., 2008). Previous works have demonstrated its usefulness to predict the ripening stage in peaches (Bonora et al., 2013; Lurie et al., 2013; Pinto et al., 2015; Ziosi et al., 2008).

Fruit softening is a quality trait directly related to the susceptibility to mechanical damage during postharvest handling (Crisosto et al., 2001) and storage time, and it poses severe limits to late harvest of fully-ripen and therefore, better quality fruit (Eccher Zerbini et al., 2006). Understanding the effect of the storage time on the fruit softening, would allow extending storage times and exporting to far countries (Diezma-Iglesias et al., 2006; Peirs et al., 2000).

There is a widespread perception about the different softening rates of peach cultivars. Traditionally, softening has been evaluated through destructive methods such as flesh firmness determination. However, many authors are currently exploring non-destructive methods, providing real-time information, such as time-resolved reflectance spectroscopy (TRS) and I_{AD} (Lurie et al., 2013; Tijskens et al., 1998). However, although peach fruit ripening and softening has been studied by many authors (Lurie et al., 2013; Tijskens et al., 1998; Ziosi et al., 2008), scarce information exists on the effect of cultivar and ripening season. For this reason, fruit ripening and softening of several nectarines from different ripening seasons were evaluated.

2. Material and methods

2.1. Plant material

Eleven common nectarine cultivars grown on commercial orchards located in the fruit production area of Lleida (Ebro Valley, Northern Spain) were evaluated during three consecutive years (2009, 2010 and 2011). Cultivars were selected in order to include different ripening seasons (early, mid and late), origins (breeder and country), and acidity groups [acid (TA ≥ 6 g malic acid L^{-1}) and low acid cultivars (TA < 6 g malic acid L^{-1})] (Iglesias and Echeverría, 2009) (Table 1).

Nineteen trees of each cultivar with similar production were selected for the study. Trees were grafted onto GF-677 rootstock, spaced 5m × 3m, and trained in the Catalan open vase system. Four trees were used to determine fruit growth. The remaining 15 trees, were divided in five plots of three trees and each plot was harvested at one harvest time (from H1 to H5) to avoid the possible effect of yield reduction by repeated harvests. Weekly (from H1 to H5) a total of 276 fruits per cultivar (92 fruit from each tree) were picked based on similar fruit size, ground color and absence of external defects. On the same day of harvest fruit were transported to the laboratory and immediately evaluated. Commercial harvest (H3) was established at flesh firmness around 55 N (N). Fruit growth, fruit quality, ethylene production and postharvest softening were evaluated for a sample of fruits from each ripening stage (from H1 to H5) as described below.

Table 1
Origin, country, group and ripening season of the 11 nectarine cultivars used in this study.

Cultivar	Origin	Country	Group[a]	Ripening season
Ambra	D.S.A. Bologna University	Italy	Acid	E
August Red	Bradford Genetics Inc.	USA	Acid	L
Big Bang	Agro Selection Fruits	France	Low acid	E
Big Nectared	Agro Selection Fruits	France	Low acid	L
Big Top	Zaiger Genetics Inc.	USA	Low acid	M
Honey Royale	Zaiger Genetics Inc.	USA	Low acid	M
Nectalady	Agro Selection Fruits	France	Low acid	L
Nectareine	Agro Selection Fruits	France	Low acid	M
Nectaross	CREA-Rome	Italy	Acid	M
Red Jim	J.C. Sorenson & J.K.Ito	USA	Acid	L
Venus	CREA-Rome	Italy	Acid	M

Abbreviations: E, early; M, mid; L, Late.
[a] Low acid, TA < 6 g malic acid L^{-1}; Acid, TA ≥ 6 g malic acid L^{-1} (Iglesias and Echeverría, 2009). These values are referred to commercial harvest (H3).

2.2. Fruit growth

A non-destructive evaluation of fruit growth was selected for the analysis in order to monitor the fruit development on each cultivar during the five harvest dates studied. Forty fruit per cultivar (ten fruits per tree) attached on the tree were labelled, numbered, and their diameter measured at weekly intervals beginning two weeks before commercial harvest (H1 and H2), at commercial harvest (H3), and one and two weeks after commercial harvest (H4 and H5) by a calliper (Mitutoyo's digimatic calliper, Japan) over two consecutive years (2009 and 2010). Fruit growth was then calculated as follows and expressed as the percentage of the fruit diameter increase:

$$\Delta \text{ Diameter } (\%) = ((D_2 - D_1)/D_2) * 100$$

being D_1: the diameter at a harvest date and D_2: the diameter at the following harvest date.

2.3. Fruit quality at harvest

From the 276 fruit collected per cultivar on each harvest date (H1 to H5), 30 fruit homogeneous in size and color (ten fruits per tree within a plot) were immediately used for fruit quality evaluation at harvest. Each fruit was assessed for skin overcolor (SC) and flesh firmness (FF), while soluble solids content (SSC) and titratable acidity (TA) were evaluated in a batch of 10 fruits. Skin overcolor (SC) was visually scored as the percentage of the skin surface with red color. Flesh firmness from two opposite peeled sides of each fruit (the most and least exposed to light) was measured with a 8-mm tip penetrometer fixed in a drill stand (Penefel; Copa-Technology; CTIFL, Saint Etienne du Gres, France). Soluble solid contents (SSC) and titratable acidity (TA) were determined on flesh juice extracted by an automatic juicer (Moulinex, Type BKA1). SSC was determined using a digitally calibrated refractometer (Atago PR-32, Tokyo, Japan) and expressed in °Brix. TA was measured with