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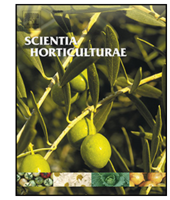

A new simple modeling approach for the early prediction of harvest date and yield in nectarines

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ABSTRACT

The ripeness at harvest of stone fruit should ensure the best balance between consumer satisfaction and ease logistic management, even if this compromise is not easy to achieve. In fact, as consequence of too early harvesting, an increased consumer dissatisfaction with peach and nectarine fruit is frequently observed. The use of the new non-destructive vis/NIR based, ripening index of absorbance difference (I_{AD}) *in planta*, may help to overcome this problem. In our experiments, the I_{AD} gave an objective measure of the nectarine ripening stage and showed a linear trend during stage 3 (S3) of fruit development, that did not appear affected nor by the climatic conditions of different years, neither by the training systems. The combined field monitoring of fruit ripening (I_{AD}) and growth (mm) during stage 3 of nectarine development allowed two-three weeks advance predictions for harvest date and yield with low errors. The new approach also appeared a more reliable method in predicting harvest date than the till now used growing degree heat unit accumulation at 30 days after full bloom (growing degree days GDD30). The model developed in the present work offers promises for future real applications under field conditions, to obtain early objective and precise predictions for harvest date and yield. Moreover, taking into account fruit ripening stage at harvest, would allow an increase in fruit quality and improve fruit management during post-harvest.

1. Introduction

Recently, the most important peach-producing countries in Europe have lost considerable market share mainly because of excessive harvesting of immature fruit (Layne and Bassi, 2008; Iglesias et al., 2005). Some of the more frequent consumer complaints about peach cultivars are hard fruit and lack of flavour at consumption, both of them caused by harvesting fruit when still immature (Della Cara, 2005). The stage of ripeness at harvest of a stone fruit should ensure the best balance between consumer satisfaction and easiness of logistic management, but this compromise is not easy to achieve. In fact, harvesting immature fruit does not allow the best expression of the potential eating quality, but does ensure an easily handled product along the commercial chain (Bonghi et al., 1999; Crisosto et al., 2006). On the other hand, fruit that reach physiological ripeness on the tree, guarantees consumer acceptance, even if they are characterized by high susceptibility to bruises and rapid deterioration (Infante, 2012). In peach, where harvest is usually performed on the basis of fruit skin colour and size (Eccher Zerbini et al., 1994) the introduction of new cultivars that develop full, intense red colour at an early stage of maturity, made harvesting even more difficult (Scorza and Sherman, 1996; Carbó and Iglesias, 2002; Bellini et al., 2004). Therefore, other physic-chemical and physiological parameters should be considered to determine the optimal harvest time, such as flesh firmness (FF), soluble solid content (SSC), titratable acidity (TA), SSC/TA ratio, ethylene production, etc., usually measured with traditional and destructive tools (Layne and Bassi, 2008).

In recent years, the interest of researchers for the development of non-destructive techniques to precisely evaluate ripening stage and assess fruit internal quality attributes has increased. Non-destructive methods showed several advantages, such as the possibility to test high number of fruit, to repeat the analyses on the same sample, to monitor physiological changes and to follow on-tree ripening, in order to establish the optimum harvest date and to increase fruit batches (Nicolai et al., 2007; Vanoli and Buccheri, 2012). Among these new non-destructive approaches, visible/near infrared (vis/NIR) spectroscopy seems particularly promising since

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it provides fast and reliable information on internal characteristics of many fruit species (Vanoli and Buccheri, 2012). In particular, the index of absorbance difference (I_{AD}) allows defining precisely peach fruit ripening stage in a non-destructive way (Infante, 2012). The I_{AD} is calculated as the difference in absorbance between two wavelengths near the chlorophyll-α peak, so it is strictly correlated to the actual chlorophyll-α content in peach fruit flesh and to the time course of ethylene production during fruit ripening (Ziosi et al., 2008). Therefore, considering that genus peach is a climacteric fruit whose chlorophyll content decreases during ripening, the I_{AD} can be considered a reliable tool to assess peach fruit ripening stage. This new maturity index is measured by a portable, user-friendly vis/NIRs device (the DA-Meter), and it can be used along the whole productive chain, from fruit still attached to the tree up to the point of sale. The usefulness of the I_{AD} to assess peach ripening stage in the field and the postharvest, has been recently reported in literature (Magnanini et al., 2010; Lleó et al., 2011; Hale et al., 2012; Dagar et al., 2012; Herrero-Langreo et al., 2011; Reig et al., 2012; Bonora et al., 2013a,b; Shinya et al., 2013; Spadoni et al., 2013). The I_{AD} showed a n high capacity for determining the harvest date and sorting stone fruit according to their ripeness, (Infante, 2012), but only few results were available on use of the I_{AD} as field ripening predictor index (Reig et al., 2012; Bonora et al., 2013a,b). Studying on tree ripening of plums, Infante et al. (2011) found a linear trend, below I_{AD} 1.5, up to harvest. Preliminary results showed similar behavior in peach fruit (Bonora et al., 2013b) during stage 3 (S3) of development leading to hypothesise that monitoring peach fruit ripening on the tree, could be easily modeled. The combination of a non-destructive technology for fruit ripening assessment with modeling systems is a topic still scarcely developed, in particular when fruit quality is considered (Marcelis et al., 1998). Goldschmidt and Lakso (2005) defined "model" as an attempt to describe a certain process or system through the use of a simplified representation, preferably a quantitative mathematical expression, that focuses on a relatively few key variables that control the process or system. Several studied tried to model different horticultural aspects of stone fruit. The virtual peach fruit model developed by Lescourret and Génard (2005), for example, integrated three previously developed submodels (carbon, water and sugar sub-models) to simulate the interactions between processes and their consequences on quality. This mechanistic (i.e. explanatory) model, based on a detailed description of physiological processes, is complex and mostly restricted to research and educational applications (Génard et al., 2009), to perform theoretical experiments and to help in understanding experimental results of complex systems, therefore of relative practical interest (Lescourret and Génard, 2005). Several statistical models for management applications were also developed during last decade. As suggested by Ahumada and Villalobos (2009) models can be used to plan the production of crops, through early prediction of harvest date and yield. Based on the heat unit accumulation during the thirty days after full bloom (expressed as growing degree hours—GDH30; Fisher, 1962; Anderson et al., 1986), the UC Davis's Harvest Prediction Model (http://fruitsandnuts.ucdavis.edu), gives an early forecast of the harvest date of peach cultivars, with an acceptable precision (Mimoun and DeJong, 1999; DeBuse et al., 2010). Jiménez and Díaz (2003) developed a model to estimate in a simple, rapid way potential yield for peach orchards, using parameters that can be easily measured at the beginning of the growing period, such as tree size, plantation density and flower bud load after pruning. Only recently, a few researchers focused on the use of non-destructive technologies to improve the prediction capacity of traditional models, but no literature was available on stone fruit. Based on UV–vis and NIR spectroscopy applied on apple, by correlating the fruit chlorophyll content with destructive analysis of soluble solids and starch, Bertone et al. (2012) showed a reliable way of predicting the optimum harvest date. Model robustness versus the variability related to the growing season and to the geographical location still has to be studied for this model. Nyasordzi et al. (2013) observed that the vis–NIR based I_{AD} might be used to predict the beginning of harvest on apple (cv's Granny Smith, Pink Lady and Starking) once the average value falls below a certain value.

Considering the demonstrated reliability of the cultivar-specific I_{AD} in the assessment of peach ripening stage (Ziosi et al., 2008), as well as its high correlation with consumer preference (Gottardi et al., 2009) and its consistency over growing seasons (Bonora et al., 2013b), it was decided to test the I_{AD} on three cultivars of nectarines. In particular, three aims were pursued: (a) to confirm the cultivar-specificity and its consistency over growing seasons of the relationships between I_{AD} and the changes in fruit ethylene production; (b) to assess the usefulness of the I_{AD} as field ripening Index for stone fruit on different nectarine cultivars and training systems in different growing seasons; (c) to use the above mentioned information to develop and validate a new, simple, modeling approach to predict harvest date and yield on nectarines.

2. Materials and methods

Trials were carried out in 2011 and 2012 on three yellow flesh nectarine [*Prunus persica* (L.) Batsch] cultivars 'Gartairo' (early season), 'Sweet Red' (mid-season) and 'California' (late season) grafted onto GF677 (*P. persica x P. amygdalus*). The seven-years old orchards were East-West oriented. The trees of the early season cultivar 'Gartairo' were trained to a palmette system with planting density of 4.0 × 2.0 m; the trees of the mid-season cultivar 'Sweet Red' were trained both to a palmette and open-vase systems with planting density of 4.0 × 1.4 m and 5.5 × 3.5 m, respectively; the trees of the late season cultivar 'California' were trained to a palmette system with planting density of 4.0 × 1.3 m. The cultivars trained to palmette were located in S.Biagio, Faenza, Italy (44° 23′N, 11° 93′S), while only cultivar 'Sweet Red' trained to open-vase was located in Prada, Faenza, Italy (44° 34′N, 12° 01′S). Routine horticultural management of the region was applied throughout the season in terms of pruning, irrigation fertilization and pest control.

2.1. Ethylene emission assessment

To establish the correlation between ethylene emission and fruit ripening stage (I_{AD}), every year, seven days before the commercial harvest, a sample of one hundred fruit representative of the orchard spatial variability was collected (Crouch, 2010) and the fruit grouped according to their I_{AD} values per each cultivar. As described by Ziosi et al. (2008), ethylene emission of five to 10 fruit per I_{AD} unit was assessed. Ethylene emission was measured by placing the whole fruit in a 1 L jar sealed with an air-tight lid equipped with a rubber stopper, and left at room temperature for 1 h. A 10 mL gas sample was taken and injected into a Dani HT 86.01 (Dani, Milan, Italy) packed-gas chromatograph as described previously by Bregoli et al. (2002).

2.2. Phenological and climatic parameters

Full bloom dates, corresponding to the 50% of open flowers (Baggiolini, 1980; Mounzer et al., 2008), were registered in spring 2011 and 2012 for each cultivar trained to palmette. Minimum and maximum temperature data were automatically recorded every day, from full bloom to harvest, by using temperature USB data loggers (Lascar Electronics Ltd.—Salisbury, United Kingdom), placed into the field. Temperature records, expressed as Growing Degree Days (GDD), were calculated using maximum and minimum temperature data based on the equation suggested by Grossman and