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Modeling systems and vis/NIR device to improve peach and nectarine pre and post-harvest fruit maturity management

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“Make it as simple as possible, but no simpler”

Albert Einstein

Abstract

During the last decade peach and nectarine fruit have lost considerable market share, due to increased consumer dissatisfaction with quality at retail markets. This is mainly due to harvesting of too immature fruit and high ripening heterogeneity. The main problem is that the traditional used maturity indexes are not able to objectively detect fruit maturity stage, neither the variability present in the field, leading to a difficult post-harvest management of the product and to high fruit losses. To assess more precisely the fruit ripening other techniques and devices can be used. Recently, a new non-destructive maturity index, based on the vis-NIR technology, the Index of Absorbance Difference (I_{AD}), that correlates with fruit degreening and ethylene production, was introduced and the I_{AD} was used to study peach and nectarine fruit ripening from the "field to the fork". In order to choose the best techniques to improve the fruit quality a detailed description of the tree structure and of the fruit distribution and ripening evolution on the tree was faced. More in details an architectural model (PlantToon®) was used to design the tree structure and the I_{AD} was used to characterize the ripening of each fruit. Their combined use provided an objective and precise evaluation of the fruit ripening variability, related to different training systems, crop load, fruit exposure and internal temperature. Based on simple field assessment of fruit maturity (as I_{AD}) and growth, based on the imposed maturity stage at harvest, a model for an early prediction of harvest date and yield, was developed and validated. The relationship between the non-destructive maturity I_{AD}, and the fruit shelf-life, was also confirmed. Finally the obtained results were validated by consumer test: the fruit sorted in different maturity classes obtained a different consumer acceptance.

In the present study are reported the main results dealing with some of the pre-harvest factors that affect fruit ripening. As far as the modelling is concerned, our finding shows that fruit ripening *in planta* followed a linear variety-specific trend that was not affected by fruit density, position within the canopy, training system, as well as, growing season. Only the timing, at which the linear phase of the fruit degreening starts, appeared influenced by the variation of the canopy microclimatic conditions related to the orchard characteristics. The improved knowledge about the ripening process and its objective measurement, leaded to an innovative management of peach and nectarine fruit, from "field to market".

Key words: *Prunus persica*, I_{AD}, PlantToon®, ripening, quality, homogeneity.

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1.0 Introduction - A general overview

Recently, the most important peach-producing countries in Europe have lost considerable market share (Layne and Bassi, 2008; Iglesias et al., 2005) with per capita consumption remaining the same or decreasing, as reported for USA (Anon, 2004) and some European countries (Liverani et al., 2002, Hilaire and Mathieu, 2004). Between 2000 and 2005, in Italy peach consumption decreased 17%, as reported by Predieri et al. (2008). A major cause of this phenomenon is identified with the "poor match" between fruit quality and consumer's expectations (Mora et al., 2008). In the case of peaches and nectarines, consumers often complain about the lack of flavor and textural characteristics associated with maturity (Bruhn et al., 1991; Crisosto et al., 2006). Poor quality of the product present in the market is often due to the harvesting of too immature fruit (Bonghi et al., 1999). Moreover, the increased presence of new licensed varieties which develop full blush color and reach relevant size early in the ripening process, create difficulties in deciding the correct time of harvesting, as described by Iglesias and Echeverria (2009). Harvesting of 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 maturity on the tree, guarantees consumer acceptance, but it is associated with high susceptibility to bruises and rapid deterioration (Infante et al. 2012). The stage of maturity at harvest of a stone fruit should ensure the best balance between consumer satisfaction and easiness of logistic management, but this compromise is difficult to achieve.

Only a proper harvest allows the achievement of normal fruit ripening on the tree, the development of the typical quality characteristics and an high consumer appreciation (Lavilla et al., 2002; Infante, 2012).

To improve the fruit quality several physiological processes and techniques must be deeply studied in order to select the methods and measures to be taken in order to ameliorate it. Some of the main aspects related to the fruit quality can be the following:

1.1 The ripening process

Stone fruits, as part of the genus *Prunus,* are fleshy fruits containing a hard pit (endocarp) that protects the embryo and a juicy mesocarp, that represents the edible part of the fruit (Brummel et al., 2001). Peach (*Prunus persica* L. Batsch; Rosaceae family) is usually classified as climacteric fruit, because of the respiration and ethylene increase that characterize its ripening process. As described by Tonutti et al. (1991), respiration rate is high during stage I of fruit development, when the growth is marked because of the high rate of cell division. Respiration decreases through stage

II (pit hardening), it rises gradually from the end of stage III, (second exponential growth, due to cell enlargement) and reaches the climacteric peak at stage VI. Associated with the respiratory rise, even if not always coincident, ethylene production follows a similar trend, due to the activation of its biosynthetic way and of an autocatalysis mechanism that involves the key enzymes ACS (1-aminocyclopropane carboxylate synthase) and ACO (1-aminocyclopropane-1-carboxylate oxidase) (Abel and Theologis, 1996; Kondo et al., 2009). The increase of ethylene biosynthesis is associated with several events in the fruit development. In fact, dramatic changes in the transcriptional profile of genes leads to fruit colour, texture, flavour, and aroma modifications, which all contribute to the overall final quality of the fruit (Trainotti et al., 2003, 2006).

1.2 Field factors affecting fruit ripening

One of the reasons why the state of ripeness of stone fruit at harvest is quite heterogeneous is because in the orchard individual fruits have different effective ages (time elapsed from bloom to harvest) due to bloom time lasting up to more than two weeks (Infante, 2012). Moreover, the fruit is exposed to uneven microclimatic conditions regarding its positioning within the canopy, thus the biochemical reactions related to ripening will start at different timing in each fruit (Marini et al., 1991). Other factors influencing fruit ripening development are punctual variations of light and temperature within a peach canopy, which are due to the relative position of each object (leaf, branches, fruit, etc.) and strictly linked with tree density, row orientation, management practices (such as thinning, summer/winter pruning, etc.) and with the training system (Sansavini et al., 2012). In particular, a training system is defined as method of manipulating the tree structure and canopy geometry to improve the interception and distribution of light, for the purpose of optimizing fruit quality and yield (Caruso et al., 2003). Numerous studies on different tree architectures pointed out that fruit position into the canopy represents one of the most critical factors for peach fruit quality development and homogeneity of fruit characteristics (Farina et al., 2005; Dani, 2007; Feng-Li et al., 2008) related to the light availability (Lewallen and Marini, 2003). Peach training systems are derived from four basic tree shapes, each of them have given rise to several variant. The open-vase or open-centre training system (variants “delayed vase”, “vaso californiano”, “vaso italiano”, etc.), that have been most common in commercial orchards for more than 150 years (Cole, 1849, Sansavini et al., 2000), increases the light available in the inner canopy, giving rise to a gradient of quality traits (Caruso et al., 1998). The palmette tree shape, introduced in the ’50 by Baldassari, allows good light penetration, due to the narrow canopy (Corelli Grappadelli and Sansavini, 1989).The central leader (and its variant “fusetto”, “free spindle” and, recently introduced by Caruso et al. (1997), “dwarfed fusetto”), that reached the maximum development during the ’80, induces excessive shading in the lower canopy layers and was judged as scarcely suitable to peach trees (Loreti et al., 1989; Sansavini and Neri, 2005). The Y-shaped training system (variants “V”, “Tatura trellis”, “Y-trellis”, “KAC-V”), of more recent introduction, intercepts twice as much radiation as the palmette and the open-centre and maintains these great levels all along the orchard life (Chalmers et al., 1978; DeJong et al., 1994; Nuzzo et al., 2000; Caruso et al., 2003). Tree training system highly influences the light available for the fruit, also depending on their canopy position. Light appears extremely important on fruit ripening processes since it also affects fruit ethylene emission which plays a major role in the ripening process of climacteric fruit, such as peaches (Génard and Gouble, 2005), and strongly affects softening (Haji et al., 2003; Hiwasa et al., 2003), color change (Flores et al., 2001), and production of aromas (Rupasinghe et al., 2000; Alexander and Grierson, 2002; Flores et al., 2002). In fact, as reported by Marini et al. (1991), the biochemical reactions related to ripening develop at different rates in each fruit depending upon the different conditions of light and temperature at which fruit are exposed. But in most cases, the effects of temperature on fruit development and quality in pre-harvest conditions have not been clearly separated from the solar radiation effects, usually associating high fruit temperatures in the field with fruit exposure to sunlight (Ferguson et al., 1998). In literature, temperature is described as one of the major factors that affect fruit development. Several researches pointed out that it might influence fruit growth (Warrington et al., 1999), gas exchanges (Pavel and Dejong, 1993), fruit chemical composition (Tomes, 1963; Marsh et al., 1999; Yamada et al., 2004) and especially fruit ripening and quality development (Weinberg, 1948; Marsh et al., 1999). Both the described, interrelated factors, light and temperature, were related to the training system and the pruning practices, but only a few studies trying to separately consider their effects on fruit ripening.

Coupled with the choice and maintenance of the tree shape with the annual pruning practices, correct management of the fruit density is required to get a homogeneous fruit distribution as well as to guarantee the final size (Caruso et al., 1998; Farina et al., 2005). Several studies in the past evaluated crop load and fruit quality distribution in different training systems (Sansavini et al., 1985; Corelli Grappadelli and Sansavini, 1989), finding that in tree shapes that allow a uniform light distribution, fruit thinning has to be homogeneously performed in every part of the tree, in order to obtain uniform fruit at harvest (Costa et al., 2003).

1.3 Harvesting indices

In order to allow optimal maturity that would result in the best quality traits for consumption, peach and nectarines, being climacteric fruit, have to be picked from the tree only when ethylene production starts (Ziosi et al., 2008). Harvesting fruit at the optimal maturity stage also allows to better meeting consumer preference reducing dissatisfaction and improving return buying (Iglesias and Echeverria, 2009). Even if multiple harvests were usually performed (five to eight) during the course of ten to fourteen days to reduce the wide variation of peach and nectarine maturity on the tree (Lurie et al., 2013), the traditional methods to determine harvesting times were subjective and not standardized. In spite of visible changes traditionally characterize peach and nectarine fruit during final development on the tree, such as ground color degreening, blush color increasing and achievement of the maximum size (Eccher Zerbini et al., 1994; Lewallen, 2000), the introduction of new varieties that early reached an extended, full, red color, increased the difficulties in notice these signals (Scorza and Sherman, 1996; Carbò and Iglesias, 2002; Bellini et al., 2004). Traditionally, the maturity stage of peach and nectarine fruit in the field is judged on the basis of farmer’s experience. In fact, at each harvest, fruit that reach an acceptable yellow background color are picked and divided in classes of homogeneous diameter. In addition, flesh firmness (FF) and soluble solids content (SSC) might be added as supplementary determinants, but they are only measured on detached fruits (Kader, 1999). Another destructive parameter recently introduced is the soluble solid content/titratable acidity (SSC/TA ratio), even if the relationship between this parameter and consumer acceptance remained unclear (Crisosto and Crisosto., 2005). Lately, the interest of researchers for the development of non-destructive techniques to precisely measure maturity stage and assess fruit internal quality attributes has increased. Among these new non-destructive approaches, visible/near infrared (vis/NIR) spectroscopy seems particularly promising since it provides fast and reliable information on internal characteristics of many fruit species, including stone fruit (Vanoli and Buccheri, 2012). Based on this technology, the Index of Absorbance Difference (I_{AD}) allows a precise measurement of peach and nectarine fruit maturity stage non-destructively (Ziosi et al., 2008; Infante, 2012). The I_{AD} is calculated as the difference in absorbance between two wavelengths (670nm and 720 nm) near the chlorophyll-α peak. It is strictly correlated to the chlorophyll-α content in the fruit flesh and to the time course of ethylene production during ripening; both processes being cultivar specific (Ziosi et al., 2008). This new maturity index is measured by a portable, user-friendly 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 and nectarine maturity stage has been recently reported in literature by several authors (Magnanini et al., 2010; Lléo et al., 2011; Hale et al., 2011; Dagar et al., 2012; Herrero-Langreo et al., 2012; Reig et al., 2012, Lurie et al., 2013). The I_{AD} showed a high capacity for determining the post-harvest life of peach and nectarine fruit, according to their ripeness at harvest (Infante et al., 2012), but not much is known on the actual capacity and reliability of the I_{AD} usage as field maturity index.

1.4 Modeling fruit quality

The development of modern agricultural crop models was closely associated with the advent of computer programming and faster computers during the last decades of the 20th century that facilitated the many calculations needed in complex models (Goldschmidt and Lasko, 2005). Annual crops such as sugar beet, potato, corn and cotton were modeled first. Fruit tree models were developed only later.

Goldschmidt and Lasko (2005) defined “model” as an attempt to describe a certain process or system through the use of a simplified representation, preferably quantitative mathematical expressions, that focuses on relatively few key variables that control the process or system. The purpose and orientation of a model may differ according to the researcher’s interest and a variety of agricultural problems have been modeled, including water use, predicting phenology, fruit ripening and climate effects, evaluating stress responses and/or pest management (Boote, et al., 1996). However, the combination of a non-destructive technology for fruit maturity assessment with modelling systems is a topic still scarcely developed (Marcelis et al., 1998). Several studies tried to model different horticultural aspects of stone fruit., architectural plant models attempts to capture and represent the spatial arrangement of each plant component, leading to a reconstruction of real information coming from the field (Prusinkiewicz, 1998). The 3D software PlantToon®, developed by Magnanini et al. (2010), is based on a descriptive model that allows a simple representation of the tree architecture. Smith et al. (1992, 1994) indicated the value of reconstruction models in the analysis of spatial distribution of plant organs in the plant canopy. The key innovation of these kind of software is that real attributes of every single component of the tree (i.e. fruit weight, SSC, FF, etc.), as well as their variation in time could be stored in the database and directly linked with their exact position within the reconstructed tree. The virtual peach fruit model developed by Lescourret and Génard (2005), integrated three previously developed submodels (carbon, water and sugar sub-models) to simulate the interactions between physiological processes and their consequences on quality. This mechanistic (i.e. explanatory) process-based model is based on a detailed description of physiological processes, becoming very complex and thus, 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). 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 et al., 1962; Anderson et al., 1986), the UC Davis’s Harvest Prediction Model (http://fruitsandnuts.ucdavis.edu), gives an early prediction of the harvest date of peach and nectarine varieties, with an acceptable precision (Mimoun and DeJong, 1999; DeBuse et al, 2010). Jimenez and Diaz (2003) developed a model to estimate in a simple, rapid way potential yield for peach plots, 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, 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. In the current year, Nyasordzy et al. (2013) observed that the vis-NIR based, non-destructive maturity index I_{AD} might be used to predict the beginning of harvest on apple (cv's Granny Smith, Pink Lady and Starking), based on field measurements.

2.0 Aim of the thesis

Ripening of stone fruit is a complex syndrome, hard to completely understand and difficult to manage, both in pre- and post-harvest conditions. The present thesis focused on some field factors affecting ripening process of peach and nectarine fruit. In particular, the influence of different training systems (palmette, open-vase, Tatura trellis) and fruit densities, as well as the effect of fruit position, solar radiation and internal temperature within the tree canopy was assessed. To achieve these goals, innovative devices (DA-meter for ripening assessment, thermistors for measuring fruit internal temperature) and software (reconstruction model PlantToon® to create 3D map of fruit position into the canopy architecture) were used. Moreover, the development of a specific model for harvest date, yield and quality prediction was created to have a tool for fruit traceability and to improve pre- and post harvest management with the final goal to reduce fruit heterogeneity *in planta*, in packing house and during storage. Achieve such objective means to fulfill the consumer expectations as far as the desired fruit quality is concerned.

2.1 How to read the thesis

The thesis core is composed by five consecutive chapters (from Chapter 2 to chapter 6), that focused on different aspects of peach and nectarine ripening, each one structured as a scientific paper, with a proper Title, Introduction, Materials and Methods, Results, Discussion, Conclusions, Literature Cited, Figures and Tables. Finally, the thesis ends with the General Conclusions, that contains knowledge increases resulted from the present work.

3.0 Modeling fruit ripening for improving peach homogeneity *in planta*

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3.1 Abstract

The combined use of a modeling system (PlantToon®) and of an innovative vis-NIR device (DA-Meter) was tested in peach. The first allows to design the tree structure and the fruit position on the tree while the DA-Meter was used to characterize non destructively the fruit ripening in planta. This instrument provides the Index of Absorbance Difference (I_{AD}), that expresses the ripening stage reached by the fruit which correlates with chlorophyll content and ethylene *production* to accurately describe the fruit ripening evolution. Combining the PlantToon® software with the DA-Meter data allows to virtually design the tree structure, to follow the fruit ripening along the season and also to determine the level of fruit heterogeneity in the field. These information can be used not only to establish the best moment to perform the harvest but also to tune up the cultural management techniques (e.g. fruit thinning and winter and summer pruning) to reduce the outliers fruit and to concentrate ripening to improve harvest and post-harvest management.

Keywords: Heterogeneity, I_{AD}, quality, Prunus persica, PlantToon®

3.2 Introduction

Variability in time of fruit to fruit maturity on the tree is greater for stone fruit than for most of the other fruit species and strictly related to fruit quality (Marini and Trout, 1984). The heterogeneity of fruit maturation and quality is a concern for the whole fruit supply chain, in particular for growers. Between fruit variability could make it very difficult to determine the optimal harvesting time especially for peach and nectarine growers, since a wide fruit ripening distribution on the tree requires multiple picks (Corelli Grappadelli and Coston, 1991). As a consequence, the selection of the proper cultural management technique (winter and summer pruning and fruit thinning in particular) could help in diminishing fruit maturity variability in order to reduce the number of harvests (Costa and Vizzotto, 2000). It could also simplify fruit post-harvest management since storing fruit at different maturity levels might create difficulties in defining the best storage conditions and fruit marketing strategies (Ziosi et al., 2008).

It is established that to pick fruit at optimal ripening stage at harvest is essential for fruit quality (Infante, 2012; Vanoli and Buccheri, 2012). The ripening stage of peach and nectarine fruit in the field is traditionally judged on the basis of farmer’s experience, by monitoring the variation in fruit background color and size (Eccher Zerbini et al., 1994; Lewallen, 2000). At each harvest, fruit that reach an acceptable yellow background color are picked and divided in classes of homogeneous diameter. Nevertheless, in several cases, background color is not a satisfactory index to define the fruit ripening, firstly because a wide variability in terms of fruit quality traits (flesh firmness [FF], soluble solids content [SSC], titratable acidity [TA]) is observed even on fruit with similar background color (Lewallen and Marini, 2003). Several authors confirmed that these traditional quality variables were not as reliable as expected and often they are more related to the characteristics of each variety, than to the fruit ripening stage. In order to allow optimal ripening which would result in the best quality traits for consumption, peaches and nectarines have to be picked from the tree only when ethylene *production* starts, as for other climacteric fruit (Ziosi et al., 2008). Harvesting fruit at the optimal maturity stage also allows to better meet consumer preference reducing dissatisfaction and improving return buying (Iglesias and Echeverria, 2009).

The introduction of new varieties characterized by the development of an extended, intense full red blush color early in the season, would add to the difficulties in defining the best harvesting time since fruit would appear ripen on the base of size and color, however all the physiological changes required to complete the maturation process did not occur yet (Carbó and Iglesias, 2002). To complete these physiological requirements, the harvesting time must be carefully determined and several new techniques were recently adopted to achieve this goal. The development of a series of crop models which describe trees in terms of biomass production, yield, number of flower and fruit, etc., tried to roughly solve the situation by providing general advices to the orchardists (Lescourret and Génard, 2005). Useful indications are also given by architectural plant models that attempt to capture spatial arrangement of plant components (Prusinkiewicz, 1998), due to the possibility to combine this models with real information coming from the field. The 3D software PlantToon® (Magnanini et al., 2010) is based on a descriptive model that allows a simple representation of the tree architecture. The key innovation of these kind of software is that real attributes of every single components of the tree (i.e. fruit weight, SSC, FF, TA, etc.), as well as their variation in time could be stored in the built in database and directly linked with their exact position within the reconstructed tree. More recently, the availability of innovative techniques, mainly operating on vis-NIR properties, allowing non-destructive monitoring in real-time condition of the ripening evolution of the fruit, were introduced. One of these devices, named DA-Meter, creates an index called Index of Absorbance Difference (I_{AD}) which correlates with fruit ethylene *production* and chlorophyll content allowing a precise description of the ripening evolution (Ziosi et al., 2008). As suggested by Costa et al. (2009), the I_{AD} can be regarded as an “easy to use marker” of peach and nectarine fruit ripening, more sensitive and confident than the physic-chemical parameters commonly used to describe the maturation process.

In the present work, the I_{AD} was used to follow fruit ripening evolution on the trees, to assess fruit homogeneity in order to choose the optimal harvest time in which fruit samples would have the same maturity level. Additional scope was to recreate the tree structure and fruit positioning in the canopy by using PlantToon® combined with the I_{AD} to allows a new representation of the last stages of fruit ripening (as I_{AD}) and of the fruit quality attributes (SSC, FF, etc.), in order to make practical decision by defining the appropriate harvesting time and reducing fruit ripening heterogeneity *in planta.*

3.3 Materials and Methods

Trials were carried out on six-year-old yellow flesh peach [*Prunus persica* (L.) Batsch] cultivar 'Royal Glory' grafted onto GF677 (*P. persica x P. amygdalus*). The orchard was located in Ferrara, Italy (44° 77' N, 11°56' S); trees were trained to a palmette system with planting density of 4.5 x 3.0 m and East-West oriented. The trees were trained with a main scaffold at 50-60 cm above the ground, from which three primary vertical branches developed to a maximum total height of 3.2 m. Routine horticultural management of the region was applied throughout the season in terms of pruning, irrigation fertilization and pest control.

To describe the tree architecture and the fruit position on the tree, the PlantToon® software was used. PlantToon® is an empirical architectural model based on the virtual reconstruction of the three-dimensional (3D) tree structure based directly on the raw data obtained in the orchard. By adopting a set of rules and a rewriting mechanism, PlantToon® tried to accurately describe the real structure of the tree. PlantToon® was developed from a previous experience on software born for editing and navigating plants scanned with a digitizing-arm (Magnanini e al., 1998). The latest version of the software (Magnanini et al., 2010) uses a single canvas for the 3D structure of the plant, and a new technique for navigation. A tool palette allows the user to add, delete, move, and select objects such as the trunk, primary and secondary branches, shoots and fruit. More objects can be added gradually according to a hierarchical organization. The time that user requires to become familiar with the environment and learn basic capabilities is reduced to a few days, due to the topological structure, together with 3D graphics, that are easy to navigate.

At the beginning of summer 2010, on a single tree, the spatial position of each fruit as well as the entire canopy structure, were identified using a custom-made "woody stick-compass system". Length, direction (°N) and horizontal projection were measured on each segment of the trunk, as well as on all branches and limbs, in an upward direction from the ground to the top of the canopy, following the insertion sequence and the direction changes of each element, as previously described by Sinoquet et al. (1997) and Sinoquet and Rivet (1997). The collected Cartesian coordinates were inserted in the PlantToon® database and also the punctual position of each fruit was catalogued. The influence of fruit position within the canopy on peach fruit ripening and quality was assessed on two additional randomly selected trees in the same orchard. Three parallel areas of equal size were identified within the canopies, related to their height from the ground (top [T], middle [M] and

bottom [B] canopy layers) as described by He et al., (2008). Ten fruit per each area of each tree on both North and South side of the trees were tagged (180 fruit in total) for continuous monitoring.
To define the fruit ripening stage the DA-Meter (TR Turoni, Forli, Italy) was used. The I_{AD} of a fruit is calculated as absorbance difference between 670 and 720 nm wavelengths. The fruit ripening evolution occurring during the span of time in which fruit were completing their development on the tree was monitored and expressed as I_{AD} (Ziosi et al., 2008)**.** The I_{AD} was weekly collected *in planta* on the tagged fruit from 89 DAFB (begin of stage III, as described by Tonutti et al., 1991) until the last pick (120 DAFB) to determine the ripening stage for optimal harvesting. To detect the maturity stage at which the ethylene climacteric occurred in cultivar 'Royal Glory', ethylene production was assessed on 5 fruit per I_{AD} class, randomly picked around 113 DAFB. Ethylene production 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).
All fruit under study were picked when they reached the onset of ethylene climacteric (I_{AD} 0.8-1.0) according to the ethylene production for cv 'Royal Glory' (ethylene production between 0.05-0.08 nl h-1 g-1 FW, Figure 3). Four picks were performed at 107, 109, 113, and 120 DAFB. The data obtained non-destructively were compared with the standard quality traits measurements (FF, SSC, TA) determined on a fruit sample of 10 fruit collected at 113 DAFB, with traditional destructive devices (penetrometer, refractometer, titrator). FF was measured on the two opposite sides of each fruit, after eliminating a thin layer of the epicarp, using an automatic pressure tester (FTA-GUSS, South Africa) fitted with an 8 mm plunger. Part of the mesocarp was squeezed and SSC was determined with an Atago digital refractometer (Optolab, Modena, Italy). TA was determined on 20 mL of flesh juice (titration with 0.25N NaOH) using a semiautomatic instrument (Compact-S Titrator, Crison, Modena, Italy).
All the collected measures of tree architecture, I_{AD} and fruit quality traits were inputted in the 3D modeling software PlantToon®. The tree architecture was recreated and modeled in order to correlate the relative position of each fruit on the tree to its maturity stage and quality attributes. Fruit distribution between I_{AD} classes was described by using a wide range of color intensities in the grayscale: the lighter is the color the riper is the fruit (a full black circle corresponds to a completely unripe fruit, with an I_{AD} value between 1.8 and 2.0; a full white to a completely ripe one, with an I_{AD} below 0.4).
Data collected were statistically evaluated using the software STATISTICA 7 (StatSoft. Inc., Tulsa, USA) and the Duncan's multiple range t-test at $p < 0.05$.

3.4 Results

Figures 1 (a, b and c) shows the PlantToon® three-dimensional reconstruction of a whole peach canopy, based on a dataset previously created. The structure of the tree, the fruiting limbs and the total number of fruit (shown as circles) are drawn identifying in which part of the tree they are mainly located. From the figures it is possible to see how the fruit ripening evolution does occur at every single position within the canopy, highlighting the differences existing between the three main canopy layers (B, M, and T). The ripening stage of each fruit, expressed as I_{AD} value, allows grouping fruit into I_{AD} classes according to the statistical differences observed in ethylene production.

The overall fruit color change from darker (unripe) to lighter (riper), visible by comparing the Figure 1 a, b and c, indicates that fruit ripening was progressing and that the I_{AD} accurately describes the fruit maturity over time. From the figure is also possible to notice that at 99, 102 and 106 DAFB the fruit positioned in the highest parts of the tree were characterized by a more advanced ripening stage than those situated in the lowest canopy layers.

The differences in the fruit ripening stages are also showed in Figure 2 in which the fruit distribution between I_{AD} classes at 99, 102 and 106 DAFB is expressed as a Gaussian curve. The graph shows that the three curves presented the same shape and amplitude only shifting toward more mature fruit in time. This trend was as also shown by the statistically different I_{AD} values measured at each date (Table 1).

In Table 1 the averages of fruit I_{AD} at each sampling date are summarized and the I_{AD} follows the peach ripening evolution. In fact, the I_{AD} value reached by the fruit at 89 DAFB is higher than the I_{AD} values obtained thereafter, when the number of DAFB increased. Only between 110 and 114 DAFB, at which the main picks were performed, fruit maturity on the tree did not vary. Instead, at the last pick (120 DAFB) the I_{AD} reached the lowest value that corresponds to the fruit highest ripening levels.

As shown in Figure 3, peach fruit characterized by an I_{AD} value between 0.6 and 1.0, less ripe, did show a very small ethylene production, around 0.5 nl $l^{-1}h^{-1}$ gFW^{-1}. Following peach fruit maturation, the I_{AD} decreased while the hormone emission increased, up to 8.0 nl $l^{-1}h^{-1}$ gFW^{-1} at which fruit reached the ripest stage (I_{AD} <0.4).

In Table 2 are reported the traditional fruit quality trait values (SSC, FF and TA) of fruit north- and south-oriented from the three different canopy layers (B, M, T). Fruit at the same maturity stage showed higher SSC values in the highest part of the tree (T), than those positioned in M and B canopy layers. This result was confirmed with PlantToon® in Figure 4, that shows that the darker fruit (as indication of low SSC value) are positioned in the lower and inner canopy layer, whereas the higher the fruit position in the tree, the lighter is the fruit color up to fruit of a white color, with an SSC value around 12-14 °Brix. Vice versa the TA tended to be lower in the fruit present in the M part of the tree (Table 2). Fruit north-oriented have the highest TA values in B and T canopy layers, while fruit south-oriented have the highest TA values in the B canopy layer of the tree. No statistical significant differences were observed in the FF of fruit from the three canopy layers of the tree.

3.5 Discussion

As several authors suggested (Carbó and Iglesias, 2002 ; Lewallen and Marini, 2003) the traditional quality parameters frequently used (FF , ground color, SSC and TA) do not provide an acceptable description of the fruit maturity stage. Considering for example, flesh stony hard peaches or early full blush-colored fruit, these traditional parameters do not vary and consequently are not helpful in characterizing the optimal harvest time nor in defining peach fruit ripening homogeneity.

Our data showed that fruit at the same ripening stage (I_{AD} range between 0.8 and 1.0) from the tree top had higher SSC (Table 2 and Figure 4) than fruit in the underlying canopy layers, while FF did not change (Table 2). As suggested by Wei et al. (2004) and Basile et al. (2007), the lower SSC observed in the B layer of the canopy could be due to a light penetration gradient and consequent different hormonal activity associated with fruit position, which affects quality factors. Dann and Jerie (1988) and Génard and Bruchou (1992) have shown that well exposed fruit, as well as fruit that develops farther from the roots, had the greatest amount of SSC. Farina et al. (2003) stated that the SSC value decreased from the top and outer canopy to the inner bottom following an exponential model.

While several authors found similar results concerning fruit SSC distribution *in planta*, different observation were done about FF on several varieties and training systems. Dann and Jerie (1988) found that fruit from the tree top were softer than those from the base; afterwards Caruso et al. (1998) found that FF did not decrease towards the tree base in both Y shaped and Central leader training systems. Our results did not identify any difference in the FF distribution (Table 2) probably because FF is ethylene dependent, so fruit harvested with similar ethylene production would show the same FF value (Ziosi et al., 2008). Light intensity seems not to be responsible of FF changes in different canopy positions (He et al., 2008). The same authors observed that TA tended to be higher in top and bottom outer fruit, than in the middle inner ones, due to the greater light intensities that more external fruit would receives. Our experiment showed different results with the highest TA values being observed in fruit from the tree bottom (Table 2), with a different behavior between the North and South side. A possible explanation could be that fruit in the tree top did not reach the highest TA values due to the high vegetative growth that the tree showed in the last weeks before harvest. This factor in combination with the unusual orientation of the tree could have influenced the normal fruit characteristics development. Moreover, as reported by Moing et al. (1998), organic acid accumulation during fruit development is strongly cultivar dependent.

In our trial fruit from the tree T canopy layer were heavier than fruit from the M and B canopy layers (data not shown). Farina et al. (2005) found similar results on harvested fruit of the cultivar 'Elegant Lady' trained to delayed vase and perpendicular Y. The presence of smaller fruit in the lower canopy could be due to lower light exposure that would affect carbohydrate supply and fruit growth (Dani M., 2007; Dann and Jerie in 1988 and Marini et al., 1991).

Our results showed that SSC and TA values are depending upon the fruit gradient from the top to the bottom of the tree as well as the row orientation (Table 2 and Figure 4). An accurate determination of these quality variables could be important since, although extremely variable, they are very important in defining the palatability of peach fruit from a consumer stand point of view, as reported by Crisosto et al., (2003).

The availability of non destructive methods that allow monitoring of the evolution of the fruit ripening on the tree, could offer a more rapid and precise method of evaluation of fruit quality attributes. In fact, the combination of the PlantToon® modeling system with the I_{AD} might play a synergistic effect which could be used as a decision support system, or reducing fruit ripening heterogeneity and improve post-harvest management. The PlantToon® software, although offering real representation of the tree, might require some improvements. In fact, Prusinkiewicz (1998) identified some drawbacks in using reconstruction models. They usually need large dataset, they stand for single plant specimen only and they do not have predictive power. However, these limits cannot exclude the usefulness of reconstruction models. The specific data collection technique adopted in our experiment, greatly reduced the dataset dimension maintaining a high level of detail. Other authors developed interactive-image based modeling, that allows the tree reconstruction from photographs, but they had difficulties in defining details of vigorous trees, like forestry species (Rui et al., 2006). Instead, fruit tree species have simple shapes that are easily and quickly reconstructed with the PlantToon® software.

The DA-Meter coupled with the PlantToon®, allows describing and monitoring the fruit ripening distribution according to the fruit position on the tree (Figure 1 a, b and c). These data are more obvious and realistic as compared to a traditional Gaussian curve graph. PlantToon® images coupled with DA-Meter values add visibility to the data, facilitating the understanding of experimental data and making their comparison with real situations easier. Although the PlantToon® is not a predicting software such as QualiTree described by Lescourret et al. (2011), when coupled with the

DA-Meter allows to describe the tree architecture, fruit position as well as fruit ripening or quality attributes and their development over time (Table 1, Figure 2). The obtained results, as I_{AD} values, have shown that fruit form the tree top are riper than fruit in the lower canopy layers and that the tree kept these gradients until harvest (Figure 1 a, b and c). Other authors found that fruit present in the lower part of the canopy were delayed in reaching physiological maturity compared to upper fruit starting at the beginning of cell enlargement stage (SIII) (Dann and Jerie, 1988). This behavior can be easily explained, because fruit from the outer top of the tree, usually receive more solar radiation than those at the bottom and in the inner part of the canopy, and also they are affected by different light quality intensity. The different light conditions may contribute to a variation in fruit development and progression of the metabolic processes associated with fruit ripening, reducing ripening rates of the fruit that receive lower amount of light, which are usually located in the canopy base and near the trunk (Chalmers, 1986; Mc Glasson, 1978). In fact, under real conditions, peach and nectarine fruit for the fresh market are generally harvested in several pickings (Crisosto and Valero, 2008), starting from the tree top of the trees. Fruit in the lower canopy layers are generally harvested few days later. In fact it has been reported that canopy position could be responsible for the changes in fruit quality attributes (Lewallen and Marini, 2003).

The use of I_{AD} on peach fruit still on the trees might represent a guide for the orchardist. In fact, it may provide early information about fruit heterogeneity distribution in planta, as well as regarding the ripening status (Figure 2). As described by Reig et al. (2012), farmer can no longer count only on their own experience, especially with new varieties characterized by a high size and an almost completely red blush color reached early in the season. Therefore, the use of I_{AD} for an early and objective assessment of fruit ripening heterogeneity *in planta* (Figure 2) Regardless of any change in peach and nectarine blush color, which already in the '50 was tagged as not a reliable maturity index (Haller, 1952), the accuracy which characterizes the I_{AD} in defining peach ripening is dependent upon the fact that the Index strongly correlates with fruit ethylene production (Figure 3), which is specific to the variety and that remain unmodified in subsequent years, as well as upon the fruit color change from green to yellow, due to the reduction in the chlorophyll content (Ziosi et al. 2008). As known, ethylene is responsible for activation and regulation of the maturity process in peach and it also affects the main quality characteristics, such as flesh firmness, flesh chlorophyll changes, soluble solid and acid content (Alba et al., 2005; Giovannoni, 2004).

3.6 Conclusions

Both the PlantToon® 3D reconstruction model and the DA-Meter represent valuable tools to improve fruit ripening homogeneity. Coupling the PlantToon® method with the I_{AD} would allows for collecting of data for the model database creation, that could be used to represent the fruit ripening distribution and quality attributes variability within different tree architectures, and would provide an objective evaluation of peach fruit ripening. The concurrent use of PlanToon® and I_{AD} can guide the adjustment of the main cultural management techniques (thinning, summer and winter pruning, defoliation, etc.) toward the creation of best management practices protocols as well as to eliminate the outliers fruit and to concentrate ripening to improve the post-harvest management.

3.7 Literature Cited

Alba R., Payton P., Fei Z., McQuinn R., Debbie P., Martin G., Tanksley S.D. and Giovannoni J.J., 2005.Transcriptome and selected metabolite analyses reveal multiple points of ethylene control during tomato fruit development. *The Plant Cell*. 17: 2954-2965.

Bregoli A.M., Scaramagli S., Costa G., Sabatini E., Biondi S., Ziosi V. and Torrigiani P., 2002. Peach (*Prunus persica* L.) fruit ripening: aminoethoxyvinylglycine (AVG) and exogenous polyamines affect ethylene emission and flesh firmness. *Physiologia Plantarum*. 114: 472-481.

Caruso T., De Michele A., Sottile F. and Marra F.P., 1998. La peschicoltura siciliana nel contesto italiano: ambiente, cultivar e tecniche colturali. Proceeding of the II Convegno sulla Peschicoltura meridionale. Paestum, 2-3 luglio. Pp. 83-88.

Carbó, J. and Iglesias I., 2002. Melocotonero: Las Variedades de Más Interés. IRTA, Barcelona.

Chalmers D.J., Burge G., Jerie P.H. and Mitchell P.D., 1986. The mechanism of regulation of 'Bartlett' pear fruit and vegetative growth by irrigation with holding and regulated deficit irrigation. Journal of the American Society for Horticultural Science. 111: 904-907.

Corelli Grappadelli L. and Coston D.C., 1991. Thinning pattern and light environment in peach tree canopies influence fruit quality. *HortScience*. 26: 1464-1466.

Costa G., Noferini M., Fiori G. and Torrigiani P., 2009. Use of Vis/NIR spectroscopy to assess fruit ripening stage and improve management in post-harvest chain. *Fresh Produce*. 1: 35-41.

Costa G. and Vizzotto G., 2000. Fruit thinning of peach trees. *Plant Growth Regulatores.* 31: 113-119.

Crisosto C.H., Crisosto G.M. and Bowerman E., 2003. Searching for consumer satisfaction: new trend in the California peach industry. In: Marra, F., Sottile, F. (Eds.), Proceedings of the First Mediterranean Peach Symposium, University of Palermo, Agrigento, Italy. Pp. 113-118.

Crisosto C.H. and Valero D., 2008. Harvesting and postharvest handling of peaches for the fresh market, In: Layne, D.R., Bassi D. (Eds.), The Peach: Botany, Production and Uses. CABI, UK. Pp: 575-596.

Dani M., 2007. Connection between the light availability and the peach fruit quality. Proceeding of the VI Alps-Adria Scientific Workshop. Pp. 337-340.

Dann I. R. And Jerie P. H., 1988. Gradients in maturity and sugar levels of fruit within peach trees. *Journal of the American Society for Horticultural Science.* 113: 27–31.

Eccher Zerbini P., Spada G.L. and Liverani C., 1994. Selection and experimental use of color charts as a maturity index for harvesting peaches and nectarines. Advance in Horticultural Science. 8: 107-113.

Farina V., Gugliuzza G., Lo Bianco R. and Inglese P., 2003. Produzione e qualità dei frutti in relazione alla collocazione spaziale e alla morfologia del ramo in alberi di pesco allevati a vaso. Proceeding of the IV Convegno Internazionale sulla Peschicoltura Meridionale. Campobello di Licata ed Agrigento, 11-12 Settembre.

Farina V., Lo Bianco R. and Inglese P., 2005.Vertical distribution of crop load and fruit quality within vase and Y-shaped canopies of ‘Elegant Lady’ peach. *HortScience*. 40: 587-591.

Génard M. and Bruchou C., 1992. Multivariate analysis of within-tree factors accounting for the variation of peach fruit quality. *Scientia Horticolturae*. 52: 37-51.

Giovannoni JJ., 2004. Genetic regulation of fruit development and ripening. *Plant Cell.* 16: 70-80.

Haller M., 1952. Handling, transportation, storage, and marketing of peaches. U.S.Dept.Agr. Bibliographical Bul. No. 21.

Feng-Lil He, Fei W., Qin-Ping W., Xiao-wei W. and Qiang Z., 2008. Relationships between the distribution of relative canopy light intensity and the peach yield and quality. *Agricultural Sciences in China*. **7**(3): 297-302.

Iglesias I. and Echeverría G., 2009. Differential effect of cultivar and harvest date on nectarine colour, quality and consumer acceptance. *Scientia Horticulturae*. 120: 41-50.

Infante R., 2012. Harvest maturity indicators in the stone fruit industry. Stewart Postharvest Review. 1-6.

Lescourret F., Moitrier N., Valsesia P. and Génard M., 2011. QualiTree, a virtual fruit tree to study the management of fruit quality. I. *Model development*. Trees. **25**(3): 519-530.

Lescourret F. and Génard M., 2005. A virtual peach fruit model simulating changes in fruit quality during the final stage of fruit growth. *Tree physiology*. **25**(10): 1303-15.

Lewallen K.S., 2000. Effect of light availability and canopy position on peach fruit quality. Master of science in Horticulture Thesis, Faculty of the Virginia Polytechnic Institute and State University.

Lewallen K. S. and Marini R. P., 2003. Relationship between flesh firmness and ground color in peach as influenced by light and canopy position. *Journal of the American Society for Horticultural Science.* 128: 163-170.

Magnanini E., Bonora E. and Vitali G., 2010. PlantToon - drawing and pruning fruit trees. In: Proceedings of the 6th International Workshop on Functional-Structural Plant Models. Davis, CA, September 12-17. Pp. 255.

Magnanini E., Corelli Grappardelli L. and Carboni F., 1998. An innovative methodology to digitize tree canopy – Proceeding of IV Giornate Scientifiche SOI, Sanremo, Italy, April 1-3. Pp. 537-538.

Marini R. P., Sowers D. and Marini M. C., 1991. Peach fruit quality is affected by shade during final swell of fruit growth. *Journal of the American Society for Horticultural Science*. **116**(3): 383-389.

Marini, R.P., Trout., R., 1984. Sampling procedures for minimizing variation in peach fruit quality. *Journal of the American Society for Horticultural Science*. 109: 361-364.

McGlasson W.B., 1978. Role of hormones in ripening and senescence. *Postharvest Biology and Biotechnology*. 77-96.

Moing A., Svanella L., Rolin D., Gaudillere M., Gaudillere J.P. and Monet R., 1998. Compositional changes during the fruit development of two peach cultivars differing in juice acidity. *Journal of the American Society for Horticultural Science*. 123: 770-775.

Prusinkiewicz P., 1998. Modeling of spatial structure and development of plants: a review. *Scientia Horticulturae.* 74: 113-149.

Reig G., Alegre S., Iglesias I. and Echeverría, G., 2012. Fruit quality, color development and Index of Absorbance Difference (I_{AD}) of different nectarine cultivars at different harvest dates. In: Proc. XXVIII IHC – ISHS on Postharvest Technology. *Acta Horticolturae*. 934: 1117-1125.

Rui W., Wei H., Hujun B. and Qunsheng P., 2006. Plant synthesis with Plantons. CAD&CG State Key Lab of Zhejiang University, China.

Sinoquet H and Rivet P., 1997. Measurement and visualization of the architecture of an adult tree based on a three-dimensional digitizing device. *Trees: Structure and Function*.11: 265-270.

Sinoquet H., Adam B., Rivet P. and Godin C., 1997. Interactions between light and plant architecture in an agroforestry walnut tree. *Agroforestry Forum.* 8: 37-40.

Vanoli M. and Buccheri M., 2012. Overview of the methods for assessing harvest maturity. *Stewart Postharvest Review*. 1-11.

Wei Q.P., Lu R.Q., Zhang X.C., Wang X.W., Gao Z.Q. and Liu,J., 2004. Relationships between distribution of relative light intensity and yield and quality in different tree canopy shapes for 'Fuji' apple. *Acta Horticulturae Sinica*. 31: 291-296.

Ziosi V., Noferini M., Fiori G., Tadiello A., Trainotti L., Casadoro G. and Costa G., 2008. A new index based on vis spectroscopy to characterize the progression of ripening in peach fruit. *Postharvest Biology and Technology*. 49: 319-329.

3.8 Figures

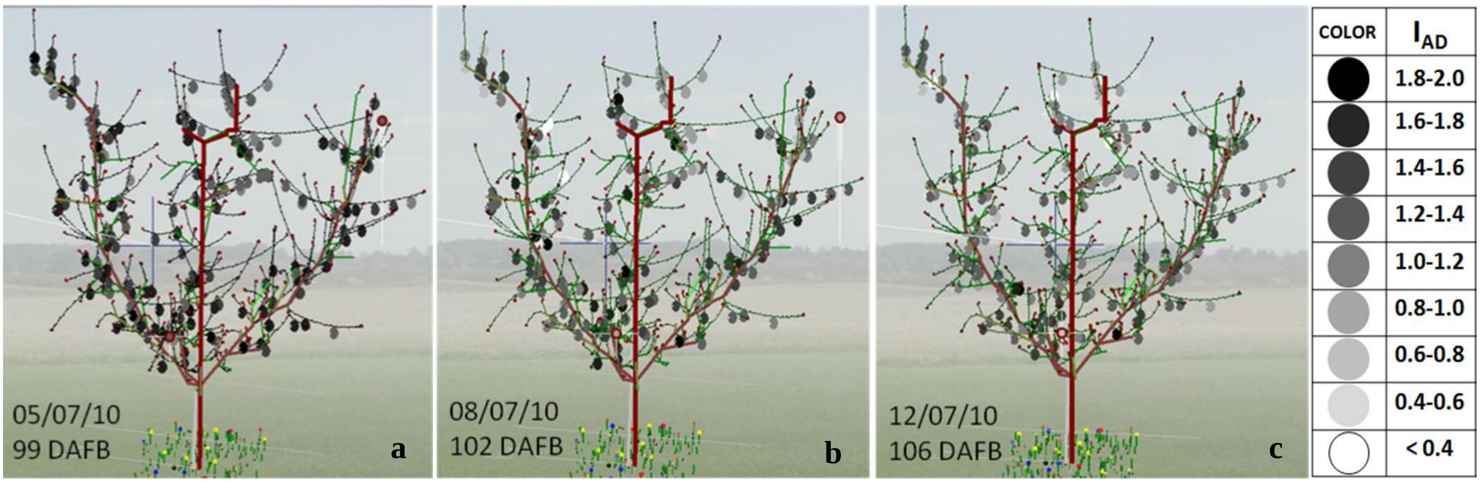

Figure 1 a, b and c: PlantToon® images of the fruit maturity distribution (I_{AD}) within the canopy of a 'Royal Glory' tree at 99 DAFB (05/07/10 –a), 102 DAFB (08/07/10 –b) and 106 DAFB (12/07/10 –c). The white and light grey circles represent riper fruits. The more the color is darker, the more fruits are unripe and

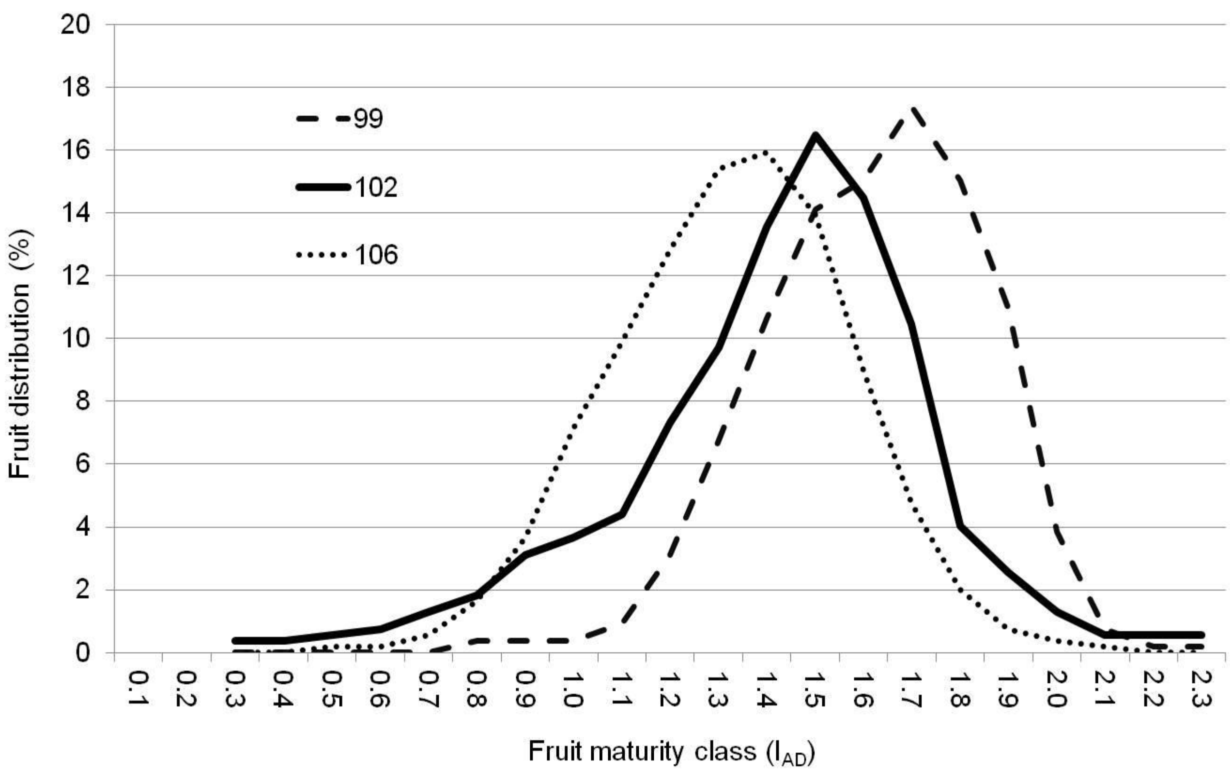

Figure 2: Fruit distribution between maturity classes (I_{AD}) at 99, 102 and 106 DAFB.

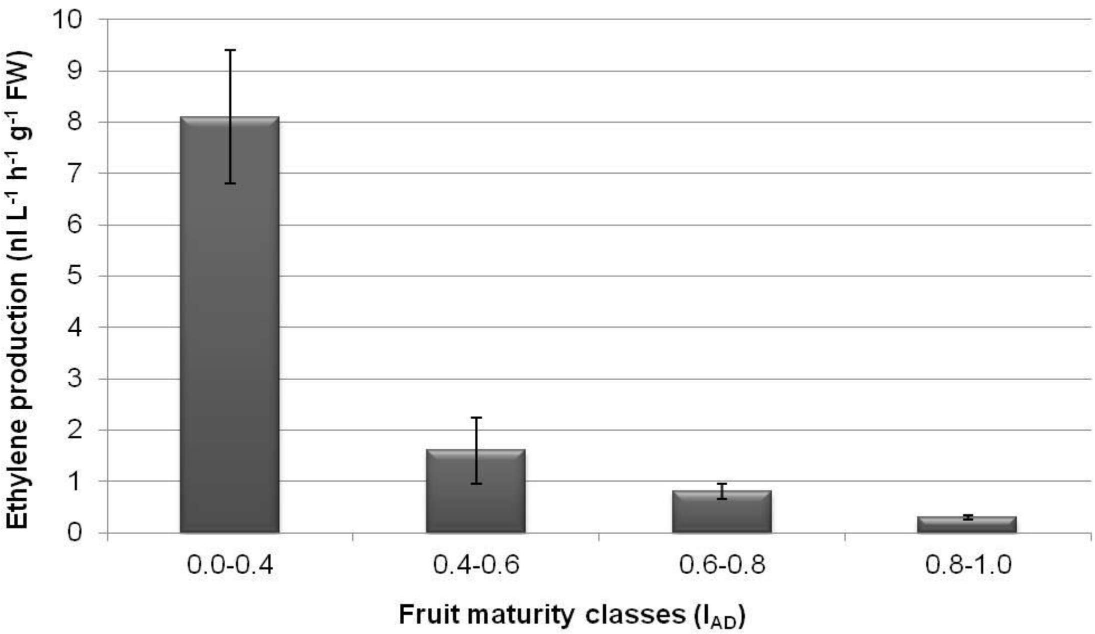

Figure 3: Fruit ethylene production at different maturity classes (I_{AD}). Bars represent the standard errors. Lower case letters represent the significant differences ($p<0.05$).

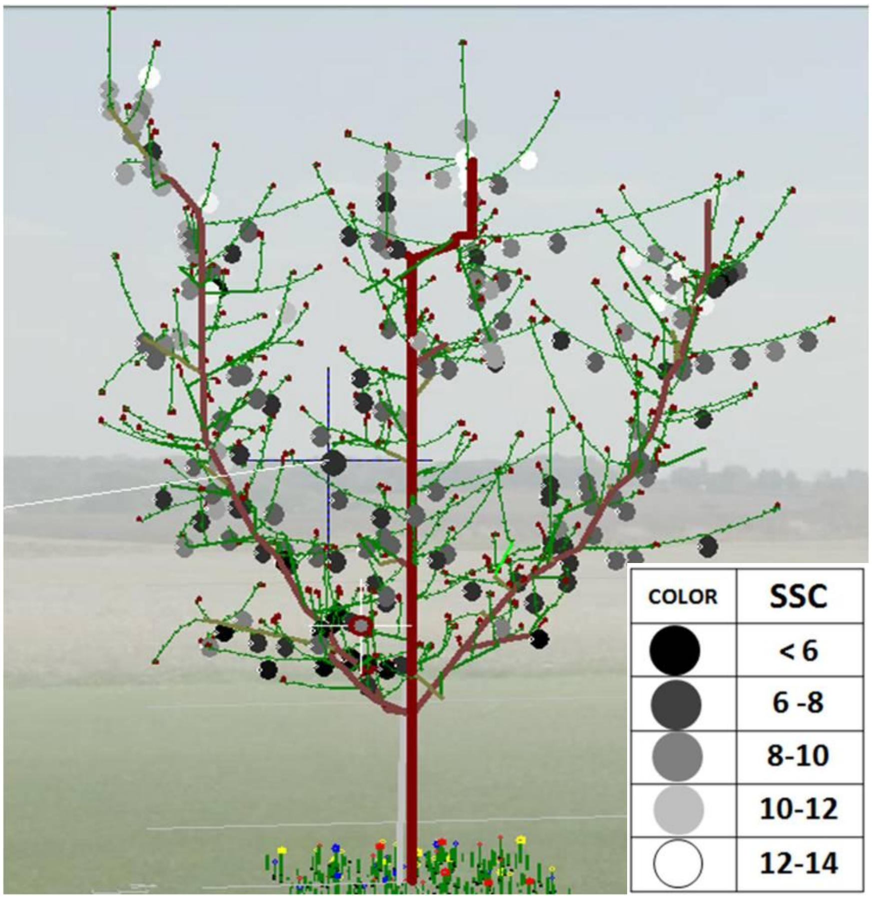

Figure 4: Fruit soluble solid content (SSC) distribution within the canopy at harvest. White circles correspond to the highest SSC content, while the more darker is the color, the less is the soluble solid content.

3.9 Tables

Table 1: Average of the fruit ripening stage (I_{AD}) on the tree from 89 to 120 DAFB.

Time (DAFB)	Fruit ripening (I_{AD})	
89	1.87	a[z]
94	1.65	b
97	1.63	c
99	1.47	d
102	1.27	e
106	1.17	f
110	1.02	g
114	0.98	g
120	0.73	h

[z]Lower case letters represent the significant differences ($p<0.05$).

Table 2: Average of flesh firmness (FF), soluble solid content (SSC) and titratable acidity (TA) on fruits from different canopy layers, both North and South oriented.

Orientation	Layer	FF	SSC	TA
North	B[z]	4.1 a[y]	7.5 b	4.4 a
	M	4.7 a	8.9 a	3.5 b
	T	3.8 a	9.1 a	4.7 a
South	B	4.3 a	7.0 b	4.9 a
	M	4.2 a	7.7 b	4.2 b
	T	4.2 a	8.8 a	4.4 b

[z]= Canopy layers: bottom (B), middle (M) and top (T).

[y]=Lower case letters represent the significant differences ($p<0.05$).

4.0 Modeling of pre-harvest non-destructive parameters for harvest date and yield prediction on three nectarine varieties

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4.1 Abstarct

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, 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 III 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 III of nectarine development allowed two-three weeks advance predictions for harvest date and yield with low errors. It also appeared a more reliable method in predicting harvest date than the till now used growing degree heat unit accumulation at 30 days after fool 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.

Key words: Index of Absorbance Difference I_{AD}, *Prunus persica*, growth, GDD, modelling

4.2 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 and nectarine cultivars are about hard fruit at consumption and a lack of flavour, and both of these problems are caused by harvesting fruit at immature stages (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, but it is associated with high susceptibility to bruises and rapid deterioration (Infante et al. 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 varieties that develop full, intense red colour at an early stage of maturity, made harvesting even more difficult (Scorza and Sherman, 1996; Carbò and Iglesias, 2002; Bellini et al., 2004). Therefore, other physic-chemical and physiological parameters, usually measured with traditional and destructive tools, 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. (Bassi and Layne, 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, to monitor on-tree ripening in order to establish the optimum harvest date and to increase fruit batches homogeneity at the packinghouse with on-line measurements (Nicolai et al., 2007; Vanoli and Buccheri, 2012). Among these new non-destructive approaches, visible/near infrared (vis/NIR) spectroscopy seems particularly promising since 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 and nectarine 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 *Prunus* 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/NIR 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 and nectarine ripening stage in the field and the post-harvest, has been recently reported in literature (Magnanini et al., 2010; Lléo et al., 2011; Hale et al., 2011; Dagar et al., 2012; Herrero-Langreo et al., 2012; Reig et al., 2012). The I_{AD} showed an high capacity for determining the harvest date and sorting stone fruit according to their ripeness, (Infante et al., 2012), but only few results were available on use of the I_{AD} as field ripening predictor index (Reig et al., 2012). 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 behaviour in peach fruit (Bonora et al., 2013b) during stage III (SIII) of development leading to hypothesise that monitoring peach and nectarine fruit ripening on the tree, could be easily modelled. The combination of a non-destructive technology for fruit ripening assessment with modelling systems is a topic still scarcely developed, in particular when fruit quality is considered (Marcelis et al., 1998). Goldschmidt and Lasko (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) process-based 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 et al., 1962; Anderson et al., 1986), the UC Davis's Harvest Prediction Model (http://fruitsandnuts.ucdavis.edu), gives an early prediction of the harvest date of peach and nectarine varieties, with an acceptable precision (Mimoun and DeJong, 1999; DeBuse et al, 2010). Jimenez and Diaz (2003) developed a model to estimate in a simple, rapid way potential yield for peach plots, 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. Nyasordzy 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 non-destructive, vis-NIR based I_{AD}, in the assessment of peach and nectarine 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., 2013, b data under publishing), it was decided to test the I_{AD} on three varieties 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 varieties and training systems in different growing seasons; c) to use the above mentioned information to develop and validate a new, simple, grower usable model predicting harvest date and yield on nectarine.

4.3 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 x 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 x 1.4 m and 5.5 x 3.5 m, respectively; the trees of the late season cultivar 'California' were trained to a palmette system with planting density of 4.0 x 1.3 m. The varieties 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.

4.3.1 Ethylene emission assessment

To establish the correlation between ethylene emission and fruit ripening stage (I_{AD}), every year, seven days before commercial harvest, a sample of one hundred fruit representative of the orchard spatial variability was collected (Costa et al., personal communication) and the fruit samples from each of the three cultivars ('Gartairo®', 'Sweet Red' and 'California'), were grouped according to their I_{AD} values. As described by Ziosi et al. (2008), ethylene emission of five to ten 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).

4.3.2 Phenological and climatic parameters

Full bloom date, corresponding to the 50% of open flowers (Baggiolini, 1980; Mounzer et al., 2008), was registered for years 2011 and 2012 at the starting of the season 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 logger (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 De Jong (1994). The base critical temperature of 7°C was chosen as temperature at which bloom starts (Zalom et al., 1983; DeJong and Goudriaan, 1989a; Marra et al., 2002; Day et al., 2008).

$$GDD = \sum_1^n [(tmax + tmin)/2] - b \qquad (1)$$

where:

$\sum$ = sum from day 1 to n

tmax = maximum daily temperature

tmin = minimum daily temperature

b = base temperature (7°C)

To test the correlation between the GDD accumulation during the 30 DAFB (GDD30) and harvest (Grossman and De Jong, 1994), dates of full bloom and harvest were collected from growers for years 2008, 2009 and 2010. Minimum and maximum daily temperature data of the 30 DAFB for years 2008, 2009 and 2010 were obtained from the Regional ARPA Wheatear Station Net (http://www.arpa.emr.it/). For each cultivar, all relative data was used together to find the relationships between the sum of GDD30 and the number of days between the full bloom and the harvest date. For each cultivar (‘Gartairo®’, ‘Sweet Red’ trained to palmette and ‘California’), the established correlation between GDH30 and harvest date was used for an early prediction of the harvest date during years 2011 and 2012.

4.3.3 Fruit ripening and growth assessments

The fruit ripening progression occurring during fruit development on the tree was monitored with the DA-meter (TR Turoni, Forli, Italy) and expressed as I_{AD} calculated as absorbance difference between 670 and 720 nm wavelengths (Ziosi et al., 2008). Fruit growth into the field was assessed with a digital caliper (Sylvac-Crissier, Switzerland) and expressed as diameter (mm). For every cultivar/training system combinations, ripening and diameter measurements were performed on a sample of, respectively, one hundred and fifty homogeneous fruit still attached on the tree. Fruit were randomly selected in the middle-outer canopy positions (as suggested by Bonora, personal communication) and data collections were performed every three-four days over the period of time described in Table 1.

4.3.4 Model input and structure

Inputs for the model were (per each cultivar):

- a minimum of three data points of fruit ripening (I_{AD}) and growth (mm);

- the I_{AD} value at commercial maturity (CM), based on the cultivar-specific relationship between ripening and ethylene production;
- the number of trees per hectare, obtained from the planting density and orchard surface;
- the crop load, obtained counting the fruit number of three to five trees per orchard, immediately after thinning was performed.

From the moment when both fruit ripening and growth became linear, the best regression lines fitting the first three I_{AD} and diameter data collected were found. The extension of the ripening regression line until the I_{AD} reached the correct value to perform commercial harvest (CM), makes possible the harvest date prediction. Therefore the vertical line passing through the I_{AD} CM value, intercepts the fruit growth prolonged regression line, highlighting the diameter that fruit will reach at the predicted harvest date (fruit diameter prediction). Based on the assumption that peach fruit volume can be calculated as the volume of a sphere:

$$V = \frac{4}{3} * \pi * r^2 \qquad (2)$$

where:

V = volume of the sphere/fruit

Π = 3.14

r = radius (diameter/2)

and that it can be considered totally composed of water (with density of 1 kg/dm^3), calculating fruit weight and knowing the number of fruit per tree as well as the number of trees per hectare, it was possible to estimate yield per hectare (Jimenez and Diaz, 2003). The yield prediction error was calculated as follow:

$$Error\ (\%) = \frac{predicted\ yield - real\ yield}{real\ yield} \qquad (3)$$

The real date of harvest, yield and fruit final diameter to validate the model were obtained from the grower at the end of each season.

The model was applied to cultivar ‘Gartairo®’, ‘Sweet Red’ trained to palmette and ‘California’, both in year 2011 and 2012.

4.3.5 Statistical analysis

All the collected data were statistically evaluated using the Duncan’s multiple range t-test at $p < 0.05$. The interactions between factors were assessed with a multiple factor ANOVA test. The correlation between variables was described using a Multiple Regression test ($p < 0.05$). All these statistical evaluations were performed with the software STATISTICA 7 (StatSoft. Inc., Tulsa, OK, USA). The Comparison of Regression Lines was performed with Statgraphics Plus (Statpoint Technologies, Inc., Warrenton, VA), considering a p value< 0.05.

4.4 Results

Fruit of the three nectarine varieties were grouped in physiological maturity (PM), commercial maturity (CM) and immature (I) classes on the basis of the relationship between maturity stage (I_{AD} value range) and ethylene emission, as showed in Table 2. Significant differences in ethylene production were observed between PM, CM and I maturity stages in each cultivar. In particular, per each variety, fruit of the PM class produced the higher ethylene amount, if compared with the other classes. Immature fruit always produced the lower gas quantity (Table 2). Comparing ethylene emission of the riper maturity stage PM of the three cultivars, the lowest ethylene amount was produced by fruit of the late variety (‘California’), while fruit of the mid-season (‘Sweet Red’) and early (‘Gartairo®’) varieties produced six times more gas (Table 2). Fruit of both the CM and I classes of cv ‘Sweet Red’ produced more ethylene than ‘California’ and ‘Gartairo®’. The ethylene emission of the early variety was the lowest when fruit reached the CM and I maturity stages (Table 2).

Figure 1 shows that when considering each maturity stage (PM, CM and I) of the cv ‘Sweet Red’ separately, no differences were found between fruit ethylene emission in the two growing seasons 2011 and 2012. Comparing the two seasons, it also emerged that differences between maturity stages were maintained. For cultivar ‘Sweet Red’, it was observed that the PM class can also be extended to the ripest fruit (I_{AD} < 0.2), because no differences in the ethylene emission were highlighted.

From Figure 2 it is possible to observe that fruit ripening of the three cultivars over the seasons 2011 and 2012, expressed as I_{AD}, showed a similar trend. During the first part of the ripening curve, a minimal I_{AD} variation over time was observed till an I_{AD} value of 1.9 (plateau part of the curve). When I_{AD} reached 1.9, the curve slope became linear and fruit ripened faster. Fruit of the early cultivar ‘Gartairo®’ (Figure 2A), reached I_{AD} 1.9 around 75 DAFB in 2011 and 85 DAFB in 2012. The mid-season cv ‘Sweet Red’ (Figure 2B) reached I_{AD} 1.9 around 115 DAFB in 2011 and 128 DAFB in 2012, while the late cv ‘California’ (Figure 2C) reached the same ripening stage at 140 DAFB both in 2011 and 2012. For each cultivar, in both seasons, the fruit linear ripening phase, ranging from the curve slope (I_{AD} roughly between 1.8 and 1.9) and harvest, was described by a regression line. For cv ‘Gartairo®’ (Figure 2A), comparing ripening data collected during the linear phase in year 2011 and 2012, it was observed that during the year 2011, fruit maintained higher I_{AD} values (of around 0.2) until harvest. An opposite trend was observed on fruit of the cultivar ‘Sweet

Red' (Figure 2B), were fruit of the year 2011 maintained constantly lower values (of around 0.2). The late variety 'California' did not show any difference (Figure 2C).

As showed in Figure 2, in both seasons 2011 and 2012, fruit growth followed a linear trend from fruit diameter around 35 mm for cv 'Gartairo®' (Figure 2A), 45 mm for cv 'Sweet Red' (Figure 2 B) and 55 mm for cv 'California' (Figure 2C), until harvest. These linear trends were also described as regression lines. Only for cv 'Sweet Red' trained to palmette, comparing growing data collected during the linear phase in seasons 2011 and 2012 (Figure 2B), it emerged that fruit grown during the season 2011 were constantly bigger than fruit grown the next year (of around 5 mm).

Table 3 reported the equation parameters, coefficient of determination and p-values of the regression lines that described the first three points of the ripening linear phase of each cultivar and for both seasons 2011 and 2012. As reported, the coefficient of determination were all above 0.90, even if the early cultivar 'Gartairo®' showed the highest values in both seasons, with an high significance (p-value<0.01). Moreover, per each cultivar, the comparison between the ripening regression lines of the two years showed p-values > 0.05 (with coefficients of determination greater than 0.90).

Table 4 reported the equation parameters, coefficient of determination and p-values of the regression lines that described the first three points of the growth linear phase (of each cultivar and for both years 2011 and 2012). As showed, the coefficient of determination were above 0.95 for the early and mid-season varieties, while the R^2 of the late cultivar 'California' was 0.99 in 2011 and 0.80 in 2012. Both in year 2011 and 2012, the growth regression lines of the early, mid-season and late variety were significantly different (data not shown). Per each cultivar, the comparison between the ripening regression lines of the two years showed p-values greater than 0.05. For the cultivar 'Sweet Red' trained to palmette was observed the highest coefficient of determination (R^2 0.99), while the other varieties showed slightly lower values.

Figure 3 shows that the linear phase of fruit ripening of the cultivar 'Sweet Red' trained to open-vase started to ripen earlier (105 DAFB) when compared with fruit on a palmette training system (128 DAFB) in year 2012. Fruit growth linear phase was already started at 92 DAFB on the open-vase shaped trees, while it began around 118 DAFB for fruit on the palmette shaped tree. During the linear phase, fruit of the open-vase training system were constantly riper (of roughly 0.4 I_{AD}) and bigger (of around 8 to 10 mm) than fruit on the palmette. For cultivar 'Sweet Red' trained to open-vase, no differences were observed comparing the regression line (fruit ripening or growth) fitting all the points collected during the linear phase, with the regression line that fitted the first three points collected (data not showed).

The regression lines of the first three points collected during the linear phase (Table 3 and Table 4), showed a high coefficient of correlation, both for diameter (R^2 0.89) and ripening (R^2 0.91). No differences were observed (Table 3) comparing the ripening regression lines of fruit from the palmette and open-vase training systems of the cv 'Sweet Red' (p-value greater than 0.05). The same result was found comparing the growing regression lines (Table 4).
Based on the regression lines described for cv 'Sweet Red' trained to palmette (Table 3 and 4), as well as on the relationship between ripening stages (I_{AD}) and fruit ethylene emission, the model described in Figure 5 represents the predictions of harvest date and final fruit diameter in year 2011 (Figure 5-1) and 2012 (Figure 5-2). For the mid-season cv 'Sweet Red', the harvest date prediction based on the GDD30 was similar for the two years (137 and 136 DAFB) and they differ from the real date about ten days (Table 5). The harvest date prediction based on the model described in Figure 5 (1 and 2) and on the I_{AD} value at harvest 0.8, was also similar in year 2011 and 2012 (147 and 149 DAFB) and they differ from the real date about three days (Table 5).
For the early and the late varieties 'Gartairo®' and 'California', the harvest date prediction based on GDD30 differed about 10 days if compared with the real harvests in the two years, with the only exception of the 2011 prediction for cv 'California', that was only 5 days in advance (Table 5).
Heat unit accumulation (GDD) form full bloom to the beginning of the ripening linear phase for the three varieties, did not show any correlation with the harvest date (data not showed).
Comparing the final diameter prediction, with the real fruit diameter at harvest, differences varied between 1 to 5 mm for the three varieties in both years (Table 5). The predictions overestimated the real final fruit diameter in the early variety, while underestimations were observed for the mid-season and late varieties both years (Table 6). Based on the estimated diameter, the fruit and tree densities per hectare, yield predictions showed errors variable between 1 and 10% in the two years for the three varieties (Table 6).

4.5 Discussion

As recently described by Nyasordzy et al., (2013) on apple, the I_{AD} is a ripening index able to detect early variations in the maturity condition of fruit. At immature stages, when the fruit is still on the tree, it correlates with the chlorophyll content up to values around 1.5-1.6 (for apple) 1.8-2.0 (for peaches), specific to the variety (Nyasordzy et al., 2013; Bonora et al., 2013 a and b). At the more mature stages, the I_{AD} showed a stronger relationship with fruit ethylene emission, as described by Ziosi et al. (2008). In the three nectarine cultivars used in our experiment, the relationship between ethylene production and fruit ripening (as I_{AD}) allowed to clearly divide fruit in three classes identified as pre-climacteric (immature - I), onset of climacteric (commercial maturity – CM) and full climacteric (physiological maturity – PM) stages of maturity (Table 2).

Little is known about the use of the DA-meter to detect the first steps of fruit ripening, in fact most of the studies involving the I_{AD} as peach and nectarine ripening index, focused on harvested fruit (Ziosi et al., 2008; Lurie et al., 2013). Results about fruit ripening on the tree are scarcely available. In accordance with Ziosi et al. (2008), that found a strong consistency of the relationship between I_{AD} classes and ethylene emission over the years (on the nectarine cv's 'Laura' and 'Stark Red Gold'), our results on the three varieties, confirmed the cultivar-specific relationships between I_{AD} and changes in ethylene production (Table 2) and the consistency of this relationship over the years (Figure 1). Figure 2 (A, B and C) and Figure 3 showed the initial ripening plateau phase and the subsequent linear decrease that characterized fruit ripening on the tree (as I_{AD}) for each of the three varieties and two training systems under study. Other authors obtained similar findings. Infante et al. (2011) observed that different genotypes of black-skinned Japanese plums ('Angeleno' and 'Autumn beaut') showed the development of I_{AD}-ethylene curves with a specific calibration per each variety, even when fruit appeared of the same color suggesting that the I_{AD} measured on the tree is a reliable parameter for a non-destructive monitoring of ripening either in deciding the optimum date for harvest or in helping retailers sorting fruit batches with similar ripeness level. Reig et al. (2012) made a similar observation trying to correlate the I_{AD} with nectarine fruit flesh firmness.

When considering the above mentioned reliability of the I_{AD} as non-destructive monitoring tool, its consistency during the years and the relationship with tree training system becomes even more important. Following nectarine ripening on the tree, our results showed that fruit of the three varieties under study presented a distinct trend (Figure 2 A, B and C), with an initial plateau phase and a subsequent linear decrease until harvest. Fruit of every nectarine variety reached the slope of the ripening curve at a slightly different I_{AD} values (Figure 2, A, B and C). Considering each variety separately, the I_{AD} value at which the curve reached the beginning of the ripening linear phase was the same in the two years (Figure 2 A, B and C), as well as in the palmette and open-vase training systems of the same variety (Figure 3), but different timing at which the linear phase started were observed, in particular between fruit from the two training systems. In fact, on the open-vase, a shift of fruit maturity was observed towards lower I_{AD} values (riper fruit), since the beginning of the ripening process (linear phase), as showed in Figure 3. During year 2012, fruit of the cv 'Sweet Red' from trees trained to open-vase appeared bigger and riper than fruit from trees trained to palmette (Figure 3). They reached the I_{AD} at harvest (0.8) fifteen days earlier and accumulated around 40 GDD less during the same period of time (data not showed). Probably the higher light interception of the open shaped training system (Layne and Bassi, 2008), allowed better conditions for fruit development. In fact, as suggested by Marini (1991), to obtain big peaches, fruit need to develop in a region of the canopy receiving about 20% full sun during the final three weeks before harvest. Also, Lewallen and Marini (2003) and Feng-Lil et al. (2008) observed that fruit size was bigger, background color more yellow and the I_{AD} value lower (up to the climacteric peak) in fruit located in the upper and outer, more illuminated tree canopy positions. Farina et al. (2005) observed a lower variability in term of fruit quality parameters, (hue angle, FF, SSC) into vase shaped tree, than into “Y” shaped. In our situation on cv ‘Sweet Red’ trained as open-vase, the higher solar radiation available probably increased chlorophyll degradation and fruit appeared riper at every sampling than fruit developed in the more shaded palmette training system (Kliewer and Lider, 1968; Budde et al., 2006; Bonora et al., 2013 b). More studies are needed to better understand peach and nectarine ripening process in relation to the training system and the interaction with environmental factors (such as light and temperature). Therefore, tree training system becomes even more of a fundamental tool for growers in their decision making process not only on general farm economy but also on fruit quality management.

Our model, to achieve its full predicting capacity, requires fruit growth data input, therefore, in addition to fruit ripening, fruit growth was also monitored on the tree (from SIII of fruit development). In accord with Pérez-Marin et al. (2009), our results showed that fruit diameter increased constantly during the last part of the classical double sigmoid curve for all the varieties tested in the two years and differences were observed in term of growth extent (Figure 2 and 3). During summer 2011, fruit growth of the variety ‘Gartairo®’ did not show significant differences compared with summer 2012 (Figure 2A). However, the final fruit diameter appeared around 6 mm bigger in 2011 than in 2012 (Table 6), probably because fruit were left four days longer on the tree and continued following a linear increase (Pérez-Marin et al., 2009). In fact, Marini (1991) reported that peach diameter increases from 2 to 4% each day the fruit is on the tree, therefore, delaying harvest as long as possible will improve fruit final size.

For cv ‘Sweet Red’ trained to palmette, during year 2011 fruit diameter appeared constantly bigger than in 2012 (Figure 2 B), with a final difference of 6 mm at harvest (Table 6). This is probably due to the unavoidable water stress that trees under normal irrigation practices suffered during the exceptional conditions of summer 2012. In fact, as known, during SIII of fruit growth irrigation is necessary to prevent water stress and weight losses (Marini, 1991), but the regional authority regimenting water supply did not allow higher water intake to deal with the emergency.

No significant differences were observed in term of ripening and growth of the late variety ‘California’, during fruit development throughout the two considered seasons (Figure 2 C). In accord with several authors (Corelli and Coston, 1991; Costa and Vizzotto, 2000; Bonora et al., 2013 a), the higher fruit density observed in year 2012 (Table 6) was probably the cause of the four days delay (Table 5) that fruit showed in reaching the I_{AD} value of commercial harvest (1.0) and of the smaller final fruit diameter (Table 6). In general, due to the exceptional climatic conditions, all the tested varieties showed a smaller final fruit diameter in 2012, than in 2011. As observed for fruit ripening, our results showed that fruit diameter increased constantly during SIII of peach and nectarine fruit development and it was well described by regression lines with high coefficient of determination (Table 4) as also reported by Pérez-Marin et al. (2009), on nectarines. In our experiment as well, the comparison between regression lines did not show differences, either comparing the two years (in all the varieties), nor the different training systems (for cv 'Sweet Red') (Table 4), even if lower coefficient of determination than for fruit ripening were observed (Table 3). This suggested that fruit growth could be less related to the cultivar and more to other external parameters (such as fruit density, irrigation practices, training system, etc), as previously observed by several authors (Marini, 1991; Berman and DeJong, 1996; Naor et al., 1999).

The variety specific data of fruit ripening and growth can be utilized in our model to achieve its prediction. On the basis of the I_{AD} value at harvest and the ripening regression line obtained by fruit I_{AD} monitoring, with the proposed model is possible to forecast fruit harvest date two-three weeks in advance (Figure 4). When compared with the already established model based on the heat unit accumulation during the thirty days after full bloom, the harvest date prediction based on the ripening regression line of each variety described in our model, appeared to predict harvest date more precisely (Table 5). In any case, the validity of the GDH30 model is not under critique. The GDH30 model showed a strong correlation with the harvest date of several peach and nectarine varieties and was introduced as one of the driving variables of the PEACH computer simulation model for the prediction of annual carbon supply and demand for reproductive and vegetative growth of peach trees (Ben Mimoun and DeJong, 1999; DeBuse et al., 2010). In our experiment, unfortunately, we had to base the calculation of the heat unit accumulated one month after full bloom on the less precise method of GDD, instead of GDH, and as several authors (Ben Mimoun and DeJong, 1999; DeBuse et al., 2010) suggested, the calculation of GDH30 is more precise than GDD for the prediction of the harvest date. In fact, by using GDH30 method, Marra et al. (2008) predicted the harvest date of thirteen peach varieties over 6 years with errors variable between 3-5 days, compared with real harvest. However, in the real conditions we wanted to simulate, the use of GDH could be too complicated and not easily usable by growers, since in most cases in Italy, the availability of meteorological data is limited to maximum-minimum daily temperatures and rarely hourly data are accessible. For this reason, we observed errors of around 10 days, adopting the

GDD30 calculation making our model more reliable in these conditions and it could be used as data integrator and harvest date predictor by itself or in association with GDD/GDH30 (Table 5).
Based on the harvest date prediction and the growth regression line obtained by fruit diameter monitoring, the model described in Figure 4 also allowed the forecasting of fruit diameter at harvest and through fruit density estimation, fruit number and tree density, orchard yield (Table 6), with small errors when compared with real values.

4.6 Conclusions

The present work confirmed the cultivar-specific relationships between I_{AD} and changes in ethylene production and the consistency of this relation over growing seasons. Similar ripening trend was observed on fruit of the three nectarine varieties, with an initial plateau phase and a subsequent linear decrease until harvest. From the beginning of the ripening linear phase, the span of time to reach harvest appeared related to the variety and it was not affected by growing season neither by training system even if the open vase training system did reduce the total length of the ripening season.
A new model was developed and validated, based on simple measurements of fruit ripening (I_{AD}) and growth (diameter), to predict the time at which fruit reached a certain ripening stage at harvest as well as their size and weight. The combined field monitoring of fruit ripening (I_{AD}) and growth (mm) during Stage III of nectarine development needed in the proposed model, resulted in two to three weeks advance in the prediction of the harvest date and yield with small predicting errors. This method, which also considers the desired nectarine ripening stage at harvest, offers promise for developing protocols that growers could use routinely under field conditions to predict more precisely the timing of their harvest operations, aiming at obtaining the highest possible quality and a more targeted fruit management during post-harvest.

4.7 Literature Cited:

Ahumada O. and Villalobos J. R., 2009. Application of planning models in the agri-food supply chain: a review. *European Journal of Operational Research.* **196**(1): 1-20.

Anderson J.L., Richardson E.A. and Kesner C.D., 1986. Validation of chill unit and flower bud phenology models for ‘Montmorency’ sour cherry. *Acta Horticolturae.* 184: 71-75.

Baggiolini M., 1980. Stades repères du cerisier- Stades repères du prunier. Stades repères de l'abricotier. Stades repères du pecher. ACTA. Guide Pratique de Dèfense des Cultures, Paris, France.

Bellini E., Giannelli G., Giordani E. and Sabbatini I., 2004. Miglioramento della qualità e de1 valore commerciale nelle nettarine. *Frutticoltura*. 1: 25-30.

Berman M. E. and DeJong T. M., 1996. Water stress and crop load effects on fruit fresh and dry weights in peach (*Prunus persica* L.). *Tree physiology*. **16**(10): 859-864.

Bertone E., Venturello A., Leardi R. and Geobaldo F., 2012. Prediction of the opti- mum harvest time of 'Scarlet' apples using DR-UV–vis and NIR spectroscopy. *Postharvest Biology and Technology*. 69: 15-23.

Bonghi C., Ramina A., Ruperti B., Vidrih R. and Tonutti, P., 1999. Peach fruit ripening and quality in relation to picking time, and hypoxic and high CO_2 short-term postharvest treatments. *Postharvest Biology and Technology*. **16**(3): 213-222.

Bonora E., Noferini M., Vidoni S. and Costa G., 2013 b Modeling fruit ripening for improving peach homogeneity *in planta*. *Scientia Horticulturae*. *Under publishing*.

Bonora E., Stefanelli D. and Costa G., 2013 a. Nectarine fruit ripening and quality assessed using the Index of Absorbance Difference (I_{AD}) *in planta*. *International Journal of Agronomy*. *Under publishing*.

Bregoli A.M., Scaramagli S., Costa G., Sabatini E., Ziosi V., Biondi S. and Torrigiani P., 2002. Peach (*Prunus persica* L.) fruit ripening: amino- ethoxyvinylglycine (AVG) and exogenous polyamines affect ethylene emission and flesh firmness. *Physiologia Plantarum*. 114: 472-481.

Budde C.O., Polenta G., Lucangeli C.D. and Murray R.E., 2006. Air immersion heat treatments affect ethylene production and organoleptic quality of 'Dixiland' peaches. *Postharvest Biology and Technology*. 41: 32-37.

Carbó J. and Iglesias I. 2002. Melocotonero: las variedades de más interés. IRTA, Barcelona.

Corelli Grappadelli L. and Coston D.C., 1991. Thinning pattern and light environment in peach tree canopies influence fruit quality. *HortScience.* 26: 1464-1466.

Costa G. and Vizzotto G., 2000. Fruit thinning of peaches. *Plant Growth Regulation*. 31: 113-119.

Crisosto C. H., Crisosto G. M., Echeverria G., and Puy J., 2006. Segregation of peach and nectarine (*Prunus persica* (L.) Batsch) cultivars according to their organoleptic characteristics. *Postharvest Biology and Technology*. **39**(1): 10-18.

Dagar A., Weksler A., Friedman H., and Lurie S., 2012. Gibberellic acid (GA_3) application at the end of pit ripening: effect on ripening and storage of two harvests of “September Snow” peach. *Scientia Horticulturae*. 140: 125-130.

Day K., Lopez G. and Dejong T., 2008. Using Growing Degree Hours Accumulated Thirty Days after Bloom to Predict Peach and Nectarine Harvest Date. Proc. VIIIth ISHS on Modelling in Fruit Research *Acta Horticolturae*. 80: 163-166.

DeBuse C., Lopez G and DeJong T., 2010. Using spring weather data to predict harvest date for Improved French prune. *Acta Horticulturae* (in press).

Della Cara R., 2005. In calo i consumi e l’export de pesche e nettarine italiane. *Rivista di Frutticoltura* 7-8: 19-20.

Eccher Zerbini P., Spada G.L. and Liverani C., 1994. Selection and experimental use of colour charts as a maturity index for harvesting peaches and nectarines. *Advances in Horticultural Science.* 8: 107-113.

Farina V., Lo Bianco R. and Inglese P., 2005.Vertical distribution of crop load and fruit quality within vase- and Y-shaped canopies of ‘Elegant Lady’ peach. *HortScience*. 40: 587-591

Feng-lil H. E., Feil W., Qin-ping W. E., Xiao-we W. and Qiang Z., 2008. Relationships between the distribution of relative canopy light intensity and the peach yield and quality. *Agricultural Sciences in China.* **7**(3): 297-302.

Fisher D.V., 1962. Heat units and number of days required to mature some pome and stone fruit in various areas of North America. *Proceedings of the American Society for Horticultural Science.* 80: 114-124.

Génard M, Gibert C., Bruchou C., Lescourret F. And Agroparc S., 2009. An intelligent virtual fruit model focussing on quality attributes. *Journal of Horticultural Science & Biotechnology*. ISAFRUIT Special Issue. 157: 157-163.

Goldschmidt E.E. And Lakso A.N., 2005. Fruit tree models: scopes and limitations. In: Information and Communication Technology (ICT) Development and Adoption: Perspectives of Technological Innovation, (E. Gelb, A. Offer, eds.), European Federation for Information Technologies in Agriculture, Food and the Environment (web only)

Gottardi F., Noferini M., Fiori G., Barbanera M., Mazzini C. and Costa G., 2009. The index of absorbance difference (I_{AD}) as a tool for segregating peaches and nectarines into homogeneous classes with different shelf-life and consumer acceptance. 8th Pangborn Sensory Science Symposium, Firenze, Italy

Grossman Y.L. and Dejong T.M., 1994. PEACH: a simulation-model of reproductive and vegetative growth in peach-trees. *Tree Physiology*. **14**(4): 329-345.

Hale G., Lopresti J., Bonora E., Stefanelli D. and Jones R., 2012. Using non-destructive methods to correlate chilling injury with fruit maturity. Proceedings of the International Symposium on Post-Harvest, Malaysia. (in press)

Herrero-Langreo A., Fernández-Ahumada E., Roger J.-M., Palagós B. and Lleó, L., 2011. Combination of optical and non-destructive mechanical techniques for the measurement of maturity in peach. *Journal of Food Engineering*. **108**(1): 150-157.

Iglesias I., Carbo´ J., Bonany J., Casals M., Dalmau R., Montserrat R., 2005. Innovacion varietal en melocotonero: especial referencia a las nuevas variedades de nectarina. *Fruticultura Profesional: Especial Melocotonero* **152**(3): 6-36.

Infante R., Contador L., Rubio P., Mesa K. and Meneses C., 2011. Non-destructive monitoring of flesh softening in the black-skinned Japanese plums “Angeleno” and “Autumn beaut” on-tree and postharvest. *Postharvest Biology and Technology*. **61**(1): 35-40.

Infante, R., 2012. Harvest maturity indicators in the stone fruit industry. *Stewart Postharvest Review*. June: 1-6.

Jiménez C. M. and Díaz J.B.R., 2003. A statistical model to estimate potential yields in peach before bloom. *Journal of the American Society for Horticultural Science.* **128**(3): 297-301.

Kliewer W.M. and Lider L.A., 1968. Influence of cluster exposure to the sun on the composition of Thompson seedless fruit. *American Journal of Enology and Viticulture.* 19: 175-184.

Layne D.R. and Bassi D. 2008. In: The peach: botany, production and uses.

Lescourret F. and Génard M., 2005. A virtual peach fruit model simulating changes in fruit quality during the final stage of fruit growth. *Tree physiology.* **25**(10): 1303-15.

Lescourret F., Ben Mimoun M. and Génard M., 1998a. A simulation model of growth at the shoot bearing fruit level I. Description, and parameterisation for peach. *European Journal of Agronomy.* 9: 170-185.

Lewallen K. S. and Marini R. P., 2003. Relationship between flesh firmness and ground color in peach as influenced by light and canopy position. *Journal of the American Society for Horticultural Science.* **28**(2):163-170.

Lleó L., Roger J. M., Herrero-Langreo A., Diezma-Iglesias B. and Barreiro P., 2011. Comparison of multispectral indexes extracted from hyperspectral images for the assessment of fruit ripening. *Journal of Food Engineering*. **104**(4): 612-620.

Lurie S., Friedman H., Weksler A., Daga, A., and Eccher P., 2013. Postharvest biology and technology maturity assessment at harvest and prediction of softening in an early and late season melting peach. *Postharvest Biology and Technology*. 76: 10-16.

Magnanini E., Bonora E. and Vitali G., 2010. PlantToon - drawing and pruning fruit trees. Proceedings of the 6th International Workshop on Functional-Structural Plant Models. Davis, CA, September 12-17. P. 255.

Marcelis L.F.M., Heuvelink E. and Goudriaan J., 1998. Modelling biomass production and yield of horticultural crops: a review. *Scientia Horticultusrae*. 74: 83-111.

Marini R.P., Sowers D., and Marini M.C., 1991. Peach fruit quality is affected by shade during final swell of fruit growth. *Journal of the American Society for Horticultural Science.* 116: 383-389.

Marra F.P., Inglese P., DeJong T.M. and Jhonson, R.S., 2002. Thermal time requirement and harvest time forecast for peach cultivars with different fruit development periods. In: Proceedings of the 5^{th} International Peach Symposium, vols. 1 and 2. Pp. 523-529.

Mimoun M.B. and DeJong T.M., 1999. Using the Relation Between Growing Degree Hours and Harvest Time to Estimate Run-Times for Peach: A Tree Growth and Yield Simulation Model. Department of Pomology, University of California, Davis.

Mounzer O.R., Conejero W., Nicolas E., Abrisqueta I., Garcia-Orellana Y.V., Tapia L.M., Vera J., Abrisqueta J.M. and Ruiz-Sanchez M., 2008. Growth pattern and phenological stages of early-maturing peach trees under a Mediterranean climate. *Hortscience.* **43**(6): 1813-1818.

Naor A, Klein I and Hupert H, 1999. Water stress and crop level interactions in relation to nectarine yield, fruit size distribution and water potentials. *Journal of the American Society for Horticultural Science*. 124: 189-93

Nicolai B.M., Beullens K., Bobelyn E., Peirs A., Saeys W., Theron K.I. and Lammertyn J., 2007. Non-destructive measurement of fruit and vegetable quality by means of NIR spectroscopy: a review. *Postharvest Biology and Technology.* 46: 99-118

Nyasordzi J., Friedman H., Schmilovitch Z., Ignat T., Weksler A., Rot I. and Lurie S., 2013. Utilizing the I_{AD} index to determine internal quality attributes of apples at harvest and after storage. *Postharvest Biology and Technology*. 77: 80-86.

Pavel E.W. and DeJong T.M., 1993b. Estimating the photosynthetic contribution of developing peach (*Prunus persica* L.) fruits to their growth and maintenance carbohydrate requirements. *Physiologia Plantarum.* 88: 331-338.

Pérez-Marín D., Sánchez M., Paz P., Soriano M., Guerrero J. and Garrido-Varo A., 2009. Non-destructive determination of quality parameters in nectarines dur- ing on-tree ripening and postharvest storage. *Postharvest Biology and Technology.* 52: 180-188.

Reig G., Alegre S., Iglesias I., Echeverría G. and Roure A. R., 2012. Fruit quality, colour development and Index of Absorbance Difference (I_{AD}) of different nectarine cultivars at different harvest dates. Pp: 1117-1126.

Scorza R. and Sherman W.B., 1996. Peaches. In: Janick, J., Moore, J.N. (Eds.), Fruit Breeding, vol. 1. *Tree and Tropical fruits*. John Wiley & Sons, Inc, N.Y. Pp. 325-440.

Vanoli M. and Buccheri M., 2012. Overview of the methods for assessing harvest maturity. *Stewart Postharvest Review*. **8**(1): 1-11.

Zalom F.G., Goodell P.B., Wilson L.T., Barnett W.W. and Bentley, W.J., 1983. Degree-days: the calculation and use of heat units in pest management. Leaflet 21373, Division of Agriculture and Natural Resources, Berkeley, University of California.

Ziosi V., Noferini M., Fiori G. Tadiello A.., Trainotti L., Casadoro G. and Costa G., 2008. A new index based on vis spectroscopy to characterize the progression of ripening in peach fruit. *Postharvest Biology and Technology*. **49**(3): 319-329.

4.8 Cited Web-sites

http://fruitsandnuts.ucdavis.edu (26/02/13)

http://www.arpa.emr.it/ (26/02/13)

4.9 Figures

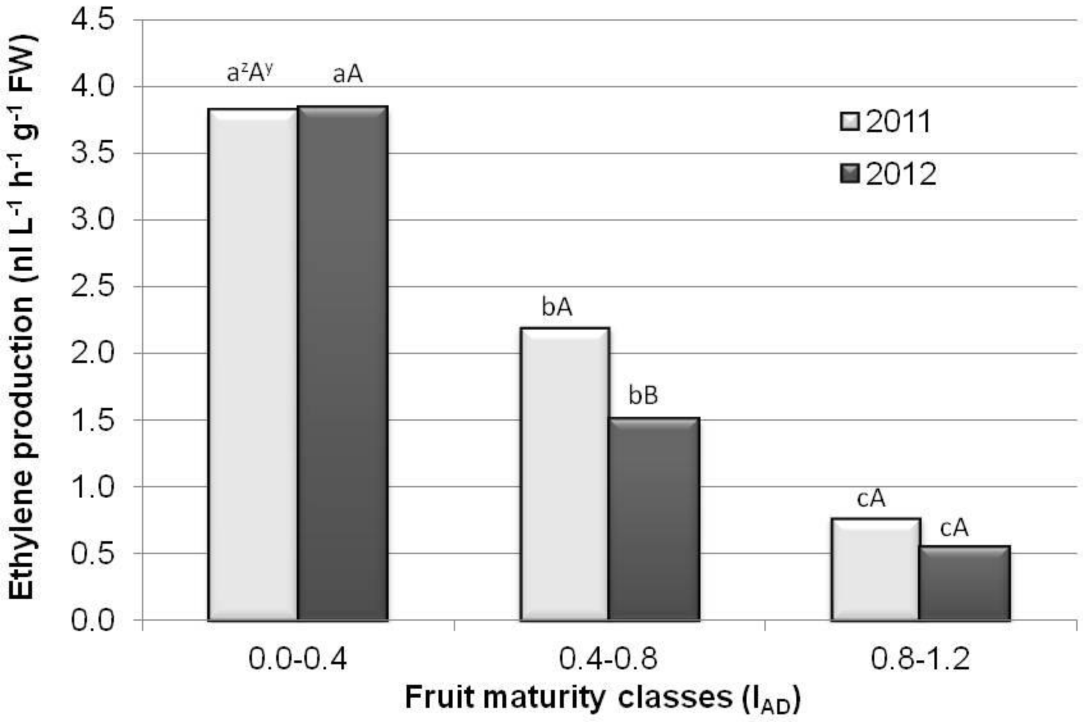

Figure 1: Fruit ethylene production at different maturity classes (I_{AD}) in the year 2011 and 2012 for cultivar 'Sweet Red' trained to central leader.

^{z}= Small letters represent significant differences between canopy layers within the same I_{AD} class at $p<0.05$.

^{y}= Capital letters represent significant differences between I_{AD} values within the same canopy layer at $p<0.05$.

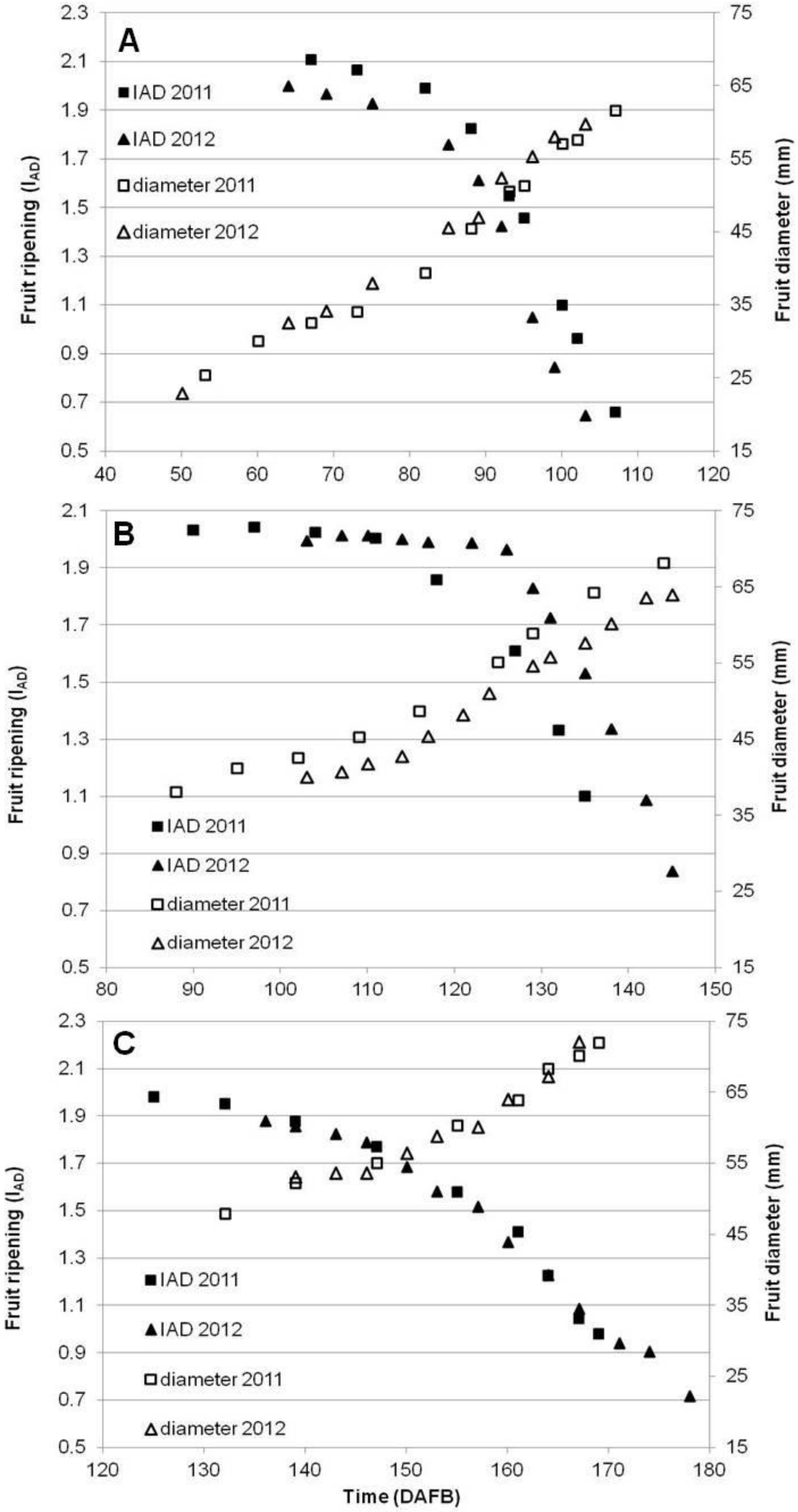

Figure 2: Trend of fruit ripening (I_{AD}; reference scale in the primary y axis) and growth (mm; reference scale in the secondary y axis) over time (DAFB; in the x axis) during years 2011 and 2012 per each cultivar (‘Gartairo®’ - graph A, ‘Sweet Red’ trained to central leader - graph B, ‘California’ – graph C).

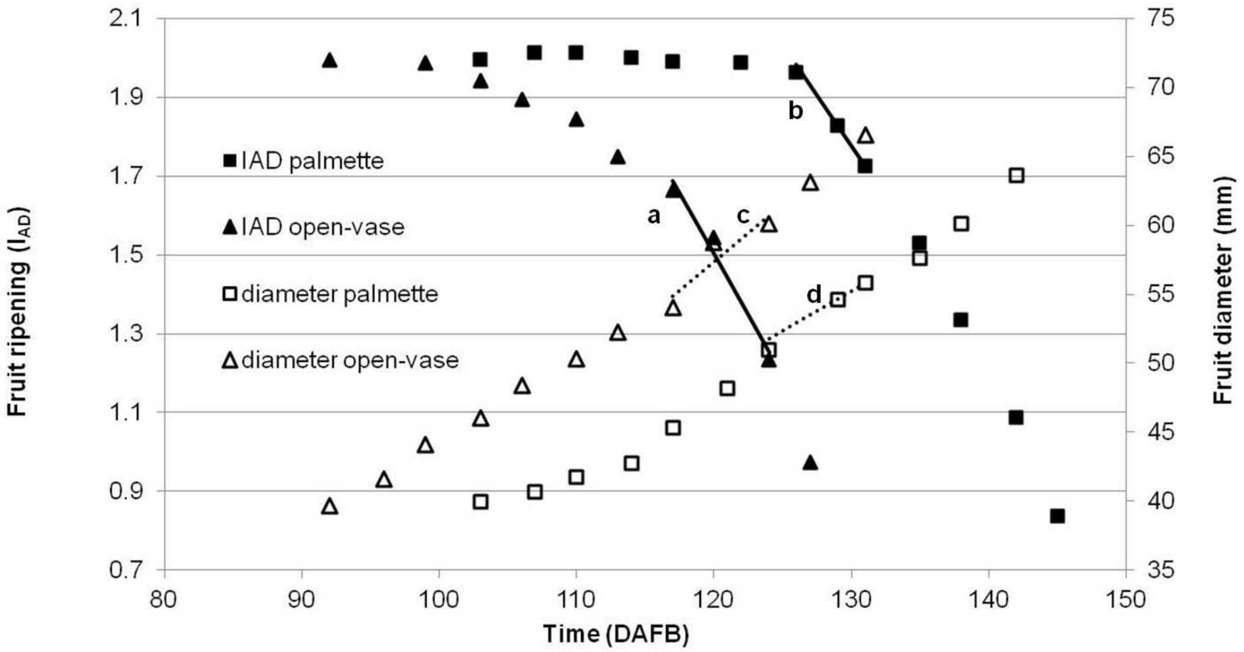

Figure 3: Trend of fruit ripening (I_{AD}; reference scale in the primary y axis) and growth (mm; reference scale in the secondary y axis) over time (DAFB; in the x axis) during year 2012 per each training system (open vase and central leader) of the cultivar 'Sweet Red'. Black straight lines represent the regression lines of three I_{AD} values for the open vase (a) and central leader (b) training systems. Black dotted straight lines represent the regression lines of three diameter points (mm) for the open vase (c) and central leader (b) training systems.

Linear equations of the regression lines, coefficients of determination (R^2) and p-values are reported in Table 2 (Ripening equations) and Table 3 (Fruit growth equations).

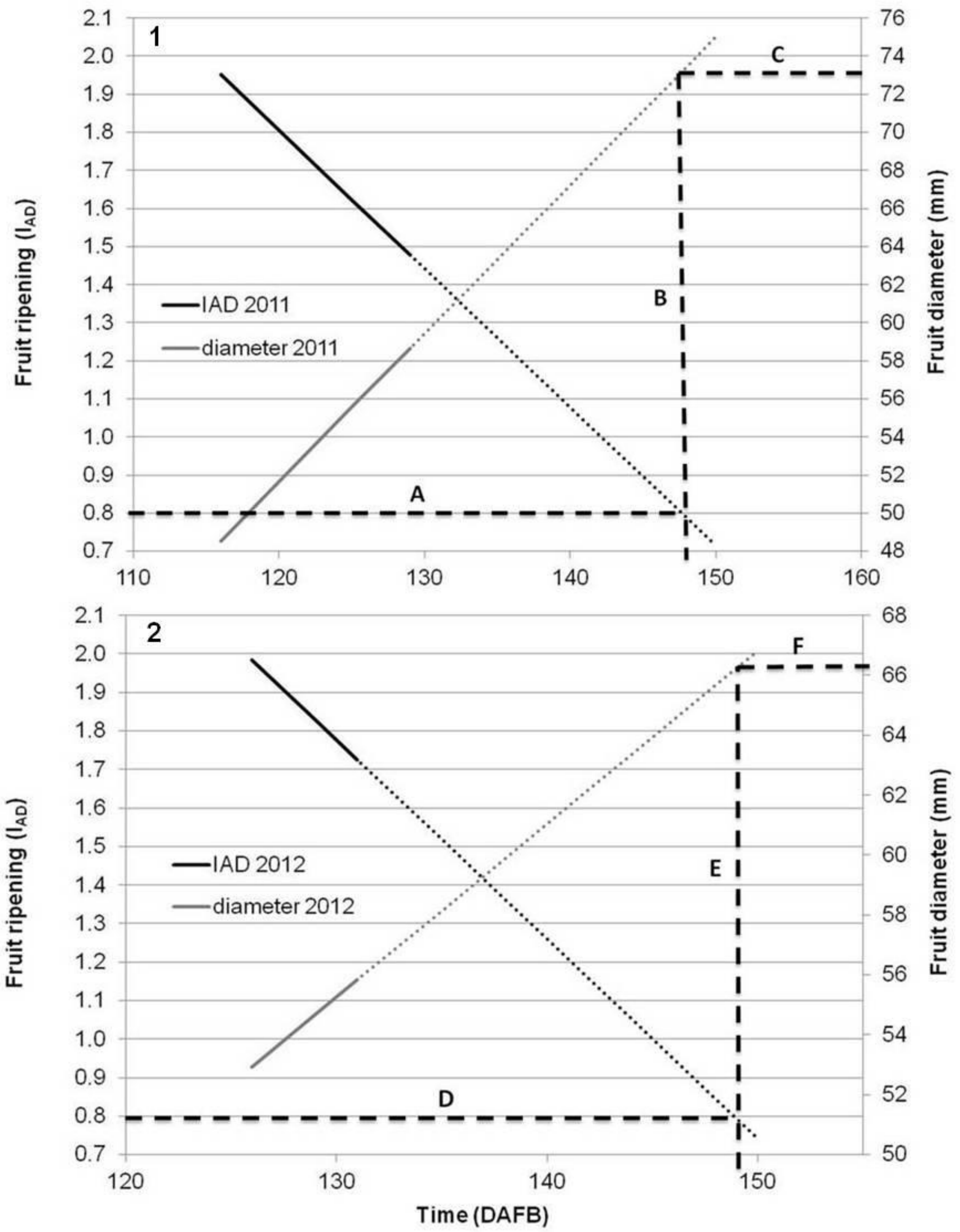

Figure 4: Regression lines of fruit ripening (I_{AD}; reference scale in the primary y axis) and growth (mm; reference scale in the secondary y axis) over time (DAFB; in the x axis) during year 2011 (graph 1) and 2012 (graph 2) for the cultivar 'Sweet Red' trained to central leader. The regression lines were divided in an initial straight part, based on real data, and a dotted last part, predicted extension of the line. The horizontal black dashed line (A in graph 1 and D in graph 2) connects the "I_{AD} at harvest" (0.8 on the primary y axis) with the extension of the I_{AD} regression line (dotted black line). The vertical black dashed line (B in graph 1 and E in graph 2), passing through the "I_{AD} at harvest", intercepts the x axis, pointing out the DAFB at

which the fruit will reach the "I_{AD} at harvest" (harvest date prediction), and intercepts the extension of the diameter regression line (dotted grey line), pointing out the diameter value that fruit will reached at the predicted harvest date. The black horizontal dashed lines (C in graph 1 and F in graph 2) connects the diameter value on the extension of the diameter regression line (dotted grey line) with the y secondary axis (diameter prediction).

Linear equations of the regression lines, coefficients of determination (R^2) and p-values are reported in Table 2 (Ripening equations) and Table 3 (Fruit growth equations).

4.10 Tables

Table1: Fruit ripening and growth field data collection period (from-to) for cultivar 'Gartairo®', 'Sweet Red' trained to palmette, 'Sweet Red' trained to open-vase and 'California', both in year 2011 and 2012.

Measured parameter (DAFB)		Gartairo		Sweet Red palmette		Sweet Red open-vase	California	
		2011	2012	2011	2012	2012	2011	2012
Ripening	from	67	64	90	88	92	125	136
	to	107	103	135	144	127	169	178
Growth	from	53	50	103	103	92	132	139
	to	107	103	145	145	131	169	167

Table 2: Fruit maturity stage, I_{AD} class and corresponding ethylene production (nl L^{-1} h^{-1} g^{-1} FW) of the three nectarine varieties 'Gartairo®', 'Sweet Red' and 'California' in the year 2012.

Maturity stage	Gartairo			Sweet Red			California		
	I_{AD} class	Ethylene (nl $L^{-1}h^{-1}gFW^{-1}$)		I_{AD} class	Ethylene (nl $L^{-1}h^{-1}gFW^{-1}$)		I_{AD} class	Ethylene (nl $L^{-1}h^{-1}gFW^{-1}$)	
PM ^{z}	0.2-0.4	3.31	$a^{y}A^{x}$	0.2-0.4	3.70	aA	0.2- 0.4	0.57	aB
CM	0.4-0.8	0.22	bC	0.4-0.8	1.50	bA	0.4-1.0	0.31	bB
I	0.8-1.0	0.04	cC	0.8-1.2	0.50	cA	1.0-1.2	0.10	cB

^{z}= Fruit maturity stages: physiological maturity (PM), commercial maturity (CM) and immature (I)

^{y}=Small letters represent significant differences between maturity stage (PM, CM and I) within the same variety at $p<0.05$.

^{x}= Capital letters represent significant differences between varieties ('Gartairo®', 'Sweet Red' and 'California') within the same maturity stage at $p<0.05$.

Table 3: Per each variety and training system (‘Gartairo®’, ‘Sweet Red’ central leader, ‘Sweet Red’ open vase and ‘California’), in the two years 2011 (with the exception of the ‘Sweet Red’ trained to open vase) and 2012, the table reports slopes (a) and intercepts (b), coefficients of determination (R^2) and p-values of the linear equations describing the fruit ripening (I_{AD}) regression lines. Also, the table reports R^2 and p-values of the comparison between the regression lines of year 2011 and 2012 per each variety (‘Gartairo®’, ‘Sweet Red’ trained to central leader and ‘California’). Only for cv ‘Sweet Red’ the same comparison is reported between the central leader and open vase training systems.

Fruit ripening equation (I_{AD})						Regression lines comparison	
Variety	Year	a	b	R^2	p-value	R^2	p-value
Gartairo	2011	-0.05	6.53	0.99	< 0.01	0.99	0.471
	2012	-0.08	8.94	0.98	< 0.01		
Sweet Red palmette	2011	-0.04	6.17	0.91	<0.05	0.90	0.409
	2012	-0.05	8.51	0.97	<0.05		
Sweet Red open-vase	2012	-0.06	8.97	0.93	<0.05	0.91	0.580
California	2011	-0.03	5.55	0.95	< 0.01	0.95	0.633
	2012	-0.03	6.16	0.99	< 0.01		

Table 4: Per each variety and training system (‘Gartairo®’, ‘Sweet Red’ central leader, ‘Sweet Red’ open vase and ‘California’), in the two years 2011 (with the exception of the ‘Sweet Red’ trained to open vase) and 2012, the table reports slopes (a) and intercepts (b), coefficients of determination (R^2) and p-values of the linear equations describing the fruit growth (mm) regression lines. Also, the table reports R^2 and p-values of the comparison between the regression lines of year 2011 and 2012 per each variety (‘Gartairo®’, ‘Sweet Red’ trained to central leader and ‘California’). Only for cv ‘Sweet Red’ the same comparison is reported between the central leader and open vase training systems.

Fruit growth equation (diameter)						Regression lines comparison	
Variety	Year	a	b	R^2	p-value	R^2	p-value
Gartairo	2011	0.87	-30.71	0.99	< 0.01	0.92	0.481
	2012	0.67	-6.50	0.95	< 0.01		
Sweet Red palmette	2011	0.78	-41.77	0.99	< 0.05	0.99	0.263
	2012	0.58	-19.94	0.97	< 0.01		
Sweet Red open-vase	2012	0.84	-43.11	0.98	< 0.01	0.89	0.553
California	2011	0.57	-23.43	0.99	< 0.01	0.89	0.611
	2012	0.72	-52.15	0.80	< 0.05		

Table 5: Per each year (2011 and 2012) and variety (‘Gartairo®’, ‘Sweet Red’ trained to central leader and Califorina), the table reports the I_{AD} at harvest, the date of full bloom, the Heat unit accumulation (GDD30) during the 30 days after full bloom (DAFB), the harvest date prediction (as DAFB) based on GDD30 and on the fruit ripening-growth model respectively, and the real harvest date (as DAFB).

Year	Variety	I_{AD} at harvest	Full Bloom	Heat unit accumulation (GDD30)	GDD30 harvest date prediction (DAFB)	Model harvest date prediction (DAFB)	Real harvest date (DAFB)
2011	Gartairo	0.6	20/03/2011	191	99	111	108
	Sweet Red	0.8	23/03/2011	212	137	147	145
	California	1.0	23/03/2011	212	169	177	174
2012	Gartairo	0.6	21/03/2012	225	94	102	104
	Sweet Red	0.8	24/03/2012	239	136	149	146
	California	1.0	23/03/2012	236	168	175	178

Table 6: Per each year (2011 and 2012) and variety (‘Gartairo®’, ‘Sweet Red’ trained to central leader and ‘California’), the table reports fruit density (as fruit/cm2 trunk) and tree density (as tree/Ha), the fruit diameter prediction based on the ripening-growth model, the real fruit diameter at harvest, the yield prediction based on the ripening-growth model (as kg/Ha) and the yield error from the comparison between predicted and real (as %).

Year	Variety	Fruit density (fruit/cm^2 trunk)	Tree density (tree/Ha)	Fruit diameter prediction (mm)	Real fruit diameter (mm)	Yield prediction (kg/Ha)	Yield Error %
2011	Gartairo	2.3	1250	71	68	34634	8
	Sweet Red	2.6	1923	68	72	49195	4
	California	2.8	1923	70	75	80119	10
2012	Gartairo	2.7	1250	64	62	27230	5
	Sweet Red	2.5	1923	63	66	40686	1
	California	3.4	1923	67	72	77358	4

5.0 Nectarine fruit ripening and quality assessed using the Index of Absorbance Difference (I_{AD}) *in planta*

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4.1 Abstract

Consistency of fruit quality is extremely important in horticulture. Fruit growth and quality in nectarine are affected by fruit position into the canopy, related to the tree shape. The "open shaped" training systems, such as Tatura Trellis, showed to improve fruit growth and quality. A study on fruit ripening heterogeneity was performed by using the Index of Absorbance Difference (I_{AD}), a new marker for nectarine quality assessment, to monitor fruit maturity stages of two cultivars trained on Tatura trellis in Victoria, Australia. Fruit of cv 'Summer Flare' 34 ('SF34') grown in different positions on the tree showed high ripening homogeneity, while fruit size was constantly bigger in the top. Fruit harvested at a similar ripening stage showed fruit firmness and soluble solid content homogeneity. Fruit from hand-thinned cv 'Summer Flare 26' ('SF26') were larger in size, had advanced ripening and showed greater homogeneity. For cv 'SF26' a weak correlation between I_{AD} and SSC was observed. The experiment showed that Tatura trellis training system increased the homogeneity of nectarine fruit if coupled with a proper management of fruit density. It also confirmed that the I_{AD} could be used as new non-destructive maturity index for nectarine fruit quality assessment in the field.

Key Words: *Prunus persica*, I_{AD}, Tatura trellis, PlantToon®, Fruit density

5.2 Introduction

A tree training system is defined as method of manipulating the tree structure and canopy geometry to improve the interception and distribution of light, for the purpose of optimizing fruit quality and yield (Caruso et al., 2003). In 1970, a group of Australian researchers developed the Tatura Trellis (Chalmers and Wilson, 1978), suitable for the complete mechanization of harvest in intensive peach orchards. Despite of the higher light available and photosynthetic rate that this tree shape allows, it was judged too expensive because of the intensive work to maintain the complex scaffold needed. Keeping the same open canopy design, simplified and cheaper tree shapes were developed during the following decades, such as the "KAC V" (DeJong, 1999) and "Y" (Caruso et al., 2003). Several aspects of the Tatura Trellis training system on apple and cherry trees were studied (Cittadini et al., 2008), but only a few experiments on tree productivity were available regarding peach fruit (Van den Ende, 1994). Numerous studies on different tree architectures pointed out that fruit position into the canopy represents one of the most critical factors for peach fruit quality development and homogeneity of fruit characteristics (Farina et al., 2005; Dani, 2007; Feng-Li et al., 2008) related to the light availability (Lewallen and Marini, 2003). The open center training systems increase the light available in the inner canopy, giving rise to a gradient of quality traits. Fruit that develops in the periphery and center of the canopy obtain higher light levels and are characterized by better quality attributes, while fruit located halfway between the tree center and periphery are more shaded and developed lower quality (Lewallen and Marini, 2003; Feng-Li et al., 2008). Final fruit size and quality may also depend on shoot length, fruit distribution on the shoot and number of fruit per centimeter of shoot length (Corelli Grappadelli and Coston, 1991). The correct management of the fruit density in relation to the position and light exposure is required to get optimal fruit size (Caruso et al., 1998; Farina et al., 2005). Several studies in the past attempted to evaluate crop load and fruit quality distribution in different training systems (Sansavini et al., 1985; Corelli Grappadelli and Sansavini, 1989). For tree shapes that allow a uniform light distribution, fruit thinning has to be homogeneously performed in every part of the tree (Costa et al., 2003). Farina et al. (2005), showed that a balanced peach fruit number on an open shape produced a greater number of large-sized fruit.

As well as the final commercial diameter, the quality traits commonly used as indicators of peach and nectarine maturity stage into the orchard are the changes in fruit firmness and background color turning from green to yellow (Delwiche and Baumgardner, 1983). Peach fruit quality characteristics such as soluble solid content, red color and background color show a clear gradient related to fruit position into the canopy (Farina et al., 2005; Lewallen and Marini, 2003; Dani, 2007). Farina et al. (2005) reported different gradients of peach fruit firmness in different training system, while other authors found that light intensity did not affect fruit firmness (Feng-Li et al., 2008). Changes in background color and fruit firmness in peaches are generally linked but light interception or canopy position may alter the relationship between these two parameters (Dani, 2007). In fact, while recent studies on peach fruit observed that as firmness declines, background color became more yellow and less green, it was also pointed out that fruit with similar background color harvested from different position into the canopy may not have the same fruit firmness (Marini et al., 1991; Dani, 2007). Iglesias and Echeverria (2009) reported that peach fruit firmness alone is not a satisfactory minimum maturity index because it varies between nectarine cultivars, and for a given cultivar firmness varies in relation to fruit size, climatic conditions and agronomical practices. Instead, background color is an informative harvest index as it reflects the chlorophyll content of the fruit (Infante et al., 2011; Cascales et al., 2005) found that changes in peach fruit background color, due to chlorophyll degradation, are proportional to those perceived by a panel of assessors. Recently, based on the vis-NIR spectroscopy, a new measurement, the “Index of Absorbance Difference” (I_{AD}) that strongly correlate with the chlorophyll-a content and the ethylene production of peach and nectarine fruit was introduced (Ziosi et al., 2008). The I_{AD} could be used for each cultivar to define the ideal timing to harvest, in accordance with consumer needs, as shown by the higher correlation with consumer acceptance than with the traditional quality parameters found by Gottardi et al. (2009). Only few results are available regarding the use of the I_{AD} as ripening Index for peach and nectarine fruit.

The objectives of this study were (a) to assess the performance of Tatura Trellis as training system for nectarine in affecting fruit quality, maturity and homogeneity and (b) to evaluate the possible application of the I_{AD} as non-destructive maturity index to follow fruit ripening in the field and objectively define the ideal harvesting time. Fruit growth and ripening were tested at different canopy layers in the canopy and with two crop densities on nectarine cv 'Summer Flare 34' ('SF34') and 'Summer Flare 26' ('SF26').

5.3 Materials and Methods

Trials were conducted in 2010 on two six-year-old yellow flesh nectarines (*Prunus persica* [L.] Stokes) cultivar 'Summer Flare 34' and 'Summer Flare 26' grafted onto GF677 (*P. persica x P. amygdalus*). The orchards were located in Ardmona, Victoria, Australia (-36.38 N, 145.32 S); trees were trained to a North-South oriented Tatura trellis system with spacing of 4.5 x 3.0 m and a planting density of 740 trees/ha. Routine horticultural management techniques were applied throughout the season in terms of pruning, irrigation, fertilization and pest control.

Full bloom dates recorded for the two varieties were 14^{th} and 16^{th} of October 2010 for 'SF34' and 'SF26' respectively. Three similar trees for 'SF34' and six similar trees for 'SF26' were randomly selected within each orchard. Canopies were divided in three parallel areas of equal size representing the top (T), middle (M) and bottom (B) canopy layers as described by Feng-Lil et al. (2008).

Fruit maturity was assessed by measuring the Index of Absorbance Difference (I_{AD}) with the DA-Meter (TR, Forlì, Italy), a portable vis/NIRs that correlates with chlorophyll-a content and ethylene production as described by Ziosi et al. (2008). Fruit of the two varieties 'SF34' and 'SF26' were catalogued in three ripening classes at harvest representing physiological maturity (PM), that corresponded to the ethylene production, commercial maturity (CM), at the onset of climacteric and immature (I), before the climacteric (Table 1).

To detect the maturity stage at which the ethylene climacteric occurred in cultivar 'SF34' and 'SF26', ethylene production was assessed on a sample of more or less 10 fruit per I_{AD} class (forty fruit in total), randomly picked one week before the main harvest. Fruit were individually placed in sealed 1 L jars and a 1.0 mL gas sample removed and injected into a Shimadzu GC-14B packed-gas chromatograph (Column = Packed Alumina SS 80/100 180cm; 140°C; Inj/Det = 180°C, Shimadzu, Kyoto, Japan). Fruit were left to incubate for at least one hour at 20° C prior to a second gas sample being removed and injected into the gas chromatograph. The ethylene production was calculated as difference between the result of the second and the first injection (Bregoli et al., 2002).

For both varieties at harvest twenty to fifty fruit per I_{AD} class were assessed with the standard quality traits measurements: fruit firmness, soluble solid content (SSC), % of blush and a* and b* on both blush and background color of the peel. Fruit firmness was measured on the two opposite cheeks using a FT011 hand-operated Effegi penetrometer (Effegi, Ravenna, Italy) equipped with an 8 mm diameter Magness-Taylor probe and mounted on a hand-operated drill press. Part of the mesocarp was squeezed and SSC was determined with a digital hand-held refractometer (PAL-1, Atago, Tokyo, Japan). The percentage of blush was visually evaluated and expressed as percentage of the fruit surface covered with a uniform red color (0% corresponded to a fruit that did not developed any blush; 100% corresponded to a fruit completely red). The a* and b* color-opponent dimensions, based on nonlinearly compressed coordinates, were measured with a CR400 Minolta digital colorimeter (Konica-Minolta, Tokyo, Japan).

Cultivar 'SF34' was used to evaluate the influence of Tatura Trellis system on fruit maturity and quality. Five fruit per each canopy layer (bottom, middle and top) from east and west side of the canopy of every tree were tagged (ninety fruit in total) and followed during the growing season. To evaluate the influence that fruit position within the canopy had on nectarine development, fruit growth (diameter) and ripening (I_{AD}) were weekly monitored on tagged fruit from 83 to 130 DAFB. The first harvest was performed at 122 DAFB and the main harvest at 130 DAFB. The fruit ripening composition was measured with the DA-meter on a total population of 100 randomly selected fruit picked from the trees under study at the main harvest. The previously described standard laboratory quality assessments were performed on a sample of twenty to fifty fruit per I_{AD} class.

On one of the trees in trial the spatial position of each fruit, as well as the complete canopy structure, was identified using a "woody stick-compass system" to obtain length, direction (°N) and horizontal projection of each element, following the protocol established by Costa (personal communication). By inputting the collected data in the 3D graphic software PlantToon® (Magnanini et al., 2010), the architecture of the tree has been recreated and modeled in order to link the relative position of each fruit with the information collected from the field (I_{AD}).

Cultivar 'SF26' was used to evaluate the effect of fruit density on fruit maturity of Tatura Trellis grown trees. Six branches with similar length (around 40 to 50 cm), one branch per each canopy layer (B, M and T) and orientation (East, West), were selected and tagged on each of the six trees in trial (thirty-six branches in total), based on the assumption that peach tree branches behaved as functionally autonomous units, as demonstrate by Volpe et al. (2008) All tagged branches from three trees were hand thinned at 4 fruit per branch (1 fruit every 10-12 cm of shoot length) 15 to 20 DAFB (as suggested by Corelli Grappadelli and Coston, 1991) while all the tagged branches from the remaining three trees were left unthinned with roughly 8 fruit per branch (1 fruit every 5-6 cm of shoot length).

Fruit growth (diameter) and ripening (I_{AD}) were weekly monitored from 68 to 89 DAFB on the fruit from all tagged branches. To assess the correlation between fruit ripening stage (I_{AD}) and SSC, during fruit growth a sample of fifteen fruit were weekly collected. I_{AD} and SSC were measured, as previously described. Harvest was performed in two picks (main harvest was at 89 DAFB), in accordance to the orchardist normal behavior. Because an overwhelming infection of *Monilia Laxa* near harvest, the standard laboratory quality assessments at harvest of cv 'SF26' were not performed.

All the collected data were statistically evaluated using the Duncan's multiple range t-test at $p < 0.05$. The interactions between factors were assessed with a multiple factor ANOVA test. Both the statistical evaluations were performed with the software STATISTICA 7 (StatSoft. Inc., Tulsa, OK, USA).

5.4 Results

Table 1 shows the I_{AD} values at which the fruit maturity stage ranges start affecting the physiology of the fruit for both 'SF34' and 'SF26' nectarine varieties. I_{AD} values are different for the two varieties even when inside the same maturity stage. Fruit at immature stage (>1.3 I_{AD} value for 'SF34' and > 1.0 for 'SF26') are in pre-climacteric with negligible ethylene production. Fruit at commercial maturity show the onset of the climacteric with the starting of ethylene production (I_{AD} values of 0.6 to 1.3 for 'SF34' and 0.6 to 1.0 for SF 26). Below 0.6 I_{AD} value in both varieties fruit are at the physiological maturity stage with high ethylene production.

As shown in Figure 1, at 101 and 108 DAFB fruit of the cultivar 'SF34' were immature, with I_{AD} values greater than 1.3-1.6. At 122 DAFB, fruit in the outer canopy appeared riper than fruit in the inner and bottom as shown by the light gray and white circles representing the riper fruit.

At every sampling, fruit ripening distribution between I_{AD} classes were concentrated in a narrow range of values (Figure 2), showing a high fruit ripening homogeneity. The three curves seemed to maintain the same shape over time and only sliding toward lower I_{AD} values when fruit became riper (122 DAFB).

As shown in table 2 significant differences were observed monitoring fruit ripening of the cultivar 'SF34' every week from 93 to 130 DAFB during which the I_{AD} values progressively decreased from around 1.8 to roughly 0.8 in a month. Fruit reached the onset of climacteric at 122 DAFB (Table 1) and harvests were performed (122 and 130 DAFB) for the ‘SF34’ cultivar. The maturity stage of the fruit was not different between the three horizontal canopy layers bottom, middle and top over time (data not shown), while fruit growth during the season was significantly affected by fruit positioning into the canopy (Table 3). At the first sampling (73 DAFB), fruit from the T canopy layer showed bigger diameter than fruit in the M and B canopy layers (44.5 mm, 42.8 mm and 41.2 mm respectively). For the rest of the season and up to the first harvest (122DAFB) fruit in the B canopy layer had on average 2 to 4 mm smaller diameters than the M and T canopy layers (Table 3). At the main harvest (130 DAFB) of cultivar ‘SF34’, no more differences were observed between fruit diameters from the three canopy layers (average of 71 to 73 mm).

Fruit of cultivar ‘SF34’ showed a high ripening homogeneity at the main harvest (130 DAFB) at which more than 80 % of the fruit were included in the CM class; only the 3% of the fruit were in the I class (I_{AD} value greater than 1.3) and the remaining (17%) were at the physiological maturity stage (I_{AD} 0.3-0.6).

Riper fruit (PM) did not show any significant differences between bottom, middle and top canopy layers in term of % of blush at harvest (55 to 60%). Fruit from top canopy layer of the CM class were more colored (60% blush) than bottom fruit (40 % blush) of the same class, while no differences were shown between fruit of the I class, that developed only 10% blush, independently of the canopy layer. Immature fruit East exposed have shown a % of blush lower than the West oriented (data not shown). No significant differences between ripening classes and canopy layers in term of a*and b* components of both blush and background color were observed (data not shown), while traditional destructive quality parameters were differently affected by the fruit ripening stage and the position in the canopy, as shown in Table 4. No differences were observed for fruit firmness between fruit within the same ripening class, coming from the three canopy layers. If we consider the canopy layers, only top showed variation between ripening classes, with riper fruit (PM) measuring the lowest fruit firmness and immature fruit (I) the highest (Table 4). Fruit of both the PM and CM classes developed the highest SSC at the top of the trees, while no differences were noticed between tree canopy layers within the immature I_{AD} class. When comparing fruit within the same canopy layer, fruit at the PM and CM ripening stages showed higher SSC values than (I) fruit while no differences were noticed between ripening classes in the bottom canopy layer (Table 4). Both fruit firmness and SSC were not affected by fruit orientation (East-West) of the canopy (data not shown).

As shown in Table 5 for cv ‘SF26’, hand-thinned fruit were bigger than the unthinned at every sampling date and in all tree canopy layer. When considering fruit density, the diameter of the hand-thinned fruit did not differ between canopy layers, while the unthinned fruit were bigger in the top canopy layer at most sampling dates. Only at 89 DAFB all fruit from the three canopy layers reached the same diameter in the unthinned fruit.

Table 6 shows that the I_{AD} value decreased during the season both for the hand-thinned and thinned thesis. Within fruit densities at every sampling time no differences were observed between the three canopy layers. Fruit density had an interactive effect with canopy layer on fruit I_{AD} values. Higher fruit density at 68 and 75 DAFB resulted in delayed ripening values in fruit from the middle and bottom canopy layers but not from the top canopy layer. In all subsequent sampling dates unthinned fruit showed delayed maturity (lower I_{AD} values) when compared with the hand-thinned fruit reaching the point at 89 DAFB (harvest) in which unthinned fruit were still at a pre-climacteric stage while hand-thinned fruit were already on the onset of climacteric (Table 1 and Table 6). The East or West orientation did affect neither fruit growth, nor ripening (data not shown).

Figure 3 describes the correlation (R^2 = 0.60 and $p<0.01$) between the I_{AD} values of fruit of the cultivar ‘SF26’ and the respective SSC during fruit growth. Unripe fruit, with an I_{AD} between 1.0 and 2.0, showed a lower SSC than the riper fruit. Fruit that reached the PM, showed the highest SSC (12-15 °Brix).

5.5 Discussion

Recently, Reig et al. (2012) used firmness instead of ethylene production to establish a correlation between the I_{AD} and fruit maturity stage, but their findings were not satisfactory as, different I_{AD} values were obtained at different firmness values and the relationship was cv dependent. In fact, as demonstrated by Ziosi et al. (2008) on nectarine of the cultivar Stark Red Gold, I_{AD} showed higher correlation with ethylene production than with fruit firmness. Both cultivars ‘SF34’ and ‘SF26’ showed a clear and different trend in ethylene production at the respective I, CM and PM fruit maturity stages (Table 1), in agreement with Ziosi et al. (2008) that defined the relationship between ethylene production and ripening stage (I_{AD}) as cultivar-specific. The I_{AD} can be regarded as a marker of peach fruit ripening more sensitive and confident than the physic-chemical parameters commonly used to describe the physiological condition including firmness, which was the most reliable measurement till now (Valero et al., 2007).

The I_{AD} value measured on fruit of cv ‘SF34’ decreased following ripening from early in the season (Table 2), even if at the onset of climacteric (CM) the ethylene production still remained very low (Table 1). Prior to that ripening level, at the immature stage, the I_{AD} probably better correlates with chlorophyll content than with the ethylene production, still remaining cultivar-specific (Cubeddu et al., 2001a; Cubeddu et al., 2001b). Ripening assessment on fruit of the cultivar ‘Stark Red Gold’

(Ziosi et al., 2008) as well as on eleven different nectarine cultivars, Reig et al. (2012) confirmed the same behavior.

The non-destructive instrument DA-meter, coupled with the 3D representation of the tree, allowed to obtain objective observations of fruit ripening in their exact collocation within the canopy (Figure 1), without removing them from the tree (Costa et al., personal communication). Our experiment showed that fruit ripening (I_{AD}) of 'SF34' trained on Tatura Trellis was not affected by fruit position inside the canopy (bottom, middle and top canopy layers) during the season as well as at harvest (Figure 1 and 2). This is probably due to the open shape of the training system that allows a better exposure of fruit in the inner and bottom part of the canopy to direct sunlight, especially during the last stages of fruit development (Nuzzo et al., 2000). A similar behavior was observed on peach and apple fruit grown on Y-trellis (Caruso et al., 2003), characterized by a wider angle between branches (45° instead of 35° of Tatura Trellis) and "perpendicular V" also called "Kearney-V" or "KAC-V" (DeJong, 1999), an hybrid between the traditional open-vase system and the Tatura trellis. All these training systems showed greater levels of intercepted radiation than delayed vase and free palmette along the life of the orchard (Layne and Bassi, 2008).

On the contrary of fruit ripening, fruit growth during the season and final size, for cv 'SF34' (Table 3), appeared strongly affected by fruit position in the canopy (Table 3). Several studies on peach trees have demonstrated that fruit position in the canopy was an important factor affecting fruit growth and size (Génard and Bruchou, 1993; Weibel, 1999). At every sampling, fruit of 'SF34' located at the top of the canopy were constantly bigger than fruit in the bottom (Table 3). Also Lewallen and Marini (2003) observed that fruit size was largest in fruit located in the outside of the canopy and a similar pattern was reported in peach trees trained to a perpendicular-Y and "delayed vase" (Farina et al., 2005). Basile et al. showed that at harvest fruit size increased moving from the top to the bottom of the canopy, while at the beginning of the growing season fruit showed an opposite trend. Likewise, only at the first sampling (73 DAFB) on cv 'SF34', no differences were observed between diameters of fruit from the middle and bottom canopy layers, while afterwards the diameters of fruit from the middle and top canopy layers were similar until harvest (Table 3). This behaviour could be due to a change in fruit diameter gradient in the canopy described by Basile et al. (2007). A possible explanation of the opposite trend early in the season, of fruit growth could be related to the time of blooming, that start form the tree bottom to the top of the tree (Dann et al., 1988). Alternatively, part of the variability in fruit growth appeared to be related to carbon (C) source limitation due to the insufficient area of leaves per fruit early in the season (Corelli Grappadelli and Coston, 1991; Costa et al., 2003). In peach, which carries vegetative and reproducticve buds at most nodes, the competition may be stronger for young fruit and this may cause stronger early fruit-to-fruit competition in the top compared to the bottom of the canopy and a slow growth in the upper part of the trees (Corelli Grappadelli and Coston, 1991). Subsequently, when fruit become then stronger competitor for the photosynthates they start to use the leaves in the vicinity as C-sources and fruit in the tree top are advantaged because more exposed to light (Basile et al., 2007). Fruit competition and usage of leaves as C-sources could explain our findings that after the main harvest of cv 'SF34', fruit diameters were similar in the three considered canopy layers, probably because fruit removal caused a redistribution of the photosynthates between the remaining fruit, which continued their growth throughout the last stages of maturation (Marini and Sowers, 1994).

Our results showed that fruit of the variety 'SF34', trained on Tatura Trellis, with the same ripening stage at harvest, were very homogeneous also in terms of firmness (Table 4) establishing a loose correlation between fruit firmness and ethylene production. This observation is in accord with other authors, who reported a rapid decline of fruit firmness after ethylene production inside the fruit has begun (Tonutti et al., 1996; Brummell et al., 2004). Conversely, Lewallen and Marini (2003) observed that fruit with similar background color, as an indication of fruit ripening, harvested from different positions within the canopy did not have the same fruit firmness, with firmer fruit in the inside positions of which the nearby leaves would be the least exposed to light. Our findings were somewhere in the middle since fruit from the bottom and middle canopy layer were found having similar firmness independently of their ripening stages (Table 4) while fruit from the top of the canopy showed that less ripen fruit were the more firm, probably also due to a combined effect of light and position as suggested by Marini and Trout (1984).

Ziosi et al. (2008) described SSC as ethylene-independent and did not observe strong differences in soluble solids between ripening stages (I_{AD}) for the cultivar 'Stark Red Gold'. Our results on cv 'SF26' seemed to validate these findings, in fact a relatively low correlation (R^2 = 0.60) between I_{AD} and SSC was observed (Figure 3). These results were also in accord with Hale et al. (2012) on the cv 'August Fire' but in contrast with a recent publication of Infante et al. (2011) on two cultivars of Japanese plums 'Angeleno' and 'Autumn Beaut'. Infante (2012) described the I_{AD} as an index having high correlation with the most common parameters used for monitoring ripening, such as fruit firmness and SSC with R^2 >0.89 and >0.70 respectively. Our results on 'SF34' (Table 4), however, showed that fruit in the middle and top canopy layers presented differences in term of SSC related to the ripening stage with immature fruit, and therefore less ethylene, having the lowest soluble solids content and fruit at commercial and physiological maturity stages having similar SSC despite their differences in ethylene production (Table 4). Only fruit from the bottom canopy layer appeared to have the same SSC independently from the ripening stage. Overall in our experiments it seems that there was a loose interaction between canopy position and fruit ripening stage in regards to SSC (Table 4) and most of the effects were probably due to the higher exposition to the light of fruit in the upper parts of the canopy than to their specific ripening stages, since only the immature or less exposed fruit of the bottom canopy layers showed lower SSC. This hypothesis is supported by other works that found a strong influence of light on peach fruit quality (Caruso et al., 2003) and, consequently, of tree growth trends, reproductive habits, training systems as well as pruning techniques on light distribution (DeJong and Doyle, 1984; Scorza et al., 1986). Despite the variation in SSC fruit content found in our experiment, trees trained in the Tatura Trellis system seemed to have a good uniformity in SSC distribution since 97% of the fruit at harvest were at the CM and PM maturity stage. Only 30 % came from the bottom canopy layer, with over 80% of the total fruit harvested having similar soluble solids content. There could also be a variety component influencing the overall correlation between SSC and I_{AD} and more research is necessary to validate this.

The highly uniform tree structure created by the Tatura Trellis system seemed to be the reason of the relatively high fruit uniformity found in our experiments, in terms of fruit maturity level, SSC and firmness. In fact, as suggested by DeJong et al. (1984), the uniform tree structure of Tatura Trellis, also allows for an easy regulation of fruit density which can be summed by just leaving about four fruit per fruiting shoot during Stage I of fruit growth (Corelli Grappadelli and Coston, 1991). From our experiment on cv 'SF26', it was observed that maintaining fruit number at the suggested density resulted in uniform fruit within the canopy, both in term of diameter and ripening stage (Table 5 and 6). These results are in contrast with previous studies that showed gradients of fruit size within peach tree canopies both in commercially and heavily-thinned peach trees (Weibel, 1999; Forlani et al., 2002; Farina et al., 2005) . The higher light availability to the fruit, coupled with a balanced crop load, probably allowed Tatura Trellis to reduce the fruit-to fruit competition with a greater distribution of the photosynthates between vegetative and reproductive structures (Faust, 1989; Pavel and Dejong, 1993; Costa and Vizzotto, 2000) which would explain the high fruit variability in term of size and maturity stage that we found when fruit density was doubled (Table 5 and 6). Our results were confirmed by other authors that observed that leaving too many fruit on a tree reduces SSC as well as fruit size at harvest (Corelli Grappadelli and Coston, 1991; Crisosto et al., 1995a).

5.6 Conclusions

The study revealed that trees trained on Tatura Trellis produced fruit with high homogeneity in terms of growth, maturation and SSC content, when fruit density is balanced. Our results also confirmed that the I_{AD} can be regarded as a sensitive, confident and non-destructive marker of nectarine fruit maturity stage that allows for an early assessment of fruit ripening still on the tree. Further investigations are required to better define the relationship between I_{AD} and the traditional quality traits fruit firmness and SSC.

5.7 Literature cited

Basile B., Solari L.I. and Dejong T.M. (2007). Intra-canopy variability of fruit growth rate in peach trees grafted on rootstocks with different vigour-control capacity. The *Journal of Horticultural Science and Biotechnology*. **82**(2): 243-256.

Bregoli A.M., Scaramagli S., Costa G., Sabatini E., Ziosi V., Biondi S. and Torrigiani P., 2002. Peach (*Prunus persica* L.) fruit ripening: amino- ethoxyvinylglycine (AVG) and exogenous polyamines affect ethylene emission and flesh firmness. *Physiologia Plantarum*. 114: 472-481.

Brummell D.A., Dal Cin V., Lurie S., Crisosto C.H. and Labavitch J.M., 2004. Cell wall metabolism during the development of chilling injury in cold-stored peach fruit: association of mealiness with arrested disassembly of cell wall pectins. *Journal of Experimental Botany*. **55**(405): 2029-2039.

Caruso T, Di Vaio C, Guarino F, Motisi A. and Nuzzo V., 2003. Peach varieties for intensive plantations in southern Italy, 44- 51 p. In: Marra FP, Sottile F (Eds.). Proceedings of the IV Congresso Nazionale sulla Peschicoltura Meridionale. Panuzzo Prontostampa, Caltanisseta, Italy.

Caruso T., De Michele A., Sottile F. and Marra F.P., 1998. La peschicoltura siciliana nel contesto italiano: ambiente, cultivar e tecniche colturali. Proceedings ogf the 2nd Convegno sulla Peschicoltura meridionale. Paestum, 2-3 luglio: 83-88.

Cascales, A. I., Costell E. and Romojaro F., 2005. Effects of the degree of maturity on the chemical composition, physical characteristics and sensory attributes of peach (*Prunus persica*) cv. Caterin. *Food Sci. and Technology International.* **11**(5): 345-52.

Chalmers, D.J. and Wilson I.B., 1978. Productivity of peach trees: tree growth and water stress in relation to fruit growth and assimilate demand. *Annals of Botany*. 42: 285-294.

Cittadini E. D., Peri P. L., Ridder N. and Keulen H., 2008. Relationship between Fruit Weight and the Fruit-to-Leaf Area Ratio , at the Spur and Whole-Tree Level , for Three Sweet Cherry Varieties. Proc. 5th ISHS on Cherry. *Acta Horticolturae*. 795**:** 669-672.

Corelli Grappadelli L. and Coston D. C., 1991. Thinning pattern and light environment in peach tree canopies influence fruit quality. *HortScience*. 26: 1464-1466.

Corelli Grappadelli L. and Sansavini S., 1989. Light interception and photosynthesis related to planting density and canopy management in apple. *Acta Horticolturae*. 243:159-174.

Costa G. and Vizzotto G., 2000. Fruit thinning of peaches. *Plant Growth Regulation.* 31:113-119.

Costa G., Noferini M., Fiori G. and Orlandi A., 2003. Non-destructive technique to assess internal fruit quality. *Acta Horticolturae.* 603: 571-575.

Crisosto C.H., DeJong T., Day K.R., Johnson R.S., Weinbaum S., Garner D., Crisosto G.M. and Morrison D., 1995a. Studies on stone fruit internal breakdown. In: 1994 research reports for California peaches and nectarines. California Tree Fruit Agreement, Sacramento, Calif.

Cubeddu R., D'Andrea C., Pifferi A., Taroni P., Torricelli A., Valentini G., Dover C., Johnson D., Ruiz-Altisent M. and Valero C., 2001a. Non-destructive quantification of chemical and physical properties of fruits by time-resolved reflectance spectroscopy in the wavelength range 650-1000 nm. *Applied Optics*. 40**:** 538-543.

Cubeddu R., D'Andrea C., Pifferi A., Taroni P., Torricelli A., Valentini G., Ruiz-Altisent M., Valero C., Ortiz C., Dover C. and Johnson D., 2001b. Time-resolved reflectance spectroscopy applied to the non destructive monitoring of the internal optical properties in apples. *Applied. Spectrum*. 55: 1368-1374.

Dani M., 2007. Connection between the light availability and the peach fruit quality. *VI. Alps-Adria Scientific Workshop*. 337-340.

Dann I. R. and Jerie P. H., 1988. Gradients in maturity and sugar levels of fruit within peach trees. *Journal of the American Society for Horticultural Science*. 113: 27-31.

DeJong T.M., 1999. Developmental and environmental control of dry-matter partitioning in peach. *HortScience*. 34: 1037-1040.

DeJong T.M. and Doyle J.F., 1984. Leaf gas exchange and growth response of mature 'Fantasia' nectarine trees to paclobutrazol. *Journal of the American Society for Horticultural Science.* 109: 878-882.

DeJong T.M., Day K.R. and Doyle J.F., 1994. The Kearney Agricultural Center perpendicular 'V' (KAC-V) orchard system for peaches and nectarines. *HortTechnology* 4: 362-367.

Delwiche M. and Baumgardner R.A., 1983. Ground colour measurements of peach. *Journal of the American Society for Horticultural Science.* 108: 1012-1016.

Farina V., Lo Bianco R. and Inglese P., 2005.Vertical distribu tion of crop load and fruit quality within vase- and Y-shaped canopies of 'Elegant Lady' peach. *HortScience*. 40: 587-591.

Faust M., 1989. Physiology of temperate zone fruit trees. John Wiley & Sons., London and New York.

Feng-Li H., Fei W., Qin-Ping W., Xiao-We W. and Qiang Z., 2008. Relationships Between the Distribution of Relative Canopy Light Intensity and the Peach Yield and Quality. *Agricultural Sciences in China.* **7**(3): 297-302.

Forlani M., Basile B., Cirillo C. and Iannini C., 2002. Effects of harvest date and fruit position along the tree canopy on peach fruit quality. *Acta Horticolturae.* 592: 459-466.

Génard M. and Bruchou C., 1993. A functional and exploratory approach to studying growth: the example of the peach fruit. *Journal of the American Society for Horticultural Science.* 118: 317-323.

Gottardi F., Noferini M., Fiori G., Barbanera M., Mazzini C. and Costa G., 2009. The Index of Absorbance Difference (I_{AD}) as a tool for segregating peaches and nectarines into homogeneous classes with different shelf-life and consumer acceptance. 8th Pangborn Sensory Science Symposium, Firenze, Italy.

Hale G., Lopresti J., Bonora E., Stefanelli D. and Jones R., 2012. Using non-destructive methods to correlate chilling injury in nectarines with fruit maturity. Proceedings of the 7th International Post-Harvest Symposium, Malaysia.

Iglesias I. and Echeverría G., 2009. Differential effect of cultivar and harvest date on nectarine colour, quality and consumer acceptance. *Scientia Horticulturae.* 120: 41-50.

Infante R., 2012. Harvest maturity indicators in the stone fruit industry. *Stewart Postharvest Review* 1-6

Infante R., Contador L., Rubio P., Mesa K. and Meneses C., 2011. Non-destructive monitoring of flesh softening in the black-skinned Japanese plums ‘Angeleno’ and ‘Autumn Beaut’ on-tree and postharvest. *Postharvest Biology and Technology*. **61**(1): 35-40.

Infante R., Pía C., Noferini M. and Costa G., 2011. Determination of harvest maturity of D’Agen plums using the chlorophyll absorbance index. *Ciencia e Investigation Agraria.* **38**(2): 199-203.

Layne D.R. and Bassi D. 2008. In: The peach: botany, production and uses.

Lewallen K.S. and Marini R.P., 2003. Relationship between flesh firmness and ground color in peach as influenced by light and canopy position. *Journal of the American Society for Horticultural Science*. 128: 163-170.

Magnanini E., Bonora E. and Vitali G., 2010. PlantToon-drawing and pruning fruit trees. Proceedings of the 6th International Workshop on Functional-Structural Plant Models. Davis, CA, September 12-17. P. 255.

Marini R. P. and Sowers D.L., 1994). Peach fruit weight is influenced by crop density and fruiting shoot length but not position on the shoot. *Journal of the American Society for Horticultural Science.* **119**(2): 180-184.

Marini R.P. and Trout J.R. (1984). Sampling procedures for minimizing variation in peach fruit quality. *Journal of the American Society for Horticultural Science.* **109**(3): 361-364.

Marini R.P., Sowers D. and Marini M.C., 1991. Peach fruit quality is affected by shade during final swell of fruit growth. *Journal of the American Society for Horticultural Science.* **116**(3): 383-389.

Nuzzo V., Dichio B., Palese A.M. and Xiloyannis C., 2000. Sviluppo della chioma ed intercettazione radiativa in piante di pesco allevate ad Y trasversale ed a vaso ritardato nei primi tre anni dall'impianto. Failla O. and Piagnani I. (eds). Proceedings of V giornate Scientifiche SOI. Edizioni Tecnos, Milan, Italy. 319-320.

Pavel E.W. and Dejong T. M., 1993. Source and sink-limited growth periods of developing peach fruits indicated by relative growth rate analysis. *Journal of the American Society for Horticultural Science.* 118: 820-824.

Reig G., Alegre S., Iglesias I., Echeverría G. and Gatius F., 2012. Fruit quality, colour development and index of absorbance difference (I_{AD}) of different nectarine cultivars at different harvest dates. Proc. 28th IHC International Symposium on Postharvest Technology, *Acta Horticolturae.* 934: 1117-1126.

Sansavini S., Corelli L. and Giunchi L., 1985. Peach yield efficiency as related to tree shape. *Acta Horticolturae.* 173:139-158.

Scorza R., Zailong L., Lightner G. W. and Gilreath L.E., 1986. Dry matter distribution and responses to pruning within a population of standard, semi-dwarf, compact, and dwarf peach seedlings. *Journal of the American Society for Horticultural Science.* 111: 541-545.

Tonutti P., Bonghi C. and Ramina A., 1996. Fruit firmness and ethylene biosynthesis in three cultivars of peach (*Prunus persica* L. Batsch). *Journal of Horticoltural Science.* 71: 141-147.

Valero C., Crisosto C.H. and Slaughter D., 2007. Relationship between non-destructive firmness measurements and commercially important ripening fruit stages for peaches, nectarines and plums. *Postharvest Biology and Technology.* 44: 248- 253.

Van den Ende B., 1994. The Tatura trellis. *Compact Fruit Tree.* 27:97.

Volpe G., Lo Bianco R. and Rieger M., 2008. Carbon autonomy of peach shoots determined by 13C-photoassimilate transport. *Tree physiology.* **28**(12): 1805-1812.

Weibel A., 1999. Effect of Size-Controlling Rootstocks on Vegetative and Reproductive Growth of Peach (*Prunus persica* [L.] Batsch). M.S. Thesis. University of California, Davis, CA, USA. Pp. 130.

Ziosi V., Noferini M., Fiori G., Tadiello L., Trainotti L., Casadoro G. and Costa G., 2008. A new index based on vis spectroscopy to characterize the progression of ripening in peach fruit. *Postharvest Biology and Technology*. **49**: 319-329.

5.8 Figures

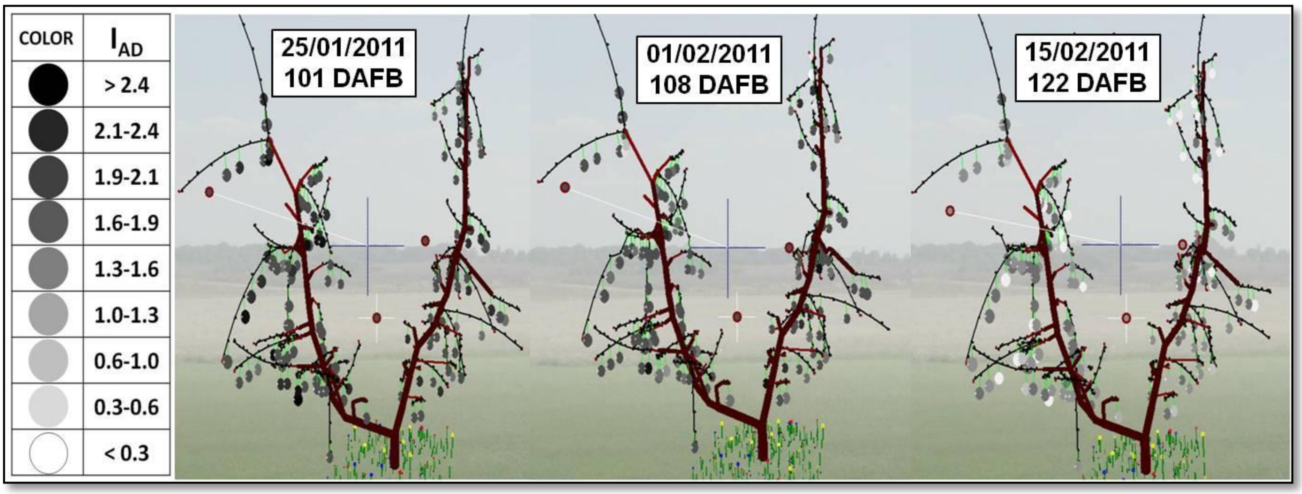

Figure 1: PlantToon® image of the fruit ripening distribution (I_{AD}) at 101, 108 and 122 DAFB (cv 'SF34'). The white circles (I_{AD} <0.3) as well as the circles colored with the lighter shade of grey (0.3< I_{AD} <0.6) represent fruits at their physiological maturity stage (PM). The higher is the I_{AD} value and the unripe is the fruit the darker became the shade of grey. The most unripe fruits are represented by black circles (I_{AD} >1.4).

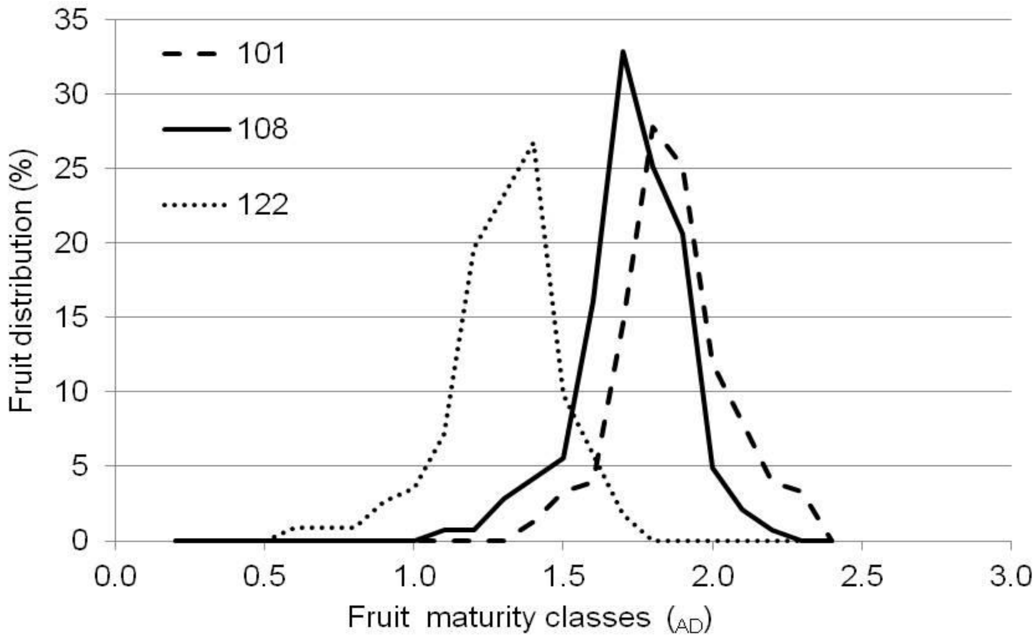

Figure 2: Fruit ripening distribution curves between IAD classes at 101, 108 and 122 DAFB ('SF34').

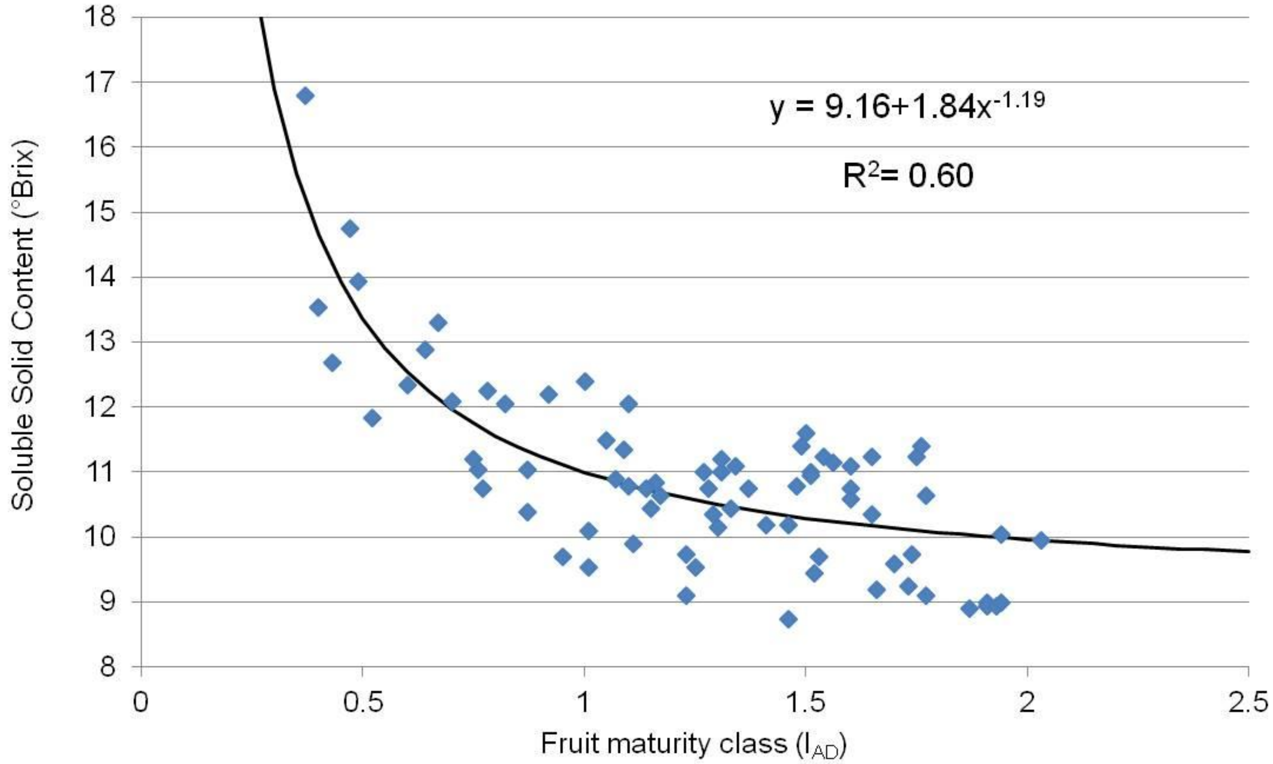

Figure 3: Correlation between fruit ripening stage (I_{AD}) and soluble solid content (°Brix), power equation and coefficient of correlation (R^2) of the cultivar 'SF26'

5.9 Tables

Table 1: Fruit maturity stage, I_{AD} value and corresponding Ethylene production (nl L^{-1} h^{-1} g^{-1} FW) of the two nectarine varieties 'SF34' and 'SF26'.

Variety	Maturity class	I_{AD} class	Ethylene production (nl L^{-1} h^{-1} g^{-1} FW)	
SF34	PM[z]	0.3-0.6	2.13	a[y]
	CM	0.6-1.3	0.26	b
	I	1.3-1.6	0.06	b
SF26	PM	0.3-0.6	2.14	a
	CM	0.6-1.0	0.40	b
	I	1.0-1.3	0.01	b

[z]= Fruit maturity stages: physiological maturity (PM), commercial maturity (CM) and immature (I)

[y]= Numbers with different letters would be statistically significant at $p<0.005$

Table 2: Average of the fruit maturity stage (I_{AD}) on the tree and standard error (SE) at 93, 101, 108 122 and 130 DAFB (cv 'SF34').

DAFB	Fruit maturity (I_{AD})	
93	1.87	a[z]
101	1.81	b
108	1.65	c
122	1.26	d
130	0.78	e

[z]= Numbers with different letters would be statistically significant at $p<0.005$

Table 3: Average of the fruit diameter in different canopy layers of the tree at 73, 80, 93, 101, 108, 122 and 130 DAFB (cv 'SF34').

Time (DAFB)	Canopy layer	Fruit diameter (mm)	
73	B[z]	41.2	b[y]
	M	42.8	b
	T	44.5	a
80	B	42.7	b
	M	44.6	a
	T	46.0	a
93	B	50.4	b
	M	53.3	a
	T	55.3	a
101	B	54.5	b
	M	57.1	ab
	T	57.7	a
108	B	58.7	b
	M	61.2	a
	T	62.3	a
122	B	65.9	b
	M	69.4	a
	T	69.2	a
130	B	71.1	a
	M	71.3	a
	T	73.2	a

[z]= Canopy layers: bottom (B), middle (M) and top (T).

[y]=Numbers with different letters would be statistically significant at $p<0.005$.

Table 4: Average of Firmness (FF kg/cm^2) and soluble solids content (SSC °Brix) of fruits at the I_{AD} classes of physiological maturity (PM), commercial maturity (CM) and immature (I) in the three considered canopy layers bottom (B), middle (M) and top (T) of the cultivar 'SF34'.

Maturity class	FF (kg/cm^2)			SSC (°Brix)		
	B	M	T	B	M	T
PM	6.6 a^z A^y	6.5 a A	5.9 a B	12.0 b A	12.3 ab A	13.4 a A
CM	6.7 a A	6.9 a A	6.8 a AB	12.4 b A	12.6 b AB	13.6 a A
I	6.5 a A	6.5 a A	7.1 a A	11.9 a A	11.6 a B	12.3 a B

^{z}= Small letters represent significant differences between canopy layers within the same I_{AD} class at $p<0.05$.

^{y}= Capital letters represent significant differences between I_{AD} values within the same canopy layer at $p<0.05$.

Table 5: Average of fruit diameter in the Hand-Thinned and Unthinned fruit densities, in the bottom (B), middle (M) and top (T) canopy layer at 68, 75, 82 and 89 DAFB (cv 'SF26').

Time (DAFB)	Canopy layer	Hand-Thinned (diameter -mm)	Unthinned (diameter-mm)
68	B	46.9 a^z A^y	35.8 b B
	M	47.3 a A	37.3 b B
	T	45.2 a A	40.5 b A
75	B	53.3 a A	40.4 b B
	M	54.2 a A	41.4 b B
	T	51.7 a A	46.0 b A
82	B	59.1 a A	43.1 b B
	M	57.3 a A	45.6 b AB
	T	56.3 a A	49.4 b A
89	B	62.9 a A	45.9 b A
	M	61.9 a A	46.3 b A
	T	56.8 a A	48.2 b A

^{z}= Small letters represent significant differences between fruit densities within the same canopy layer (B, M, T) at $p<0.05$.

^{y}= Capital letters represent significant differences between canopy layers within the same fruit density (Hand-Thinned or Unthinned) at $p<0.05$.

Table 6: Average of fruit ripening stage (I_{AD}) in the Hand-Thinned and Unthinned thesis, in the three canopy layers (B, M and T), at 68, 75, 82 and 89 DAFB (cv 'SF26').

Time (DAFB)	Canopy layer	Hand-Thinned			Unthinned		
		(ripening-I_{AD})			(ripening-I_{AD})		
68	B	1.84	b[z]	A[y]	1.99	a	A
	M	1.82	b	A	1.96	a	A
	T	1.89	a	A	1.91	a	A
75	B	1.64	b	A	1.76	a	A
	M	1.64	b	A	1.71	a	A
	T	1.66	a	A	1.69	a	A
82	B	1.33	b	A	1.58	a	A
	M	1.28	b	A	1.48	a	A
	T	1.18	b	A	1.45	a	A
89	B	0.92	b	A	1.29	a	A
	M	0.72	b	A	1.28	a	A
	T	0.88	b	A	1.21	a	A

[z]= Small letters represent significant differences between fruit densities within the same canopy layer (B, M, T) at $p<0.05$.

[y]= Capital letters represent significant differences between canopy layers within the same fruit density (Hand-Thinned or Unthinned) at $p<0.05$.

6.0 Fruit ripening stage/internal temperature relationship varies depending on tree canopy position and the resulting solar exposure in peach cv 'Royal Glory'

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6.1 Abstract

Fruit maturity heterogeneity in the tree and consequently in the field is an ongoing issue that affects the quality and management along the entire production chain. Peach fruit ripening and quality are affected by light interception and temperature whithin the canopy. The heterogeneity of peach fruit development (expressed mainly as fruit dimension and quality traits) is usually attributed to the light variation, without considering fruit temperature. In fact, the combined study of peach fruit internal temperature and ripening, may provide a better understanding of fruit development in open field toward the most appropriate cultural techniques to implement to reduce fruit heterogeneity. During the 2011 and 2012 seasons, fruit ripening was measured in different tree canopy positions (top –T, middle –M, bottom –B), two fruit light exposures ("sunlit" –L and "shaded" –S) and the obtained values correlated with internal temperature. Ripening was measured with a new non-destructive, vis-NIR based , Index of Absorbance Difference (I_{AD}) while temperature with thermistors and expressed as growing degree hours (GDH). The results showed that the heterogeneity of peach fruit ripening observed between canopy layers is partially due to a combination between tree structure, light conditions and fruit temperature, since it cannot be explained only considering fruit internal heat accumulation. The results also demonstrated that during the cell enlargment phase (Stage III) fruit ripening has the same linear trend over different years and canopy positions, confirming the reliability of the I_{AD} as a maturity index that can be obtained in field condition. It was also confirmed the adequacy of thermistors for the assessment of the internal temperature in peach fruit.

Key Words: Index of Absorbance Difference I_{AD}, GDH, *Prunus persica*, fruit quality, ripening homogeneity

6.2 Introduction

Stone fruit ripening is quite a complex syndrome that characterizes the last phase of fruit development, during which fruit reach adequate quality traits and ripeness for harvesting. It involves changes in several fruit quality characteristics (Kader et al., 1994) such as soluble solids content (SSC), titratable acidity (TA), flesh firmness (FF), skin and flesh colour, juice content, volatile emission (Visai and Vanoli, 1996), phenolic content (Moing et al., 1998), etc. The ripening stage of stone fruit at harvest is quite heterogeneous and often causes difficulties in defining the correct harvesting time that translates in poor post-harvest fruit management creating difficulties in the marketing chain which results in failing consumer expectations (Vanoli and Buccheri, 2012). Therefore, there is the need for a specific index to objectively and consistently assess fruit ripening all along the productive chain, from "field to table", and to evaluate fruit heterogeneity at harvest. Kader et al. (1994) defined a maturity index as a simple, non-destructive measurable variable that requires relatively inexpensive equipment, easly usable in the field as well as into the packing-house. The search for an objective determination of maturity has occupied the attention of many horticulturists working with a wide range of fruit for many years. Nevertheless, the number of satisfactory indices that have been suggested is rather small, and for most of the considered fruit specie this search has not ended yet (Vanoli and Buccheri, 2012).

During the last decade, innovative techniques, mainly operating on vis-NIR properties, allowing non-destructive monitoring in real-time condition of fruit ripening evolution, became available. One of these devices, the DA-Meter, measures an index called Index of Absorbance Difference (I_{AD}), which correlates with fruit ethylene production and chlorophyll content (Ziosi et al., 2008). The I_{AD} can be regarded as an “easy to use” parameter to precisely describe the ripening evolution in peach and nectarine (Ziosi et al., 2008). The I_{AD} is more correlated with fruit ripeness and more reliable than the physic-chemical variables commonly used to describe the maturation process (Costa et al. 2009). In the present study, the I_{AD} was used as maturity index to follow peach fruit maturity development on the tree and to assess differences related to fruit position within the canopy, often responsible for the lack of uniformity of peach fruit at harvest (Lewallen and Marini, 2003). In fact, in peaches, ripening heterogeneity in the tree depends upon different conditions of light and temperature at which fruit are exposed in the different canopy positions (outer and inner, as well as top or bottom of the tree) (Lewallen., 2000). As a consequence the biochemical reactions related to ripening develop at different rates in each fruit (Marini et al., 1991).

Light appears extremely important on fruit ripening processes since it also affects fruit ethylene production which plays a major role in the ripening process of climacteric fruit, such as peaches (Génard and Gouble, 2005), and strongly affects softening (Haji et al., 2003; Hiwasa et al., 2003), color change (Flores et al., 2001), and production of aromas (Rupasinghe et al., 2000; Alexander and Grierson, 2002; Flores et al., 2002). Chan and Linse (1989) studied the effect of solar radiation on peach ripening, focusing on ethylene production. They found that increasing field sun exposure resulted in peach fruit ripening delay and suggested that probably the ethylene biosynthetic pathway could be involved. As supposed by Marini et al. (1991) the biochemical reactions related to ripening develop at different rates in each fruit depending upon the different conditions of light and temperature at which fruit are exposed. In fact, more detailed postharvest studies confirmed that fruit treated at high temperatures displayed a much lower level of the 1-aminocyclopropane-1-carboxylic acid (ACC) oxidase 1, ACO1, than fruit of the same post-harvest age maintained at ambient temperature, since ACO1 is a transcript encoding involved in ethylene synthesis that usually appeared during fruit ripening (Lara et al., 2009).

In most cases, the effects of temperature on fruit development and quality in pre-harvest conditions have not been clearly separated from the solar radiation effects, usually associating high fruit temperatures in the field with fruit exposure to sunlight (Ferguson et al., 1998). In literature, temperature is described as one of the major factors that affect fruit development. Several researches pointed out that it might influence fruit growth (Warrington et al., 1999), gas exchanges (Pavel and Dejong, 1993; Lescourret et al., 2000), fruit chemical composition (Tomes, 1963; Marsh et al., 1999; Yamada et al., 2004) and especially fruit ripening and quality development (Weinberg, 1948; Marsh et al., 1999; Lopez and Dejong, 2007). The In particular, consequences on fruit quality such as size, color, sugar and acid content, nutritional attributes, sunburn injury (Lakso and Kliewer, 1975; Austin et al., 1999; Marsh et al., 1999; Warrington et al., 1999; Lobit et al., 2003; Piskolczi et al., 2004; Génard and Gouble, 2005; Génard et al., 2007), and pest development (Kuhrt et al., 2006b) are known. While several authors focused mostly on the effects of solar radiation on fruit quality in the orchard, (Kliewer and Smart, 1989; Palmer, 1989; Bible and Singha, 1993; Correlli-Grappadelli and Coston, 1991; Day et al., 1989; Erez and Flore, 1986; Marini, 1985), post-harvest studies have been carried out to a limited extent and often on detached fruits, describing the effect of temperature (Ferguson et al., 1998). It was found that the increase of 1°C in post-harvest heat treatments on detached peaches, may lead to variation in ethylene production up to 100%, resulting sometimes in an inhibition of ethylene production (Eaks, 1978; Lurie and Klein, 1990, 1991; Ferguson et al., 1994; Genard and Gouble, 2005; Lobit et al., 2003; Lara et al., 2009).

Field studies trying to separately consider the temperature influence on the fruit itself and its ripening *in planta* become then necessary, since only a few experiments focused on the use of sensors for measuring the internal temperature of peach fruit. During the last years, Saudreau et al. (2009, 2011) developed a physically-based fruit-temperature dynamic model linked to three-dimensional virtual tree representations, with the objective to model both the internal temperature gradients of apple fruit and the variability in fruit temperature as related to different training systems. The availability of devices for detecting small microclimatic parameter variations, for example fruit internal temperature, allowed data collection by putting small sensors on each organ (Gutschick et al.,1985) such as thermocouples which are a simple, stable and accurate method to measure the temperature inside the tissue of a plant (Esau et al., 1956; Graham and Mullin, 1969). More recently, thermistores were used due to their smaller response time and sensitivity of the electric resistance to temperature changes, which is more than thousand times that of thermocouples (Wang et al., 2001). Usually, these temperature data, described as heat unit accumulated from the plant organ and expressed as growing degree days (GDD) or growing degree hours (GDH) (Anderson et al., 1986), are often used to predict the rate of phonological development of plant species (Austin et al., 1999). Fisher (1962) showed that heat unit accumulation as degree days could be used effectively to measure developmental time in stone fruit, to create a phenological calendar (Mounzer et al., 2008).

In the present study, the non-destructive ripening $I_{AD,}$ coupled with microclimatic sensors (thermistors), was used on peach fruit of cv 'Royal Glory' to explain ripening heterogeneity at harvest by correlating fruit maturity stage, depending on position within the canopy and solar radiation exposure, with fruit internal temperature expressed as heat unit accumulation (GDH). The efficacy of the I_{AD} as peach ripening index was also evaluated and coupled with microclimatic sensors (thermistors) to collect the physical data.

6.3 Materials and Methods

Trials were carried out on six-year-old yellow flesh peach [*Prunus persica* (L.) Batsch] cultivar 'Royal Glory' grafted onto GF677 (*P. persica x P. amygdalus*) during the 2001 and 2012 growing seasons. The orchard was located in Ferrara, Italy (44° 77' N, 11°56' S); trees were trained to a palmette system with planting density of 4.5 x 3.0 m and East-West oriented. The trees were trained with a main scaffold at 50-60 cm above the ground, from which three primary vertical branches developed to a maximum total height of 3.2 m. Standard cultural management techniques and pest and disease control typical of the region were applied throughout the season.

6.3.1 Fruit ripening assessment

The fruit ripening evolution on the tree during fruit development was monitored with the DA-meter (TR Turoni, Forli, Italy) and expressed as I_{AD} calculated as absorbance difference between 670 and 720 nm wavelengths (Ziosi et al., 2008).

Full blossom was registered on the 25th of March in 2011 and on the 23th of March in 2012. At the beginning of 2011, at full bloom, five trees similar for fruit load and vigour were randomly selected within the orchard . To assess the efficacy of the I_{AD} as maturity stage index, ripening was measured twice a week on a sample of twenty random fruit per tree (10 north and 10 south oriented), for a total of 100 fruit assessed at each sampling from 58 to 118 DAFB, during year 2011.

To assess the influence of fruit canopy position on peach fruit ripening, growth and quality, three parallel areas, related to their height from the ground (top [T], middle [M] and bottom [B] layers), of equal size were identified within the canopies of three of the five trees in 2012, as described by Feng-lil et al., (2008). Fruit diameter from cheek to cheek and the I_{AD} (to also continue the efficacy assessment) were monitored twice a week on five random fruit per area on both North and South (90 fruit in total were measured at each sampling) from 91 to 119 DAFB during year 2012.

6.3.2 Fruit internal temperature assessment

To evaluate the relationship between fruit temperature and ripening in different positions within the canopy, a system of thermistor probes and dataloggers was used. The thermistors (GMR-Firenze, Italy) used were passive two-terminal electrical component that implements electrical resistance to measure temperature. Fruit of uniform sized were selected to guarantee uniform heating inside the flesh as per Tang et al, (2007). At each canopy layer described above, two fruit were selected, one in an outer position and defined as "sunlit fruit" ("L fruit"), and one in an inner position and defined as "shaded fruit" ("S fruit"). A total of thirty-six fruit, two per each combination of orientation and canopy layer were selected and tagged. The I_{AD} was monitored every two-three days (Costa et al., personal communication) to obtain the correlation between fruit ripening and internal heat accumulation..

At 102 DAFB one probe per fruit was introduced into 1 cm deep holes inside the flesh and positioned at the sun exposed face of each "S" and "L fruit" (Figure 1), as described by Saudreau et al. (2007) on apple. From 102 to 120 DAFB, temperature data were automatically recorded every hour by Sky DataHog2 Logger (Skye Instruments-Powys, UK). Temperature records were expressed as Growing Degree Hours (GDH). GDH were calculated using hourly temperature data based on the equation presented by Anderson et al. (1986) and the base, optimum and critical temperature as suggested by Day et al. (2008):

$$GDH = \frac{A}{2}(1 + \cos\left(\pi + \frac{\pi(TH - TB)}{TU - TB}\right))$$

GDH = the accumulation of growing degree hours during an hour

TH = the hourly temperature

TB = the base temperature (4°C for fruit trees)

TU = the optimum temperature (25°C for fruit trees)

TC = the critical temperature (35°C for fruit trees)

A = TU-TB (the amplitude of the growth curve)

Π = mathematical constant approximately equal to 3.14

To assess the correlation between solar radiation and internal temperature, two detached branches of 20 cm in length and bearing one fruit, were used as reference and monitored for 24 hrs during cloudless days at 106, 112 and 118 DAFB. The base of each branch was inserted in a 0.01 L tube full of irrigation water (as described by Costa et al., 2010). One branch was positioned in the upper part of the tree in a complete sunlit position and considered as reference for "sunlit fruit". The other branch was positioned inside the canopy, were the foliage was denser and considered as reference for shaded fruit. Branches, as well as the carried fruit, were replaced after 24 hours monitoring following Morandi et al. (2007) that reported that fruit transpiration losses during 24 hours remain similar to those of fruit detached and left in the same place in the canopy, both during fruit cell division (SI) and cell enlargement (SIII). At the starting of the 24 hours monitoring, a thermistor probe was inserted in each reference fruit, as described before. In the proximity of each fruit, a PAR sensor (SKP 215, Skye Instruments-Powys, UK) that measure solar radiation (Watt.m^{-2}) was positioned. Light levels measured on a clear day were deemed sufficient to describe the relationship with the temperature (Campbell and Norman, 1998**), s**ince during the last two weeks before harvest canopy was fully developed and the light environment of the fruit can be considered constant, as reported in similar experiment (Corelli Grappadelli and Coston, 1991).

6.3.3 Fruit quality assessment

To evaluate the influence of different canopy positions on quality of fruit clusters of homogenous ripening, the traditional fruit quality traits (flesh firmness [FF] and soluble solid content [SSC]) were measured at harvest.

One week before harvest, a sample of one hundred fruit were harvested, measured with the DA-meter and grouped on the basis of their I_{AD} value. Ethylene production was measured on a subsample of ten fruit per each I_{AD} value 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). Three homogeneous ripening groups were created on the basis of fruit ethylene production, as described by Ziosi et al. (2008).When the main harvest was performed, at 120 DAFB, a sample of five fruit per each identified I_{AD} class (physiological maturity-PM, commercial maturity CM and immature-I) and tree canopy height (B, M, T) was collected.

The standard quality traits such as firmness (FF), soluble solids content (SSC) and titratable acidity (TA) were measured on the same fruit sample with traditional destructive devices. FF (kg.cm^{-2}) was measured on the two opposite sides of each fruit, after eliminating a thin layer of the epicarp, using an automatic pressure tester (FTA-GUSS, South Africa) fitted with an 8 mm plunger. Part of the mesocarp was squeezed and SSC (°Brix) was determined with an Atago digital refractometer (Optolab, Modena, Italy).

6.3.4 Statistical analysis

All the collected data were statistically evaluated using the Duncan's multiple range t-test at $p < 0.05$. The interactions between factors were assessed with a multiple factor ANOVA test. The correlation between variables was described using a Multiple Regression test ($p < 0.05$). All the statistical evaluations were performed with the software STATISTICA 7 (StatSoft. Inc., Tulsa, OK, USA). The Comparison of Regression Lines was performed with Statgraphics Plus (Statpoint Technologies, Inc., Warrenton, VA), considering a p value< 0.05).

6.4 Results

Fruit ripening evolution in 2011 showed an inverse rise to max type shape curve (Figure 2). Minimal variations were observed in I_{AD} values over time between fruit which slowly (around 90 days) decreased till a value of 1.8 (plateau part of the curve). When I_{AD} reached 1.8, the curve slope became linear with fruit ripening fast. Both in 2011 and 2012, fruit ripening decreased from I_{AD} 1.8 to 0.6 in about thirty days. No differences were detected as far as I_{AD} regression lines, slopes and intercepts in both years of observations (Figure 2).

In 2012, ripening of the fruit located in the three canopy layers (T, M and B) was described by linear regression lines, from I_{AD} below 1.8 to harvest, all with coefficient of determination greater than 0.95 (Figure 3). Comparing slopes and intercepts of the three equations describing fruit ripening (I_{AD}), no differences were observed between T, M and B canopy layers. Fruit from the T layer were more mature than fruit in the M and B canopy layers over the entire season, with a constant difference of I_{AD} 0.2.

Fruit growth during cell enlargement (SIII) appeared linear in the three layers, with R^2 greater than 0.95 (Figure 4). Similar slopes and intercept were found comparing the equations of fruit growth in the B and M and T canopy layers.. Fruit in the T canopy layer were significantly bigger than fruit in the M and B canopy layers from 87 to 119 DAFB.

Ethylene production of the riper I_{AD} class (PM) was significantly higher when compared with the other two classes. Considering fruit within the same ripening class, no differences in ethylene production were observed between the three tree layers (data not shown).

The traditional quality trait measured for each ripening class and tree layer were reported in Table 1. At harvest, riper fruit (PM) were softer than immature fruit in the three layers of the tree, while CM fruit were somewhat in the middle and did not show a clear trend. When each ripening stage is considered separately, only fruit of the ripe class appear affected by the position in the canopy, being harder in the top than in the lower canopy layers, even if significance was not that great.

Fruit at the same ripening stage (I_{AD}) did not show any difference in terms of SSC between the three canopy layers. Considering every single canopy layer, only in the base and middle positions within the canopy, riper fruit showed the lower SSC while no differences were observed between the three ripening stages in the tree top (Table 1).

No differences were observed in term of fruit size, comparing the three ripening classes (data not showed).

The ripening behavior (as I_{AD}) of "sunlit" ("L") and a "shaded" ("S") fruit left on the tree till physiological maturity (I_{AD} below 0.4) were reported in Figure 5. "L fruit" reached the onset of the climacteric (when the ethylene production started) almost one week before "S fruit". They also showed an initial higher rate of ripening (0.1 I_{AD} day^{-1}) than S fruit (0.06 I_{AD} day^{-1}) until 109 DAFB. After the onset of climacteric (between I_{AD} 1.0 and 0.8), both "L" and "S fruit" increased their daily ripening rate. Then, while ripening of the "S fruit" continued showing a progressive decrease of the I_{AD} value and a correspondent increase of the daily ripening rate, the ripening of "L fruit" slowed down. In fact, the daily ripening rate of "L fruit" remained constant until I_{AD} of 0.4, while below this index value, when fruit reached the ethylene pick and completed their physiological maturation, both "S" and "L fruit" showed again an increase of daily ripening rate (Figure 5).

The differences in term of internal heat accumulated (as GDH) and solar radiation received (as Wcm^{-2}) were reported in Figure 6. As shown, during a clear day, "L fruit" received roughly six times the solar radiation of "S fruit". Moreover, "L fruit" reached an internal maximum temperature of 6°C higher than "S fruit" and needed one more hour than a shaded fruit to decrease the internal temperature below 30°C. When considering the evolution of internal temperature and amount of solar radiation received during the 24 hours span of a sunny day, both "L" and "S" reference fruit maintained the same internal temperature from sunrise, around 6:00, to roughly 10:00 in the morning, even if the "L fruit" received seven times the solar radiation level (Figure 6). Continuing during the day, the internal temperature and the solar radiation received from the "L fruit" continued to increase until early afternoon (14:00) when it reached the maximum of 39°C and 1100 Wm^{-2} respectively. For the "S fruit" during the same period, the amount of solar radiation remained constant (near 200 Wm^{-2}) and the internal temperature did not exceed the critical temperature for peach of 35°C. Both the "L" and "S fruit" maintained the same internal temperature for the subsequent three hours, while the amount of solar radiation decreases to 800 Wm^{-2} and 100 Wm^{-2} respectively. Thereafter the fruit internal temperature as well as the amount of solar radiation gradually and steadily decreased until it reached 28°C at late sunset (21:00) for the "L fruit" and one hour earlier for the "S fruit". During the night, when the solar radiation was absent, the internal temperature of both fruit progressively decreased reaching 16°C at 5:00 in the morning (Figure 6).

Figure 7(A B C) showed the fruit internal heat accumulation needed to ripen for a "shaded" and "sunlit" fruit located in different canopy layers, while for the same fruit, Figure 7 (D E F) showed the daily variation of I_{AD} as function of the internal heat unit daily increase. The average fruit internal heat accumulation between I_{AD} 1.45 (completely unripe stage) to I_{AD} 0.4 (completely ripe stage) did not show significant differences between fruit in the B, M and T canopy layers (1080, 1040 and 1025 GDH respectively, data not shown). Even by separating ripening of fruit in sunlit and shaded positions, no significant differences of GDH accumulation were observed within the M canopy layer, all along the ripening process (Figure 7 B). In the tree base, "S fruit" showed an accumulation of around 200 GDH more than "L fruit" to reach the commercial maturity stage (CM, that corresponded to $0.8<I_{AD}<1.0$), then fruit reached the ripest stage (PM, that corresponded to $0.4<I_{AD}<0.8$) showing a similar final heat accumulation. (Figure 7C).

"L" and "S fruit" in the top canopy layer showed a similar initial internal heat accumulation from I_{AD} 1.45 to 1.2 (Figure 7 A) after which L fruit accumulated around 100 GDH more than "S fruit" to reach the CM ripening stage ($0.8<I_{AD}<1.0$). After that, "L fruit" continued to accumulate much more internal heat than "S fruit" (Figure 7 A), until the PM stage (I_{AD} of 0.4), at which it was observed the maximum difference (of around 400 GDH).

In the bottom canopy layer (Figure 7 F), the daily I_{AD} variation showed an inversely proportional correlation with the fruit internal daily heat accumulation unit, with coefficients of determination of 0.95 and 0.87 respectively for "shaded" and "sunlit fruit" (p value <0.01). In the middle canopy layer (Figure 7 E), S fruit showed similar behavior to that of bottom canopy layer fruit, but with a lower coefficient of determination (0.72). "L fruit" in the middle canopy did not show a clear correlation between the daily I_{AD} variation and the daily heat accumulation unit (R^2 of 0.11), but only a vague trend was observed (Figure 7 E). Figure 7 D showed that "L" and "S fruit" of the canopy top did not follow clear trends. However, "S fruit" seemed to maintain the same inverse correlation, while "L fruit" showed a direct relationship between daily I_{AD} variation and the daily heat accumulation unit, even if both at low coefficients of determination (0.44 and 0.35 respectively).

6.5 Discussion

As described by Ziosi et al. (2008), the I_{AD} correlates with ethylene production and fruit chlorophyll content, two of the main events that characterize peach ripening process. The I_{AD} represents an index able to sort fruit on the basis of their ripening stage at harvest (Ziosi et al., 2008), but not much is known about the use of this ripening index *in planta*. Preliminary and unpublished results on the same cv ‘Royal Glory’, showed that at immature stages, when fruit ethylene production is at minimum levels, the I_{AD} correlates more with fruit chlorophyll content up to values around 1.8. Our results (Figure 2) confirmed the efficacy of the I_{AD} as peach ripening stage index by showing similar trends and also that, at I_{AD} values around 1.9-2.0, the sensitivity of the index seemed too low to perceive any difference between fruit, probably because the chlorophyll content was at the highest levels. At these immature stages (I_{AD} 1.9-2.0 for cultivar ‘Royal Glory’), the I_{AD} was probably no longer a reliable index of fruit development and more precise instruments were probably needed to detect variations. Below value of 1.8 up to physiological maturity (0.4), fruit I_{AD} for the peach variety ‘Royal Glory’ followed a linear decrease, which did not vary in subsequent years (Figure 2) further demonstrating its efficacy as ripening index even in field evaluations. These results are however, somewhat in contradiction with Reig et al. (2012), that found that, on the two peach cultivars ‘Venus’ and ‘Nectaross’, the I_{AD} changed from 2.0 to I_{AD} 0.5 without following a linear trend, possibly because data collection frequency (once a week) was not sufficient to detect minor variations in the I_{AD} decrease.

It has been reported that fruit ripening variability within each tree is greater for peach than for other fruit (Lewallen and Marini, 2003), which explains why to reduce the heterogeneity, fruit are usually harvested in multiple picks (Lurie et al., 2013). In the present work, the ability of the I_{AD} in discriminating fruit at different ripening stages affected by the position inside the canopy directly *in planta* was also demonstrated (Figure 3, 5 and 7). From the reported results, it appeared that for cv ‘Royal Glory’ trained to palmette, fruit position within the canopy did not affect ripening, intended as the I_{AD} linear trend of decrease. In fact, no differences were observed comparing the I_{AD} regression line coefficients for fruit developed at various heights in the canopy (Figure 3). However the constant difference of 0.2 I_{AD} (Figure 3) as well as the bigger size (Figure 4) shown in the top layers compared with the other two layers of the canopy, confirmed the expected ripening heterogeneity into the tree (Lewallen and Marini, 2003). Compared to other more open training systems, such as Tatura Trellis, the palmette is characterized by a reduced light interception in the inner and lower canopy layers (Bassi and Layne, 2008). This factor could probably be responsible for the delayed ripening observed in the middle and bottom of the tree.

Only few researchers in the past studied the influence that environmental factors, such as light and temperature, have on fruit ripening (intended as degreening of the fruit background color) and they did not clearly distinguished between the two effects (Lewallen and Marini., 2003). Marini et al. (1991), reported that uneven conditions of light and temperature are strictly linked to the tree shape and the pruning practices and the variable exposition correlated with the position of the fruit within the canopy is also involved in defining ripening variability within a peach tree (Infante et al., 2012). Our results confirmed these findings by showing that "shaded fruit" followed a different ripening evolution than "sunlit" exposed fruit (Figure 5). In fact, "shaded fruit" reached the onset of climacteric (corresponding to commercial maturity for this variety) around seven days later than "sunlit fruit". The ripening delay observed for "shaded fruit" until the onset of climacteric (Figure 5 and Figure 7A B) is probably due to the combined effect of light and temperature. In fact, as shown in Figure 6, during a typical summer clear day, the "shaded fruit" internal temperature did not exceed the 32-33°C, while the "sunlit fruit" reached around 39°C. Considering the peach critical temperature of 35°C as the maximum "positive" heat usable for fruit biochemical reactions (Day et al., 2008), "shaded fruit" would probably need more days to accumulate the same heat than "sunlit fruit" during the season, as Kliewer and Lider (1968) found in open field conditions on grapevine berries exposed to direct sunlight which ripened faster than shaded berries. At the same time the high amount of solar radiation received by "sunlit fruit", that appeared roughly six times greater than for "shaded fruit" (Figure 6), could also be responsible for their faster reaching of the climacteric stage due possibly to the consequent increase of chlorophyll degradation as defense mechanism. In fact, fruit exposed to the coupled effect of high radiation, both as direct light or sun flecks, and high temperature, are subjected to high oxidative stress that could damage the PSII and triggers internal defense mechanisms (Long et al.,1994). Merzlyak and Solovchenko (2002) found that the decrease in chlorophyll content, as well as the maintenance of a high carotenoid level would help apple fruit to protect from an excessive light absorption. In fact, carotenoids had greater photostability than chlorophylls and play an important role in thermal dissipation. Similar behavior was also observed on detached fruit exposed to a 39 °C air forced heat treatment, in which the epidermis and the pulp colors were modified, with lower chlorophyll content and the synthesis of pigments responsible of the orange-reddish color (Budde et al., 2006).

In addition the temperature of a fruit could be considered as the consequence of the heat exchanges between the fruit and the surrounding microclimate (Monteith and Unsworth, 1990), the components of which – i.e., radiation, convection and evaporation – are strongly affected by plant architecture (Sinoquet et al., 2005; Michaletz and Johnson, 2006). Sun flecks should also be considered and could possibly have an effect on "shaded fruit". In fact, the vertical development of the palmette training system, subjected to wind exposure in the highest layers, probably increased the presence of sun flecks in the tree top and middle, affecting also normally "shaded fruit" (Jackson et al., 1971). Several other authors confirmed these findings, showing that fruit temperature could be strongly variable because of the fluctuating microclimate (Thorpe, 1974; Cellier et al., 1993; Saudreau et al., 2007). Due to the canopy structure and tree vigor in the bottom (no summer pruning was performed in the orchard), the microclimate variability in our experiment, both in term of sun flecks and temperature, was probably minimum for “shaded fruit” located in the canopy bottom respect to them located in the upper canopy layers. In fact, as reported in Figure 7, the higher coefficients of determinations of the regression lines between increase and daily I_{AD} variation were observed in both “shaded” and “lighted fruit” in the tree bottom (Figure 7 F), probably because the shade and sun conditions were more homogeneous than in the middle and top canopy layers. Figure 7 E and F showed that the inverse relationship between daily fruit heating and I_{AD} decrease only remained on “shaded fruit” of the middle layer and was not observed in the tree top.

There seemed to be a variable behavior of the specific fruit depending on the actual stage of ripening reached. Due to the palmette training system architecture, where “sunlit fruit” are mainly located in the tree top, this canopy layer would probably reach the optimal commercial maturity earlier (I_{AD} class 0.8-1.0 for fruit of the cv Royal Glory). “Shaded fruit” in the tree bottom would be the last to reach the optimal maturity on the palmette training system. Heterogeneity was probably due to the ripening advance of “sunlit fruit” compared with “shaded fruit” as we previously discussed. However, when fruit were left on the tree up to the physiological maturity (I_{AD} 0.4 and below), the high temperature reached by the more exposed fruit (L), especially in the tree top, strongly affected fruit ripening causing a slowdown in maturity development (Figure 5). In fact, after the commercial maturity stage, when ethylene production is beginning to rise, a different relationship between ripening (as I_{AD}) and microclimatic conditions was observed. “Shaded” and “sunlit fruit” in the middle and bottom layers, accumulated the same internal heat to reach the ripening stage correspondent to the climacteric pick (I_{AD} 0.4). Both “shaded” and “sunlit fruit” reached I_{AD} 0.4 in the same length of time but the rate of ripening to reach the same point seemed different. As shown in Figure 5, for “shaded fruit” the daily I_{AD} variation increased dramatically up to the physiological maturity and the I_{AD} value quickly declined. “Sunlit fruit”, instead, experienced an initial decrease, followed by a slowdown of around ten days before reaching the climacteric peak, at which point the I_{AD} daily variation appeared constant. The expected ripening advanced of “sunlit fruit” disappeared at the physiological maturity stage (Figure 5) probably because of the negative effect that temperature above 35°C and light exposure had on the ethylene production (Chan and Linse, 1989). In accord with our results, several authors reported that heat treatments at 39°C on detached peach fruit would immediately decrease or inhibit ethylene production (Eaks, 1978; Lurie and Klein, 1990, 1991; Ferguson et al., 1994; Lara et al., 2009). When fruit ripening on the tree continued after I_{AD} 0.4, as described in Figure 5, the opposite behavior would be observed, with “sunlit fruit” reaching I_{AD} 0.2 six days later than “shaded fruit”. This observation is also confirmed in Figure 7 F, for both “shaded” and “sunlit fruit”, and in Figure 7 E, only for “shaded fruit”, from which emerged that high internal heat unit daily increase had a negative effect delaying fruit ripening (as I_{AD} decrement). This behavior appeared not so clear in “sunlit fruit” of the middle layer and in the canopy top (Figure 7 E and D), probably due to the more intense light effect on fruit ripening, as described above. The maximum negative effect of the temperature/light combination on the I_{AD} decrease was observed on “sunlit fruit” of the tree top that accumulated from 100 to 400 more GDH than shaded fruit, to move from the commercial to the physiological ripening stage (Figure 7 A).

From our results, the I_{AD} appeared a useful index to detect the ripening stage of peach fruit and when combined with thermistors for the assessment of peach internal temperature, it also allowed for a better understanding of the effects that this microclimatic parameter could have on the fruit ripening process.

To further understanding the on tree fruit variability and to evaluate the relationship with the I_{AD} measurements, the traditional ripening parameters firmness and soluble solids content were measured on fruit of each ripening class per canopy layer. Most of the variability found was mostly due to the stage of fruit ripening while the fruit position in the canopy layers did not seem to have as strong an effect on the above mentioned variables as on the previously discussed fruit maturity. As shown in Table 1, riper fruit (PM class) were softer than the other fruit along the entire canopy confirming that fruit producing significant ethylene production at harvest would show lower but similar FF value independently of position, probably because FF is ethylene dependent (Ziosi et al., 2008). Our results suggested that for cv ‘Royal Glory’, more ripen fruit inside the same I_{AD} class were characterized by similar FF, while fruit at immature development stages did not show stable FF values (Table 1). Fruit position seemed to influence fruit firmness only at pre-climateric stages. The SSC (Table 1) of fruit at the same ripening stage was not affected by fruit position within the canopy, maintaining similar values per I_{AD} class at any location. In our experiment, riper fruit grown in the higher canopy layers did not show the expected highest SSC when compared with fruit from the lower layers (Table 1) despite most of the literature stating the opposite (Dann and Jerie, 1988; Wei et al., 2004; Basile et al., 2007). This was probably due to the exceptional and extended high temperatures reached in the open field during summer 2012. In fact, as described by Genard and Souty (1996), microclimatic factors, such as high temperatures, act on carbohydrates breakdown for fruit respiration and reduce fruit SSC.

Fruit size is another important quality parameter for peach fruit at harvest, mainly because it determines the final fruit price, that is higher at increasing peach caliper. Similar to fruit ripening, peach fruit growth during SIII stage appeared linear (Figure 4). While fruit in the lower and middle canopy layers showed the same rate of growth, a clear gradient in size was found with fruit becoming bigger from the bottom of the canopy to the top (Figure 4). As Lewallen and Marini (2003) observed, fruit size was largest in fruit located in the outside and top layer of the canopy in different training systems. Other authors suggested that peach fruit develop better in the high and middle layers of the tree canopy due to better light interception (Bergamini and Giulivo, 1969; Feng-lil et al., 2008).

6.6 Conclusions

The present study confirmed the consistency of the I_{AD} as peach ripening index, able to discriminate differences related to fruit position *in planta* for the variety 'Royal Glory'. At I_{AD} values higher than 1.8 -2.0 the sensitivity of the Index seemed too low to perceive any difference between fruit and more precise instruments were probably needed to detect variations. Combined with thermistors for the assessment of peach internal temperature, it also allowed better understanding of the effect that the microclimatic canopy variations has on the ripening process.

For the variety under study, trained to palmette, fruit ripening (as I_{AD}) followed the same linear trend over years, independently from fruit position within the tree. The variability observed was related to the length of time that fruit from different parts of the canopy took to reach a certain stage of maturity.

When harvest was performed at commercial maturity (I_{AD} class 0.8-1.0), fruit heterogeneity seemed mainly due to the combined effect of light and temperature: sunlit fruit located in the tree top ripened faster, while shaded fruit of the bottom were slower to reach the wanted ripening stage. When harvest was performed at the physiological maturity, the effect of high temperature on sunlit fruit seemed to slowdown the ripening process, reducing heterogeneity until causing a delay in the ripening process of the more exposed fruit. Peach fruit position within the tree also affects fruit size, while flesh softening appeared more related to ethylene production. The exceptional climatic conditions of the 2012 season seemed to have nullified the soluble solids content variability expected at the various canopy layers.

The ripening heterogeneity observed within the canopy seemed partially due to fruit temperature, but it cannot be fully explained considering only the fruit internal heat accumulation. More precise and extensive studies taking into account also physical phenomena (i.e. heat fluxes at fruit surface) and biochemical aspects (i.e. photooxidation, photoprotection, hormone biosynthesis) should be undertaken to accurately predict the temperature within fruit and relate it to the fruit development stages.

6.7 Literature Cited

Alexander L. and Grierson D., 2002. Ethylene biosynthesis and action in tomato: a model for climacteric fruit ripening. *Journal of Experimental Botany*. 53: 2039-2055

Anderson J.L., Richardson E.A. and Kesner, C.D., 1986. Validation of chill unit and flower bud phenology models for 'Montmorency' sour cherry. *Acta Horticolturae*. 184: 71-75.

Austin P.T., Hall A.J., Gandar P.W., Warrington I.J., Fulton T.A. and Halligan E.A., 1999. A compartment model of the effect of early-season temperatures on potential size and growth of 'Delicious' apple fruit. *Annals of Botany*. 83: 129-143.

Basile B., Solari L.I. and Dejong T.M., 2007. Intra-canopy variability of fruit growth rate in peach trees grafted on rootstocks with different vigour-control capacity. The *Journal of Horticultural Science and Biotechnology*. **82**(2): 243-256.

Bassi D and Layne D.R., 2008. The Peach: botany, production and uses (Layne D.R. and Bassi D. Eds.). Pp: 264-289.

Bergamini A. and Giulivo, 1969. Osservazioni sulle dimensioni e sul colore dei frutti in rapporto alla loro distribuzione nella chioma di alberi di melo (cv. "Jonathan") allevati a vaso e a palmetta. Atti giornata di studio sulla potatura degli alberi da frutto, Firenze. P. 37-49.

Bible B. and Singha S., 1993. Canopy position influences CIELAB coordinates of peach color. *HortScience*. **28**(10):992-993.

Bregoli A.M., Scaramagli S., Costa G., Sabatini E., Ziosi V., Biondi S. and Torrigiani P., 2002. Peach (*Prunus persica* L.) fruit ripening: amino- ethoxyvinylglycine (AVG) and exogenous polyamines affect ethylene emission and flesh firmness. *Physiologia Plantarum* 114: 472-481.

Budde C.O., Polenta G., Lucangeli C.D. and Murray R.E., 2006. Air immersion heat treatments affect ethylene production and organoleptic quality of 'Dixiland' peaches. *Postharvest Biology and Technology*. 41: 32-37.

Campbell G.S. and Norman J.M., 1998. An Introduction to Environmental Biophysics. New York, NY: Springer New York.

Cellier P., Ruget F., Chartier M. and Bonhomme R., 1993. Estimating the temperature of a maize apex during early growth stages. *Agricultural and Forest Meteorology*. 63: 35-54.

Chan H.T. and Linse. E., 1989. Conditioning cucumbers for quarantine heat treatments. *HortScience*. 24: 985-989.

Corelli Grappadelli L. and D.C. Coston, 1991. Thinning pattern and light environment in peach tree canopies influence fruit quality. *HortScience*. 26:1464-1466.

Costa G., Bonora E., Piccinini L. and Soto A., 2010 Abscisic acid, a new use of a known plant hormone. Evaluation of its effect on stone fruit. 28th International Horticoltural Congress Lisboa. P. 510.

Costa, G., Noferini, M., Fiori, G. and Torrigiani, P., 2009. Use of Vis/NIR spectroscopy to assess fruit ripening stage and improve management in post-harvest chain. *Fresh Produce*. 1: 35-41.

Dann I.R. and Jerie P.H., 1988 Gradients in maturity and sugar levels of fruit within peach trees. *Journal of the American Society for Horticultural Science*. 113: 27-31.

Day K., Lopez G.and DeJong T., 2008. Using Growing Degree Hours Accumulated Thirty Days after Bloom to Predict Peach and Nectarine Harvest Date. *Acta Horticolturae.* 803. Proc. VIIIth ISHS on Modelling in Fruit Research Pp. 163-166.

Day K.R., DeJong T.M. and Hewitt A.A., 1989. Postharvest and preharvest summer pruning of ‘Firebrite’ nectarine trees. *HortScience*. 24: 238-240.

Eaks I.L., 1978. Ripening, respiration, and ethylene production of ‘Hass’ avocado fruit at 20°C and 40°C. *Journal of the American Society of Horticultural Science.* 103: 576-578.

Erez A., Flore J.A., 1986. The quantitative effect of solar radiation on ’Redhaven’ peach fruit skin color. *Hortscience*. 21: 1424-1426

Esau P., 1956. Construction and application of thermocouples for continuous temperature recording of tree buds and fruit. *Proceedings of the American Society for Horticultural Science.* 68: 15-19.

Feng-Lil, He, Fei, W., Qin-Ping, W., Xiao-wei, W. and Qiang, Z., 2008. Relationships between the distribution of relative canopy light intensity and the peach yield and quality. *Agricultural Sciences in China*. **7**(3): 297-302

Ferguson I.B., Snelgar W., Lay-Yee M., Watkins C.B. and Bowen J.H., 1998. Heat shock response in apple fruit in the field. *Australian Journal of Plant Physiology*. 25: 155-163.

Ferguson I.B., Lurie S. and Bowen J.H., 1994. Protein synthesis and breakdown during heat shock of cultured pear (*Pyrus communis* L.) cells. *Plant Physiology.* 104: 1429-1437.

Fisher D.V. 1962. Heat units and number of days required to mature some pome and stone fruit in various areas of North America. *Proceedings of the American Society for Horticultural Science.* 80:114-124

Flores F., Ben Amor M., Jones B., Pech J.C., Bouzayen M., Latché A. and Romojaro F., 2001. The use of ethylene-suppressed lines to assess differential sensitivity to ethylene of the various ripening pathways in Cantaloupe melons. *Physiol Plantarum.* 113: 128-133.

Flores F., El-Yahyaoui F., de Billerbeck G., Romojaro F., Latche A., Bouzayen M., Pech J.C. and Ambid C., 2002. Role of ethylene in the biosynthetic pathway of aliphatic ester aroma volatiles in Charentais Cantaloupe melons. *Journal of Experimental Botany*. 53: 201-206

Gènard M., Bertin N. and Borel C., 2007. Towards a virtual fruit focusing on quality: modelling features and potential uses. *Journal of Experimental Botany.* 58: 917-928.

Gènard M. and Gouble B., 2005. ETHY: a theory of fruit climacteric ethylene emission. *Plant Physiology*. 139: 531-545.

Génard M. and Souty M., 1996. Modelling the peach sugar contents in relation to fruit growth. *Journal of the American Society for Horticultural Science.* 121: 1122-1131.

Graham P. And Mullin R., 1969. The determination of lethal freezing temperature of deciduous Azalea florets and stems by freezing curve method. *HortScience*. **4**(2): 153.

Gutschick V.P., Barron M.H., Waechter D.A. and Wolf M.A., 1985. Portable monitor for solar radiation that accumulates irradiance histograms for 32 leaf-mounted sensors. *Agricultural and Forest Meteorology* 33: 281-290.

Haji T., Yaegaki H. and Yamaguchi M., 2003. Softening of stony hard peach by ethylene and the induction of endogenous ethylene by 1-aminocyclo- propane-1-carboxylic acid (ACC). *Journal of the Japanese Society for Horticultural Science*. 72: 212-217.

Hiwasa K., Kinugasa Y.,Amano S., Hashimoto A., Nakano R., Inaba A. and Kubo Y., 2003. Ethylene is required for both the initiation and progression of softening in pear (Pyrus *communis* L.) fruit. *Journal of Experimental Botany*. 54: 771-779.

Infante R., 2012. Harvest maturity indicators in the stone fruit industry. *Stewart Postharvest Review.* 1-6

Jackson, J.E., Sharples R.O. and Palmer J.W., 1971. The influence of shade and within-tree position on apple fruit size, colour, and storage quality. *Journal of Horticultural Science*. 46: 277-287.

Kader A.A., 1994. Maturation and maturity indices. In: Postharvest technology of horticultural crops. Edition of third edition. University of California. Pp.55–62.

Kliewer W.M. and Lider L.A., 1968. Influence of cluster exposure to the sun on the composition of Thompson seedless fruit. *American Journal of Enology and Viticulture*. 19: 175-184.

Kliewer, W.M. and R.E. Smart., 1989. Canopy manipulation for optimizing vine microclimate, crop yield, and composition of grapes. In: C.J. Wright (ed.). Manipulation of Fruiting. Butterworth, London. P. 275–291.

Kuhrt U., Samietz J. and Dorn S., 2006b. Thermal response in adult codling moth. *Physiological Entomology*. 31: 80-88.

Lakso A.N. and Kliewer W.M., 1975. The influence of temperature on malic acid metabolism in grape berries: I. Enzyme responses. *Plant Physiology.* 56: 370-372.

Lara M.V., Borsani J., Budde C.O., Lauxmann M.A, Lombardo V.A., Murray R. and Andreo C. S., 2009. Biochemical and proteomic analysis of “Dixiland” peach fruit (Prunus persica) upon heat treatment. *Journal of Experimental Botany*. **60**(15): 4315-4333.

Lescourret F., Inizan O. and Gnard M., 2000. Analyse de l’etemporel de la floraison et influence de la variabilité coce des pela chute et de la croissance prétalement intra-arbre deches. *Canadian Journal of Plant Science.* 80: 129-136.

Lewallen K.S. and Marini R.P., 2003. Relationship between flesh firmness and ground color in peach as influenced by light and canopy position. *Journal of the American Society for Horticultural Science*. 128: 163-170.

Lewallen K.S., 2000. Effect of light availability and canopy position on peach fruit quality. Master of science in Horticulture Thesis, Faculty of the Virginia Polytechnic Institute and State University.

Lobit P., Génard M., Wu B.H., Soing P. and Habib R., 2003. Modelling citrate metabolism in fruit: responses to growth and temperature. *Journal of Experimental Botany*, 54: 2489-2501.

Long S.P., Humphries S. and Falkowski P.G., 1994. Photoinhibition of photosynthesis in nature. *Annual Review of Plant Molecular Biology*. 45: 633-662.

Lopez G. and Dejong T.M., 2007. Spring temperatures have a major effect on early stages of peach fruit growth. *Journal of Horticultural Science & Biotechnology*. 82: 507-512.

Lurie S. and Klein J.D., 1990. Heat treatment of apples differential effects on physiology and biochemistry. *Physiologia Plantarum*. 78:181-186

Lurie S. and Klein J.D., 1991. Acquisition of low temperature tolerance in tomatoes by exposure to high temperature stress. *Journal of the American Society for Horticultural Science.* 116: 1007-1012.

Lurie S., Friedman H., Weksler A., Dagar A. and Eccher P., 2013. Maturity assessment at harvest and prediction of softening in an early and late season melting peach. *Postharvest Biology and Technology*. 76: 10-16.

Marini R.P., 1985. Vegetative growth, yield, and fruit quality of peach as influenced by dor- mant pruning, summer pruning, and summer topping. *Journal of the American Society for Horticultural Science.* 110: 133-139.

Marini R.P., Sowers D. And Marini M.C., 1991. Peach fruit quality is affected by shade during final swell of fruit growth. *Journal of the American Society for Horticultural Science*. 116: 383-389.

Marsh K.B., Richardson A.C. and Macrae E.A., 1999. Early and mid season temp erature effects on the growth and composition of Satsuma mandarins. *Journal of Horticultural Science and Biotechnology*. 74: 443-451.

Merzlyak M.N. and Solovchenko A.E., 2002 Photostability of pigments in ripening apple fruit: a possible photoprotective role of carotenoids during plant senescence. *Plant Science*.**163**(4): 881-888.

Michaletz S.T. and Johnson E.A., 2006. Foliage influences forced convection heat transfer in conifer branches and buds. *New Phytologist*. **170**(1): 87-98.

Moing A., Svanella L., Rolin D., Gaudillere M., Gaudillere J.P. and Monet R., 1998. Compositional changes during the fruit development of two peach cultivars differing in juice acidity. *Journal of the American Society for Horticultural Science.* 123: 770-775.

Monteith J.L. and Unsworth M.H., 1990. Principles of environmental physics. London: Edward Arnold.

Morandi B., Manfrini L., Zibordi M., Noferini M., Fiori G. and Corelli Grappadelli L., 2007. A low-cost device for accurate and continuous measurements of fruit diameter. *Hortscience*. 42: 1380-1382.

Mounzer O.R., Conejero W., Nicolas E., Abrisqueta I., Garcia-Orellana Y.V., Tapia L.M., Vera J., Abrisqueta J.M. and Ruiz-Sanchez M., 2008. Growth pattern and phenological stages of early-maturing peach trees under a Mediterranean climate. *Hortscience*. **43**(6): 1813-1818.

Palmer J.W., 1989. Canopy manipulation for optimum utilization of light. In: C.J. Wright (ed). Manipulation of Fruiting. Butterworth & Co., London.

Pavel E.W. and Dejong T.M., 1993. Estimating the photosynthetic contribution of developing peach (*Prunus persica*) fruit to their growth and maintenance carbohydrate requirements. *Physiologia Plantarum.* 88: 331-338.

Piskolczi M., Varga C. and Racsko J., 2004. A review of the meteorological causes of sunburn injury on the surface of apple fruit (*Malus domestica* Borkh). *Journal of Fruit and Ornamental Plant Research.* 12: 245-252.

Reig G., Alegre S., Iglesias I. and Echeverría G., 2012. Fruit Quality, Colour Development and Index of Absorbance Difference (I_{AD}) of Different Nectarine Cultivars at Different Harvest Dates. *Acta Hort*. 934, ISHS 2012 Proc. XXVIIIth IHC – IS on Postharvest Technology. Pp. 1117-1126.

Rupasinghe H.P.V., Murr D.P., Paliyath G. and Skog L., 2000. Inhibitory effect of 1-MCP on ripening and superficial scald development in 'McIntosh' and 'Delicious' apples. *Journal of Horticultural Science and Biotechnology*. 75: 271-276

Saudreau M., Marquier A., Adam B., Monney P. and Sinoquet H., 2009. Experimental study of fruit temperature dynamics within apple tree crowns. *Agricultural and Forest Meteorology*. 149: 362-372.

Saudreau M., Marquier A., Adam B. and Sinoquet H., 2011. Modelling fruit-temperature dynamics within apple tree crowns using virtual plants. *Annals of Botany*. 108: 1111-1120.

Saudreau M., Sinoquet H. and Santin O., 2007. A 3D model for simulating the spatial and temporal distribution of temperature within ellipsoidal fruit. *Agricultural and Forest Meteorology* 147: 1-15.

Sinoquet H., Sonohat G., Phattaralerphong J. and Godin C., 2005. Foliage randomness and light interception in 3D digitised trees: an analysis from multiscale discretisation of the canopy. *Plant, Cell & Environment.* 28: 1158-1170.

Tang J., Mitcham E., Wang S. and Lurie S., 2007. Heat Treatments For Post Harvest Pest Control: Theory And Practice. Pp.56-77.

Thorpe MR., 1974. Radiant heating of apples. *Journal of Applied Ecology*. 11: 755-760.

Tomes M.L., 1963. Temperature inhibition of carotene synthesis in tomato. *Botanical Gazette.* 11: 180-185.

Vanoli M. and Buccheri M., 2012. Overview of the methods for assessing harvest maturity. *Stewart Postharvest Review*. **8**(1): 1-11.

Visai C and Vanoli M., 1997.Volatile compound production during growth and ripening of peaches and nectarines. *Scientia Horticulturae*. 70: 15-24.

Wang J. H., Bowen, I. E., Weir A. Allan C., Ferguson I. B., 2001. Heat-induced protection against death of suspension- cultured apple fruit cells exposed to low temperature. *Plant, Cell and Environment*. 24: 1199-1207.

Warrington I.J., Fulton T.A., Halligan E.A. and Silva H.N.D., 1999. Apple fruit growth and maturity are affected by early season temperatures. *Journal of the American Society for Horticultural Science* 124: 468-477.

Weinberg J. H., 1948. Influence of temperature following bloom on fruit development period of 'Elberta' peach. *Proceedings of the American Society for Horticultural Science.* 51: 175-178.

Wei Q.P., Lu R.Q., Zhang X.C., Wang X.W., Gao Z.Q. and Liu J., 2004. Relationships between distribution of relative light intensity and yield and quality in different tree canopy shapes for 'Fuji' apple. *Acta Horticulturae Sinica.* 31: 291-296.

Yamada H., Takechi K., Hoshi A. and Amano S., 2004. Comparison of water relations in watercored and non watercored apples induced by fruit temperature treatment. *Scientia Horticulturae*. 99: 309-318.

Ziosi V., Noferini M., Fiori G., Tadiello A., Trainotti L., Casadoro G. and Costa G., 2008. A new index based on vis spectroscopy to characterize the progression of ripening in peach fruit. *Postharvest Biology and Technology*. 49: 319-329.

6.8 Figures

Figure 1: GMR Temperature probes inserted in the flesh of peach fruit at different maturity stages (unripe fruit [left] and ripe fruit [right]).

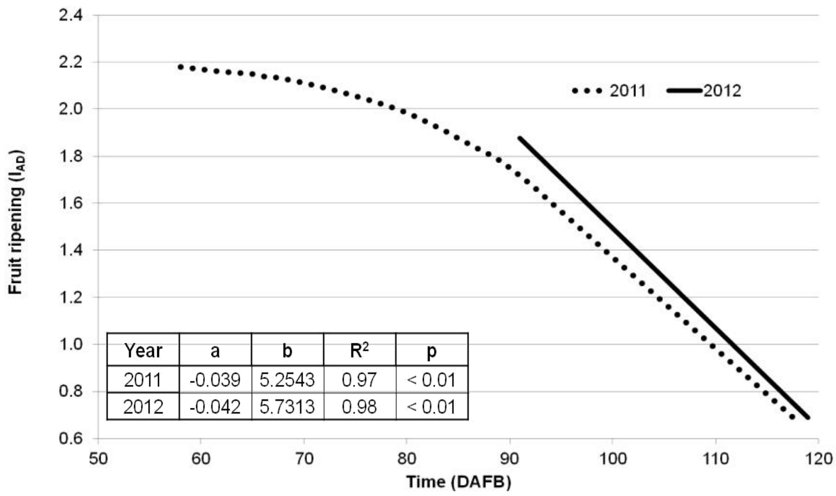
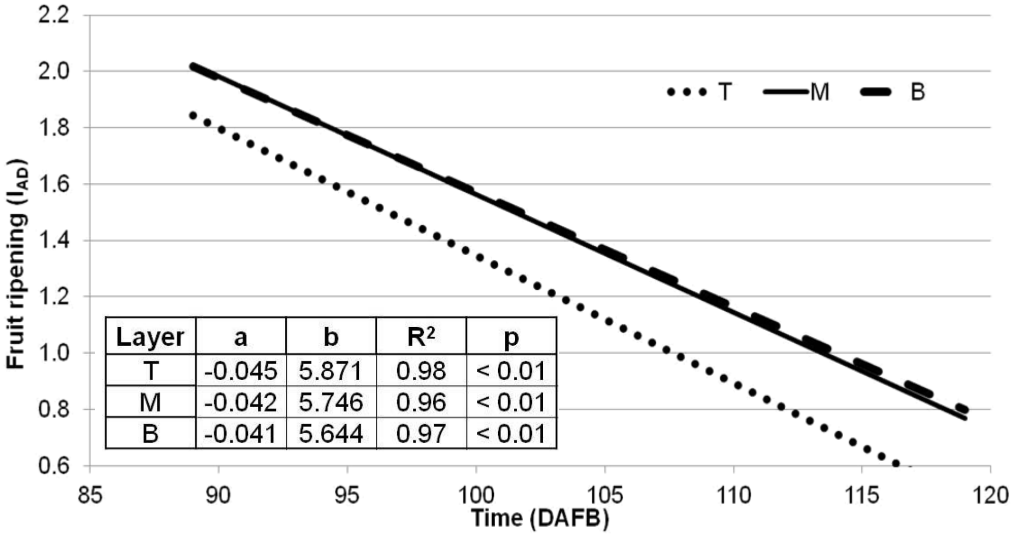
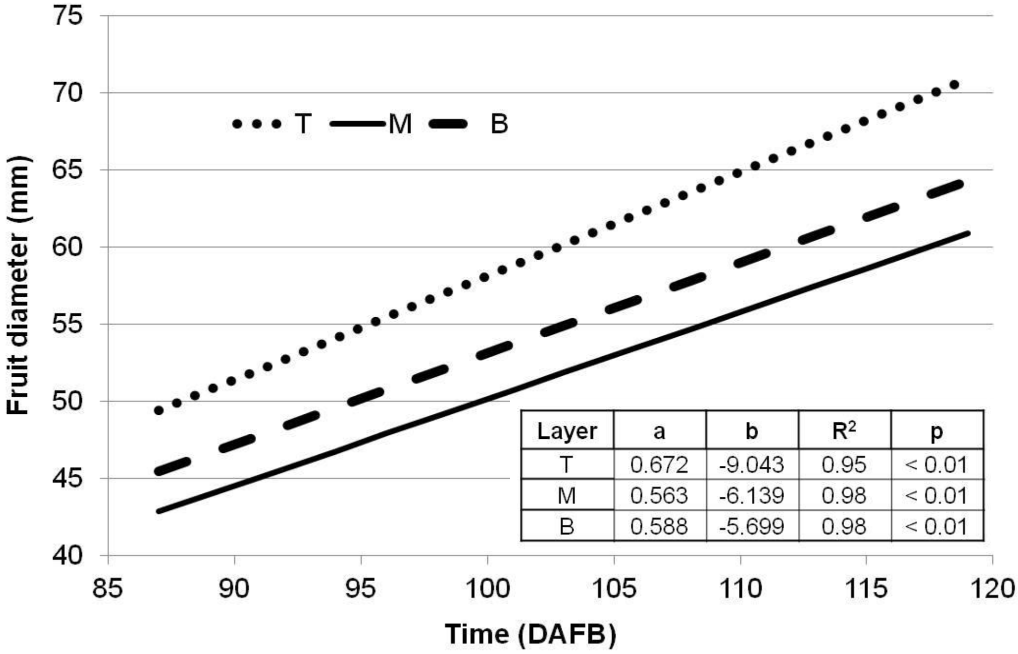


Figure 2: Regression lines of fruit ripening (I_{AD}) in 2011 (dotted line) and 2012 (black line). The table reports slopes (a) and intercepts (b), the coefficient of determination R^2 and p-value of the linear equations in both years. The comparison between regression lines showed a p-value = 0.1888.



Layer	a	b	R²	p
T	-0.045	5.871	0.98	< 0.01
M	-0.042	5.746	0.96	< 0.01
B	-0.041	5.644	0.97	< 0.01

Figure 3: Regression lines of fruit ripening in the top (T), middle (M) and bottom (B) layers of the tree canopy during 2011. The table reports slopes (a), intercepts (b), the coefficient of determination R^2 and p-value of the linear equations. The comparison between regression lines shows a p-value = 0.1888.



Layer	a	b	R²	p
T	0.672	-9.043	0.95	< 0.01
M	0.563	-6.139	0.98	< 0.01
B	0.588	-5.699	0.98	< 0.01

Figure 4: Regression lines of fruit growth (diameter) in the top (T), middle (M) and bottom (B) layers of the tree canopy during 2012. The table reports slopes (a) and intercepts (b), the coefficient of determination R^2 and p-value of the linear equations. The comparison between regression lines shows a p-value=0.0665.

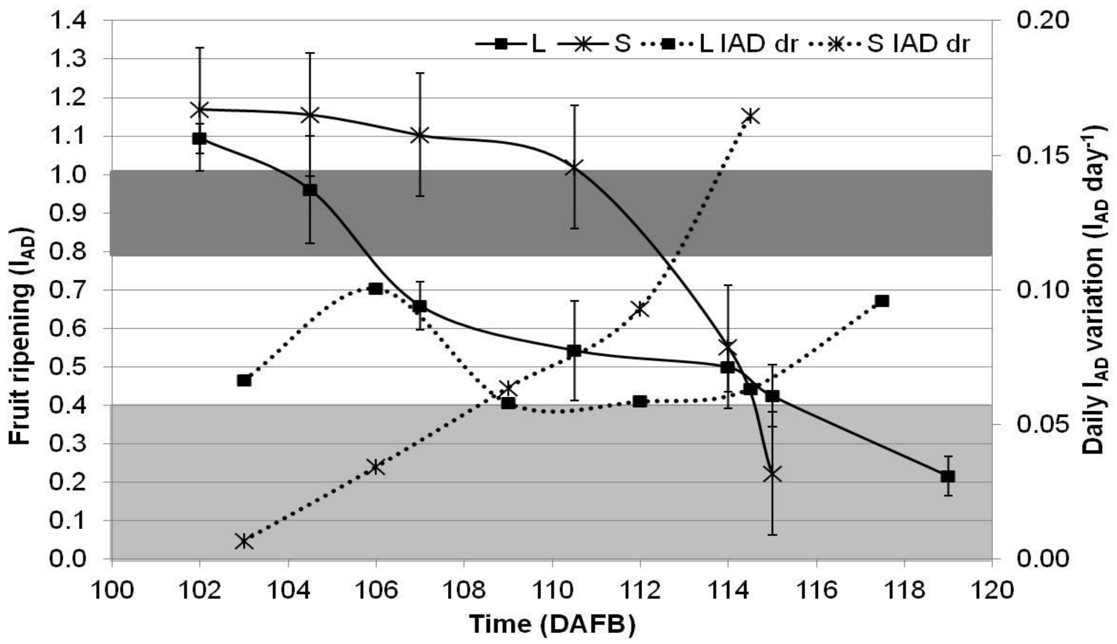


Figure 5: Fruit ripening (I_{AD}) and I_{AD} daily decrease rate (I_{AD} day^{-1}) of "sunlit" (L and L I_{AD} dr) and "shaded" (S and S I_{AD} dr) fruit over the season. The dark gray rectangle represent the I_{AD} value range (0.8-1.0) in which the onset of the fruit climacteric was verified, while the light grey rectangle represent the I_{AD} value range (0.0-0.4) in which the climacteric pick appeared.

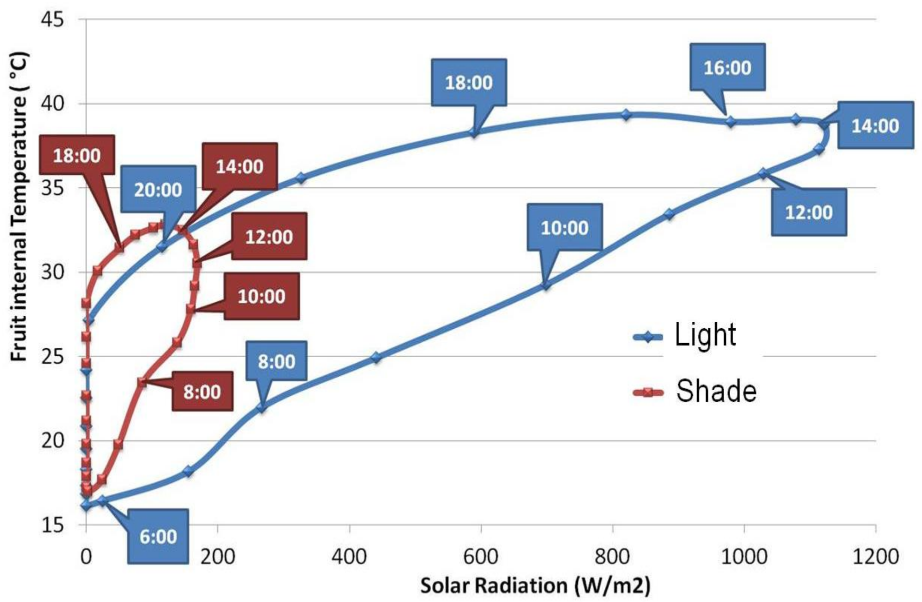


Figure 6: Fruit Internal Temperature (°C) at different Solar Radiation values (W/m^2) during each hour (reported in the boxes) of a sunny day for a sunlit (blue) and shaded fruit (red).

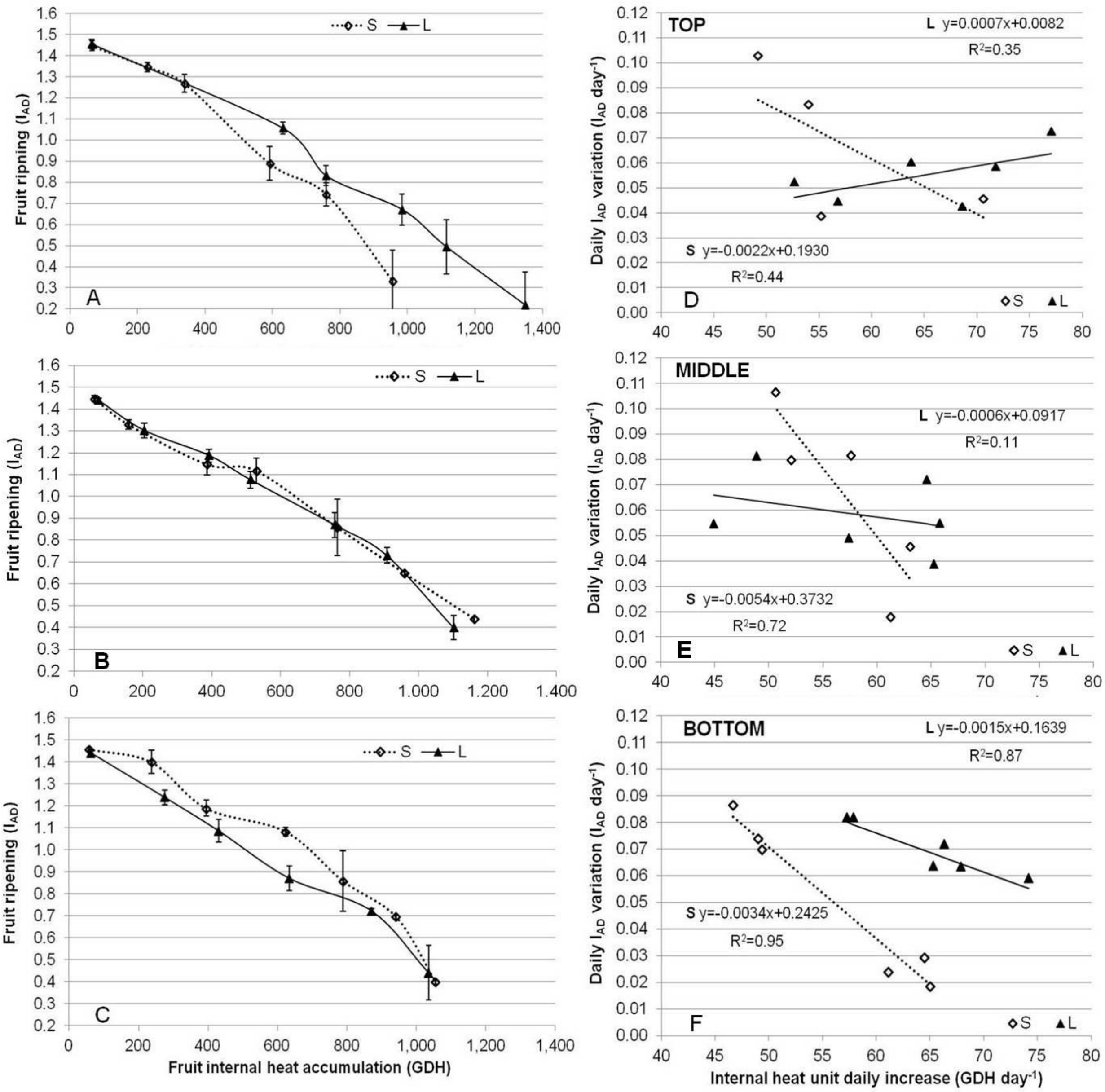


Figure 7 (A B C D E F): Fruit internal heat accumulation at different ripening stages (I_{AD}) (A-B-C) and variation of the GDH accumulation rate at different I_{AD} decrease rates (D-E-F) of "sunlit" (L) and "shaded" (S) fruits in the top (T), middle (M) and bottom (B) layers of the tree. In figures A-B-C, bars represent the standard error. In the D, E and F graphs were reported equations and coefficient of determination (R^2) of the regression lines for the S and L fruit.

6.9 Tables

Table 1: Flesh firmness (FF, kg/cm²) and soluble solid content (SSC, °Brix) of fruits of cv 'Royal Glory' at different maturity classes (I_{AD} classes 0.6-0.8, 0.8-1.0 and 1.0-1.2) in the three layers of the tree canopy (B-bottom, M-middle and T-top).

Quality trait	I_{AD} class	Maturity class	Bottom	Middle	Top
FF (kg/cm²)	0.4-0.8	PM[z]	3.8 a[y] B[w]	4.5 a AB	3.6 a B
	0.8-1.0	CM	4.8 ab AB	4.3 b B	5.0 a A
	1.0-1.2	I	5.4 a A	5.0 a A	5.6 a A
SSC (°Brix)	0.4-0.8	PM	9.98 a B	10.90 a A	9.98 a A
	0.8-1.0	CM	10.07 a A	9.90 a B	10.07 a A
	1.0-1.2	I	10.59 a A	10.54 a A	10.59 a A

[z]= Fruit maturity stages: physiological maturity (PM), commercial maturity (CM) and immature (I).

[y]= Small letters represent significant differences between canopy layers within the same I_{AD} class at $p<0.05$.

[w]= Capital letters represent significant differences between I_{AD} values within the same canopy layer at $p<0.05$.

6.0 Correlation of the I_{AD} with shelf life and consumer preference for peach fruit at different maturity stages

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6.1 Abstarct

In the last decade, peaches and nectarines encountered recurrent problems on the market, with a consumption decrease of the 17% in Italy, due to consumer's dissatisfaction in term of eating quality of the product. Grower tendency to pick unripen fruit and high level of fruit maturity heterogeneity at harvest did not allow for sufficient and uniform ripening of the fruit at the time of consumption. The present work evaluated and confirmed the consistency and specificity of the new non-destructive ripening Index of Absorbance Difference (I_{AD}) during shelf-life and its correlation with consumer preference on three white and three yellow fleshed peach varieties over two years. No relationship was observed between the I_{AD} and the traditional quality traits such as flesh firmness (FF) and soluble solid content (SSC). Good correlation was instead found between I_{AD} and consumer preference. Categorizing fruit on the basis of their ripening stage by using the I_{AD} value at harvest allows to sort peach fruit for their shelf life potential and consumer preference and consequently, to better satisfy market needs.

Keywords: I_{AD}, *Prunus persica*, post-harvest, quality, heterogeneity, maturity.

7.2 Introduction

In the last decade, peaches and nectarines encountered recurrent problems on several markets (Mora et al., 2008) with per capita consumption remaining the same or even decreasing in the USA (Anon., 2004) and some European countries (Liverani et al., 2002, Hilaire and Mathieu, 2004). Between 2000 and 2005, peach and nectarine consumption decreased of the 17% in Italy, as reported by Predieri et al. (2008). A major cause of this decrease in consumption is identified with the "poor match" between fruit quality and consumer's expectations (Mora et al., 2008). As described by Kader (1999), consumer judges quality firstly on the basis of appearance and initial firmness, while subsequent purchases depend upon the consumer's satisfaction in term of eating quality of the product. As known, in peach and nectarines, being climacteric, the ripening process and changes in the chemical composition and physical characteristics of the fruit, both controlled by the production of ethylene (Grierson, 1987), are responsible for the main quality trait such as colour, odour, flavour and texture which define consumer acceptance (Biale and Young, 1981; Leshem et al., 1986). In the case of peaches and nectarines, consumers often complain about the lack of flavor and textural characteristics, such as mealiness and crunchiness, associated with ripening (Bruhn et al., 1991; Crisosto, 2002; Crisosto et al., 2006) As described by Harker (2001) for apple fruit, Consumers can remember previous taste experiences, comparing the fruit they are eating with this specific memory, therefore bad buying experiences, induces consumer to change cultivar, switch to other types of fruit or stop buying for a while, reducing its fidelity to the product, as described by Harker (2001) for apple fruit. Growers and packers, therefore, can have a direct influence on demand by growing, harvesting, and storing apples in ways that optimize eating quality.

Poor quality of peaches and nectarines present in the market is often due to unripe fruit at harvest (Bonghi et al., 1999). In fact, fruit destined to distant markets are usually harvested still unripe, due to their high flesh firmness ability to withstand manipulation during packaging and transport. Recently, however, also peach and nectarines harvested for local markets were picked at unripe stages. This is due to the increased presence of new licensed varieties that develop a full blush color and reach good sizes when still unripe confusing growers on the correct harvesting time (Iglesias and Echeverria, 2009). An anticipated harvest would not permit the normal fruit ripening and the development of the typical quality characteristics on the tree (Lavilla et al., 2002; Infante, 2012). Besides uncorrected harvests, another cause for the drop in sales are product losses (more than the 50% at the retail market, Noferini personal communication, 2012) due to the ripening heterogeneity of fruit batches. Multiple harvests are usually performed during the course of ten to fourteen days trying to reduce the wide variability in peach and nectarine fruit maturity on the tree (Lurie et al., 2013), but with scarce results, mainly due to the subjectivity of the common harvesting index, based on grower experience. Moreover, breeders introduces several new varieties on the marketplace every year, increasing the confusion of the final consumer, that does not recognize the same product over time. This leads to a consumer increasing disaffection.

The parameters generally used to determine the correct harvesting time are fruit size and peel background color variation from green to yellow (Eccher Zerbini et al., 1994; Kader, 1999). In addition, firmness and soluble solids content may be added as additional determinants, but they are destructive measurements (Kader, 1999). Another destructive variable recently introduced is the SSC/TA ratio which supposedly correlates with consumer acceptance (Crisosto and Crisosto., 2005). 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. Among these new non-destructive approaches, visible/near infrared (vis/NIR) spectroscopy seems particularly promising since it provides fast and reliable information on internal characteristics of many fruit species, including stone fruit (Vanoli and Buccheri, 2012). In particular, the non-destructive Index of Absorbance Difference (I_{AD}) corresponds precisely with peach and nectarine fruit maturity stage (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 flesh chlorophyll-α content and to ethylene production during fruit ripening (Ziosi et al., 2008). The relationship between ethylene production and peach maturity stage (as I_{AD}) is cultivar specific, as reported for yellow fleshed peaches and nectarines by Ziosi et al. (2008). No much is known about the use of the I_{AD} as field ripening index. Nevertheless, from preliminary results emerged that the I_{AD} allowed to objectively define peaches and nectarines maturity stage during fruit development *in planta*, up to harvest. A few more information were available on the use of the I_{AD} as ripening index for harvested stone fruit. As described by Lurie et al. (2013), during the post-harvest of two white fleshed varieties, I_{AD} decay and fruit softening appeared synchronized processes and their respective biological shift factors can be mutually exchanged by a linear relation. Measuring I_{AD} at harvest, it can be used to predict softening of peaches and therefore designate fruits for different marketing strategies.

The present work has the aim to confirm the specificity and the consistency of the I_{AD} as peach ripening index, as well as its ability to categorize fruit in postharvest on the basis of their maturity stage in correlation with consumer preference. Experiments were performed on three white and three yellow fleshed peach varieties assessing the ripening evolution (I_{AD} values) during shelf life in comparison with the main traditional quality traits. The relationship between fruit ripening at consumption (as I_{AD}) and consumer preference was also investigated.

7.3 Materials and Methods

The experiment was carried out during 2011 and 2012 growing seasons, on three yellow fleshed peach varieties, and, only during year 2012, on three white fleshed peach varieties, as described in Table 1. Per each variety and year, a sample of one hundred random fruit was collected from the pick corresponding to a minimum of 20% fruit harvested in commercial orchards. Only for the variety Royal Majestic® the sample of one hundred fruit at harvest was collected also in 2010. The ripening stage of each fruit from each variety in the experiment was measured with the DA-meter (TR Turoni, Forlì, Italy) and expressed as I_{AD} (Ziosi et al., 2008). As described by Ziosi et al. (2008), ethylene production of five to ten fruit per I_{AD} value 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). Fruit were sorted into three groups representing physiological maturity (PM), that corresponded to full climacteric, commercial maturity (CM), at the onset of climacteric and immature (I), before the climacteric, according with the cultivar specific correlation between fruit ripening stage (I_{AD}) and ethylene production (Ziosi et al., 2008). To assess the repeatability of the relationship between ethylene production and maturity stage (I_{AD}) over years, fruit ripening distribution between I_{AD}

values and ethylene production were assessed in 2010, 2011 and 2012, for the variety Royal Majestic®.

Considering the pre-climacteric maturity stage (I) as correspondent to a not sufficient ethylene production to guarantee the development of the minimum quality traits for consumption, this class was excluded from the traditional quality traits assessment and from the consumer test. On a sample of twenty fruit of the PM and CM ripening groups, per each variety at harvest, the standard quality traits were assessed. Flesh firmness (FF) was measured on the two opposite sides of each fruit, after eliminating a thin layer of the epicarp, using an automatic pressure tester (FTA-GUSS, South Africa) fitted with an 8 mm plunger. Part of the mesocarp was squeezed and the soluble solid content (SSC) was determined with an Atago digital refractometer (Optolab, Modena, Italy).

A sample of forty-five more fruit from the PM and CM ripening groups, per each variety, were selected at harvest and transferred in a growth chamber at 20°C for three days (as described by Tijskens et al., 2007 and Lurie et al., 2013), to simulate the shelf life of fruits in retail market conditions. After three days,, I_{AD} and standard quality traits were assessed on twenty fruit per ripening class, , as described above.

A sensory analysis, as consumer test, was performed after three days of shelf life (S3), on a sample of twenty-five fruit of the PM and CM ripening groups, per each yellow fleshed variety, to obtain data about which maturity stage consumer preferred (comparative test) (Carpenter et al., 2000). The consumer test was organized by COOP Italia, the largest supermarket chain in Italy, on a number between forty and fifty (called “mini-consumer”) of untrained personnel recruited directly at the supermarkets (Iso 8586/1 – Iso 8586/2 – Guideline n. 37 CCFRA).

Each consumer expressed an overall degree of liking, by evaluating color, texture, sweetness, taste of the fruit, and the likelihood of repurchasing (Carpenter et al., 2000). The overall degree of liking judgment was performed in a scale from 1 to 5. A score of 1 corresponded to “I do not like it at all”, a score of 2.5 corresponded to “It is indifferent”, while a score of 5 corresponded to “I like it very much”. The consumer expressed his likelihood of repurchasing as “Yes” or “No” and the result was reported as percentage of consumer that select the option.

Data collected were statistically evaluated using the software STATISTICA 7 (StatSoft. Inc., Tulsa, USA) and the Duncan’s multiple range t-test at $p < 0.05$. The comparison between groups was performed with the Fisher’s LSD test, that considered a minimum significant difference of 0.05.

7.4 Results

Fruit ripening distribution between I_{AD} classes for the variety 'Royal Majestic®', did not present significant differences between years (Figure 1) showing classical "bell curves". Only in 2012 the percentage of ripen fruit seemed higher than the other two seasons. Figure 1 shows that in 2012 a high percentage of fruit (≈ 70%) had I_{AD} values between 0.5 and 0.7, while in 2010 and 2011 between 50% and 60% of the fruit had I_{AD} values between 0.6 and 0.8. Similar behavior was observed in Figure 2, in which fruit were grouped in the three classes [physiological maturity (PM), commercial maturity (CM) and immature (I)] depending on their maturity stage, on the basis of their ethylene production. The higher fruit concentration was found in the CM class in 2010 and 2011 seasons and in the PM class in the 2012 season. Fruit of the PM class showed the highest ethylene production during the three years (Figure 2). Significant differences were also observed between the CM and I classes, especially in 2012 (Figure 2). Considering the ethylene production of fruit within the same maturity class, no significant differences were observed between the three years (Figure 2), table 2 shows fruit ethylene production per each maturity class for the 2012 season for the six varieties under study. The highest emissions were observed at the lowest I_{AD} values, while the lowest ethylene productions were observed at the higher I_{AD} values. The level of ethylene production was cultivar dependent. Yellow fleshed cultivars produced higher levels of ethylene than white fleshed cultivars (Table 2).

Comparing year 2011 and 2012, no differences were found in the I_{AD} values at harvest (H) for the three yellow fleshed varieties in each maturity class (PM and CM) (Table 3). Similar results were also observed after three days of shelf life (S3) (Table 3). Both at harvest and after three days of shelf life, the CM class showed a significantly higher I_{AD} than the PM class. The same behavior was observed in the two years 2011 and 2012. The early- and mid-season ripening yellow fleshed varieties continued to ripen during the three days of shelf life showing an I_{AD} decrease around 0.2 in both years and both maturity classes (Table 3). The late-season ripening variety 'Kaweah®' showed a higher I_{AD} decrease, around 0.3 both years, for the CM class (Table 3). No significant differences were observed in firmness between the two growing season at harvest with few exceptions, which disappeared during shelf life (Table 3). There was a generalized decrease in flesh firmness (3.0-4.0 kg/cm^2), independently of ripening class or year, after three days of shelf-life (Table 3). No differences in flesh firmness were measured between the maturity classes (PM and CM) in fruit of the early variety 'Royal Majestic®' (Table 3). For the other two varieties, fruit from the more mature class PM, than fruit from the CM class. Similar behavior was observed in both 2011 and 2012 growing seasons (Table 3)

Comparing the two growing seasons, fruit of the early-season ripening variety 'Royal Majestic®' did not show any difference in term of soluble solid content (SSC) independently of the maturity stage (Table 3). Fruit of the mid-season variety 'Diamond Princess' showed significantly higher soluble solid content in 2011 than in 2012 while the opposite was observed for the late-season variety 'Kaweah®' (Table 3). Similar behavior was observed both at harvest and after three days of shelf-life.

Slight differences in SSC were observed between maturity classes in fruit of the early- and mid-season varieties depending on the growing season, with fruit from the PM and CM maturity classes not showing significant differences in 2011, while riper fruit from the PM class showed 0.5-1.0 °Brix higher than the less mature fruit (CM class) in 2012 (table 3). PM fruit of the late-season variety 'Kaweah®' measured a higher SSC than CM fruit, both in 2011 and 2012 (Table 3). No differences were measured in SSC in fruit of the cv 'Diamond Princess' and 'Kaweah®', while for the variety 'Royal Majestic®' greater SSC were measured after three days of shelf-life (Table 3).

Regarding the white fleshed varieties, as shown in Table 4, significant differences were observed between the I_{AD} of the maturity classes (PM, and CM), both at harvest and three days after (S3). Shelf-life caused a generalised I_{AD} value decrease of around 0.1-0.2.

Early- and late-season ripening white fleshed varieties 'Patty®' and 'Kevina®' did not show any difference in term of flesh firmness at harvest between fruit of the PM and CM maturity classes, while lower FF values were observed in riper fruits (PM) after three days of shelf life (S3), as showed in Table 4. Conversely, on fruit from different maturity classes of the mid-season cultivar 'Maurà®', it was observed an opposite behavior with more mature fruit (PM) being softer at harvest, while no significant differences were observed between the two maturity classes after shelf-life (Table 4). Fruit at each ripening stage of every white fleshed variety, were softer at S3, compared with the FF at harvest (Table 4). In any case, shelf-life caused a generalized decrease in flesh firmness between 2.4 and 3.7 kg/cm^2 (Table 4).

No significant differences were observed in soluble solid content between maturity classes, both at harvest and after shelf-life (Table 4). Only the early-season variety 'Patty®', showed a significant increase in SSC after three days of shelf life in both maturity classes (Table 4).

As reported in Table 5, the overall degree of liking and the likelihood of return buying from the participants to the panel test was greater for the more mature fruit (PM class) of the mid- and late-season varieties 'Diamond Princess' and 'Kaweah®', while no significant differences were perceived

7.5 Discussion

Fruit distribution between maturity values (I_{AD}) showed similar trends in the three years under evaluation for the variety 'Royal Majestic®' with a slight shift towards lower I_{AD} values (more mature fruit) in year 2012 (Figure 1). This slight maturity difference was probably due to both a later full bloom registered in spring 2012 and the exceptional and prolonged high temperatures and intense light conditions observed during summer, which maintained trees under water and temperature stress, influencing the timing of fruit maturity (Marini et al., 1991; Stefanelli, 2012 personal communication).

To reduce this ripening variability, at harvest fruit were grouped in three maturity classes according to their I_{AD} values on the basis of their ethylene production, as suggested by Ziosi et al. (2008), resulting in no measurable differences in ethylene production between the years (Figure 2 and Table 2). These results are also in accord with Ziosi et al. (2008) that reported the repeatability over years of the relationship between maturity stage (as I_{AD}) and ethylene production for peaches and nectarines prunes (Infante et al., 2011a), and Japanese plums (Infante et al., 2011b). The variety specificity of the relationship between ethylene production and maturity stage described from the previously mentioned authors was confirmed from our results shown in Table 2. It was also confirmed the consistency of the I_{AD} in sorting harvested fruit on the basis of their maturity stage, its ability to measure objectively the heterogeneity of fruit batches and the variety specific ripening evolution. Objectiveness, consistency and specificity appeared as innovative characteristics for a ripening index, that might lead to a standardization of fruit harvesting and reduction of ripening variability, also throughout the creation of specific protocols useful in the different stages of the production chain, as suggested by Nyasordzy et al. (2013) for apple fruit.I_{AD} variety specificity is also found in post-harvest, as reported in Lurie et al. (2013) on two white fleshed peach and nectarine cultivars and by Reig et al. (2012) on several yellow fleshed nectarine varieties. These authors observed that the I_{AD} decrease after harvest is cultivar dependent. Our results also confirmed that the I_{AD} could be efficient also in following peach fruit post-harvest ripening evolution since the fruit from all the maturity classes and varieties under evaluation resulted more mature after shelf-life (lower I_{AD}) (Table 3 and 4). The I_{AD} ability to identify variety differences in post-harvest was also demonstrated by discriminating between the yellow and white fleshed peach cultivars, which showed variable decrease of the I_{AD} value after three days of shelf life at the same temperature conditions (Table 3 and 4).

Our results showed that all tested fruit were softer after three days of shelf life than at harvest and that fruit from the more mature class (PM) were softer than fruit of the less mature class (CM), at harvest and after three days of shelf life, both for yellow and white fleshed varieties (Table 3 and 4).

Reig et al. (2012) also found that detached nectarine fruit shows a quick rise in the ethylene production after harvest and as a consequence, during shelf-life fruit with similar I_{AD} could exhibit different ethylene emission levels and quality parameters, because metabolic processes occurring during on- and off-tree ripening profoundly differ. Studying the shelf life of two white fleshed peach varieties, Lurie et al. (2013) observed that the degreening of fruit skin (measured with the I_{AD}) and fruit softening are two synchronized processes, and concluded that the I_{AD} at harvest can be used to predict softening depending on the variety. The same authors found an inverse relationship between the earliness of the cultivar ripening season and the softening rate after harvest. Our results confirmed this trend, in fact the early- and mid-season varieties 'Patty®' and 'Maurà®' showed a slightly greater decrease in term of flesh firmness (around 3.7), than the late variety 'Kevina®' (around 3.0) after three days of shelf life (Table 4). A probable reason of the observed variability in term of flesh firmness could be that several pre-harvest factors, such as fruit position within the canopy, microclimate conditions, water content, mineral nutrient balance, stress conditions, etc., may affect this quality trait (Lewallen and Marini, 2003). Nevertheless, from our results flesh firmness did not appear a consistent index of fruit ripening, mainly because it is strongly affected by pre-harvest factors, and no clear relationships with the I_{AD} emerged. More in depth studies on the correlations between peach ripening, ethylene emission and flesh softening during shelf life are probably necessary.

In addition to flesh firmness, fruit soluble solid content is another trait traditionally considered in defining peach quality at harvest and for consumption. In our investigation fruit of the early-season ripening yellow and white fleshed varieties, after three days of shelf life (S3) showed a significantly increase in soluble solid content (SSC) independently of the maturity stage (Table 3 and 4). Our results were similar to those of Gupta and Jawandha (2010) and Prashant and Masoodi (2009), that found a progressive increase in reducing sugar content during the earliest period of storage of fruit picked at pre-optimum and optimum stage of maturity. This behavior was explained for the reason that in the first days after harvest, the starch hydrolysis is higher than the utilization of sugars for fruit respiration, as suggested by Gupta and Jawandha (2010). Also Pérez-Marin et al., (2009) observed that on peach fruit soluble solid content increased continuously during postharvest storage, while Ziosi et al. (2008) did not observed any change in the SSC of each ripening class of the peach and nectarine varieties tested.

The mid- and late-season ripening varieties tested in the present work did not show any variation in SSC content during shelf life. No relationship of the soluble solid content with the initial fruit ripening stage were anyway observed, probably because, SSC in peaches is strongly related to the variety genetic characteristics, as suggested by Kader (1999). Crisosto et al. (2003) also stated that environmental conditions, such as temperature, might affect the fruit SSC content, which could explains why fruit of the mid-season variety ‘Diamond Princess’ showed a significantly higher soluble solid content in 2011 than in 2012. In fact, the prolonged and elevated temperature that characterized late spring and summer of year 2012 could have reduced fruit soluble solid content, by acting on the carbohydrate breakdown to maintain the high fruit respiration rates (Génard and Souty, 1996).

From our results, it emerged that the traditional quality parameters frequently used (FF and SSC) do not provide a sufficient description of peach and nectarine maturity stages at harvest and post-harvest behavior, in accord with several authors (Carbò and Iglesias, 2002 ; Lewallen and Marini, 2003; Crisosto et al., 1995). In fact, consumer complaints about stone fruit are often due to their inability to understand the differences between unripe and ripe (“ready to eat”) fruit (Crisosto, 2006). Nevertheless, several researchers in the past studied these quality parameters trying to found a relationship between their variability and consumer acceptance. Delgado (1998) suggested a minimum SSC of 10-12° Brix and balanced soluble solid content/titratable acidity (SSC/TA) ratio to obtain an acceptable flavor of peach and nectarine fruit at consumption. Successively Crisosto et al. (2003), also in peach, found that consumer acceptance increases with SSC only when the SSC/TA ratio is low, while Predieri et al., (2006) found a low or no significant correlation between SSC and consumer liking for peach fruit. After sorting fruit with the DA-meter, our results showed a relationship between the ripening class (I_{AD}) at harvest and the consumer acceptance after three days of shelf life (Table 5). As observed in Figure 5,more mature peach (PM class) of the yellow varieties tested, showed a significantly greater overall degree of liking and likelihood to return buying than less mature fruit (CM class). The only exception was observed for fruit of the early-season variety Royal Majestic®, were no differences were reported, probably because of the variety characteristics. In fact, as described by Iglesias and Echeverria (2009), peach breeding in the last decades, especially for early-season ripening varieties, focused on fruit developing full, intense red color at an early stage of maturity, which are very attractive, but are characterized by a lack of adequate quality characteristics leading to low consumer acceptance. This was reflected in Table 3 by the lack of differences in firmness and soluble solids content in the variety ‘Royal Majestic®’, which probably contributed to flatten the taste differences between the two maturity classes under evaluation.

In addition to give the state of ripeness of peach and nectarine fruits and be able to reduce variability by sorting fruit into homogeneous groups, the I_{AD} can also be used to assess the maturity stage of stored fruit, and to give information about the shelf-life that can be expected. Moreover, fruit grouped on the basis of their I_{AD} at harvest differently correlates with the final consumer judge.

This might lead to cultivation, harvesting or post-harvest innovative strategies, based on the maturity I_{AD}, for reducing peach and nectarine heterogeneity in order to uniform fruit that reach the final consumer and maintain a constant quality in the product at the retail market, even over years. This might lead to an increased consumer satisfaction and fidelity to the stone fruit product.

Moreover, the possibility to sort fruit on the basis of their ripening characteristics, might allows designate fruits for different marketing strategies in accord with consumer needs.

More studies are probably needed to confirm the possibility to predict peach and nectarine fruit post-harvest life and consumer acceptance, based on their ripening stage at harvest (as I_{AD}).

7.6 Conclusions

Our results confirmed the cultivar-specific relationship between ethylene emission and fruit maturity stage (I_{AD} classes) and its reliability over years, as well as the consistency of the I_{AD} in sorting fruit on the basis of their maturity class. Fruit of each variety and I_{AD} class at harvest, followed a specific ripening trend during post-harvest, without clear relationship with the traditional quality traits (flesh firmness and soluble solid content).

Yellow fleshed peach fruit of each ripening class showed a different impact on the consumer overall degree of liking and likelihood of return buying, that was always greater for mature fruit, with low I_{AD} values.

From our work, it emerged that the ripening Index of Absorbance Difference at harvest allows to sort peach fruit on the basis of their maturity stage, shelf life potential and consumer preferences and consequently, to precisely satisfy market needs.

7.7 Literature Cited

Anon, B. 2004. Fruit and Tree Nuts: Situation and Outlook Yearbook, TFS- 271. United States Department of Agriculture, Economic Research Service.

Biale J.B. and Young R.E., 1981. Respiration and ripening in fruits retrospect and prospect. In: Friend, J., Rhodes, M.J.C. (Eds.), Recent Advances in the Biochemistry of Fruit and Vegetables. Academic Press, London. Pp. 1-39.

Bonghi C., Ramina A., Ruperti B., Vidrih R. and Tonutti P., 1999. Peach fruit ripening and quality in relation to picking time, and hypoxic and high CO_2 short-term postharvest treatments. *Postharvest Biology and Technology*. **16**(3): 213-222.

Bregoli A.M., Scaramagli S., Costa G., Sabatini E., Ziosi V., Biondi S. and Torrigiani P., 2002. Peach (*Prunus persica* L.) fruit ripening: amino-ethoxyvinylglycine (AVG) and exogenous polyamines affect ethylene production and flesh firmness. *Physiologia Plantarum.* **114**: 472-481.

Bruhn C.M., Feldman N., Garlitz C., Hardwood J., Ivan E., Marshall M., Riley A., Thurber D. and Williamson E., 1991. Consumer perceptions of quality: Apricots, cantaloupes, peaches, pears, strawberries, and tomatoes. *Journal of Food Quality.* 14: 187-195.

Carbo´ J. and Iglesias I., 2002. Melocotonero: las variedades de mas interes. Ed.: Institut de Recerca y Tecologia Agroalimentaries, Barcelona. P. 285.

Carpenter R.P., Lyon D.H. and Hasdell T.A., 2000. Guidelines for sensory analysis in food product development and quality control.

Crisosto C.H., 2002. How do we increase peach consumption? *Acta Horticulturae.* 592: 601-605.

Crisosto C. H. and Crisosto G. M., 2005. Relationship between ripe soluble solids concentration (RSSC) and consumer acceptance of high and low acid melting flesh peach and nectarine (*Prunus persica* (L.) Batsch) cultivars. *Postharvest Biology and Technology*. **38**(3): 239-246.

Crisosto C. H., Crisosto G. M., Echeverria G. and Puy, J., 2006. Segregation of peach and nectarine (*Prunus persica* (L.) Batsch) cultivars according to their organoleptic characteristics. *Postharvest Biology and Technology*. **39**(1): 10-18.

Crisosto C.H., Crisosto G. and Bowerman E., 2003. Searching for consumer satisfaction: new trends in the California peach industry. In: Marra, F., Sottile, F. (Eds.), Proceedings of the First Mediterranean Peach Symposium. Agrigento, Italy, 10 September. Pp. 113-118

Crisosto C.H., Mitchell F.G. and Johnson S., 1995. Factors in fresh market stone fruit quality. *Postharvest News and Information.* **6**(2): 17-21.

Delgado M., 1998. Plus de sucres pour les douces. *L'Arboriculture Fruitière*. 519: 21-23.

Eccher Zerbini P., Spada G.L. and Liverani C., 1994. Selection and experimental use of colour charts as a maturity index for harvesting peaches and nectarines. *Advances in Horticultural Science.* 8: 107-113.

Grierson D., 1987. Senescence in fruits. *HortScience*. 22: 859-862.

Gupta N. and Jawandha S. K., 2010. Influence of maturity stage on fruit quality during storage of 'Earli Grande' peaches. *Notulae Scientia Biologicae.* **2**(3): 96-99.

Harker R., 2001. Consumer response to apples. Washington tree fruit postharvest conference, March 13th and 14th, Wenatchee, WA. Pp: 1-7.

Hilaire, C. and Mathieu, V., 2004. Le Point sur la qualite gustative des peches et nectarines. Infos-Ctifl 201: 27-31.

Iglesias I. and Echeverría G., 2009. Differential effect of cultivar and harvest date on nectarine colour, quality and consumer acceptance. *Scientia Horticulturae*. **120**(1): 41-50.

Infante R., 2012. Harvest maturity indicators in the stone fruit industry. Stewart *Postharvest Review*. (June): 1-6.

Infante R., Contador L., Rubio P., Mesa K. and Meneses C., 2011a. Non-destructive monitoring of flesh softening in the black-skinned Japanese plums "Angeleno" and "Autumn beaut" on-tree and postharvest. *Postharvest Biology and Technology*. **61**(1): 35-40.

Infante R., Rubio P., Contador L., Noferini M. and Costa G., 2011b. Determination of harvest maturity of D 'Agen plums using the chlorophyll absorbance index. 38: 199-203.

Kader, A.A., 1999. Fruit maturity, ripening, and quality relationships. *Acta Horticulturae*. 485: 203-208.

Lavilla T., Recasens I., Lopez M. and Puy J., 2002. Multivariate analysis of maturity stages, including quality and aroma, in 'Royal Glory' peaches and 'Big Top' nectarines. *Journal of the Science of Food and Agriculture.* **82**(15): 1842-1849.

Leshem Y.Y., Halevy A.H. and Frenkel C., 1986. Fruit Ripening. Processes and Control of Plant Senescence. Amsterdam: Elsevier Science Publishers. Pp. 162-210.

Lewallen K. S. and Marini R. P., 2003. Relationship between flesh firmness and ground color in peach as influenced by light and canopy position. *Journal of the American Society for Horticultural Science*. 128: 163-170.

Liverani, A., Giovannini, D. and Brandi,F., 2002. Increasing fruit quality of peaches and nectarines: the main goals of ISF-FO (Italy). *Acta Horticulturae.* 592: 507-514.

Lurie S., Friedman H., Weksler A., Dagar A. and Eccher P., 2013. Maturity assessment at harvest and prediction of softening in an early and late season melting peach. *Postharvest Biology and Technology*. 76: 10-16.

Marini R. P., Sowers D. and Marini M. C., 1991. Peach Fruit quality is affected by shade during final swell of fruit growth. **116**(3): 383-389.

Mora M., Echeverría G., Predieri S. and Infante R., 2008. Results of a consumer survey conducted in Chile-Italy and Spain on market potential of peach and nectarines. Proceedings of the VI Convegno Nazionale sulla Peschicoltura Meridionale. Caserta, Italy, 6-7 marzo. Pp: 336-339.

Nyasordzi J., Friedman H., Schmilovitch Z., Ignat T., Weksler A., Rot I. and Lurie, S., 2013. Utilizing the I_{AD} index to determine internal quality attributes of apples at harvest and after storage. *Postharvest Biology and Technology*. 77: 80-86.

Pérez-Marín D., Sánchez M., Paz P., Soriano M., Guerrero J. and Garrido-Varo A., 2009. Non-destructive determination of quality parameters in nectarines dur- ing on-tree ripening and postharvest storage. *Postharvest Biology and Technology.* 52: 180-188.

Prashant B. and F. A. Masoodi, 2009. Effect of various storage conditions on chemical characteristics and processing of peach cv. 'Flordasun'. *Journal of Food Science and Technolology.* 46: 271-274.

Predieri S., Liverani A., Gatti E., and Versari N., 2008. Italian consumer preferences according to peach fruit organoleptic characteristics. Proceedings of the VI Convegno Nazionale sulla Peschicoltura Meridionale. Caserta, Italy, 6-7 marzo. Pp: 318-323.

Predieri S., Ragazzini P. and Rondelli R., 2006. Sensory evaluation of peach fruit quality. *Acta Horticolturae.* 713: 322-327.

Reig G., Alegre S., Iglesias I., Echeverría G. and Roure A. R., 2012. Fruit quality, colour development and Index of Absorbance Difference (I_{AD}) of different nectarine cultivars at different harvest hates. Proceedings of the XXVIIIth IHC-ISHS on Postharvest Technology *Acta Horticolturae*. 934: 1117-1126.

Tijskens L.M.M., Eccher Zerbini P., Schouten R.E., Vanoli M., Jacob S., Grassi M., Cubeddu R., Spinelli L. and Torricelli A., 2007. Assessing harvest maturity in nectarines. *Postharvest Biology and Technology*. 45: 204-213.

Vanoli M. and Buccheri M., 2012. Overview of the methods for assessing harvest maturity. *Stewart Postharvest Review*. **8**(1): 1-11.

Ziosi V., Noferini M., Fiori G., Tadiello A., Trainotti L., Casadoro G. and Costa G., 2008. A new index based on vis-spectroscopy to characterize the progression of ripening in peach fruit. *Postharvest Biology and Technology*. **49**(3): 319-329.

7.8 Figures

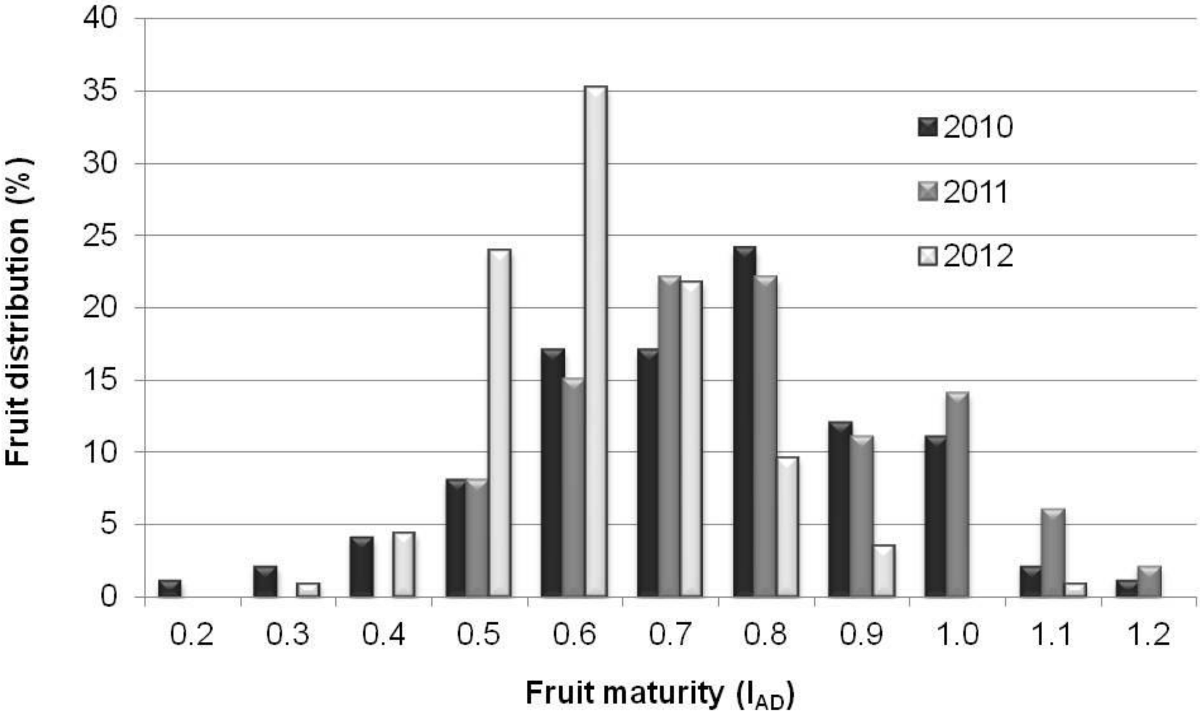

Figure 1: Fruit distribution between maturity values (I_{AD}) during year 2010, 2011 and 2012, for the variety Royal Majestic.

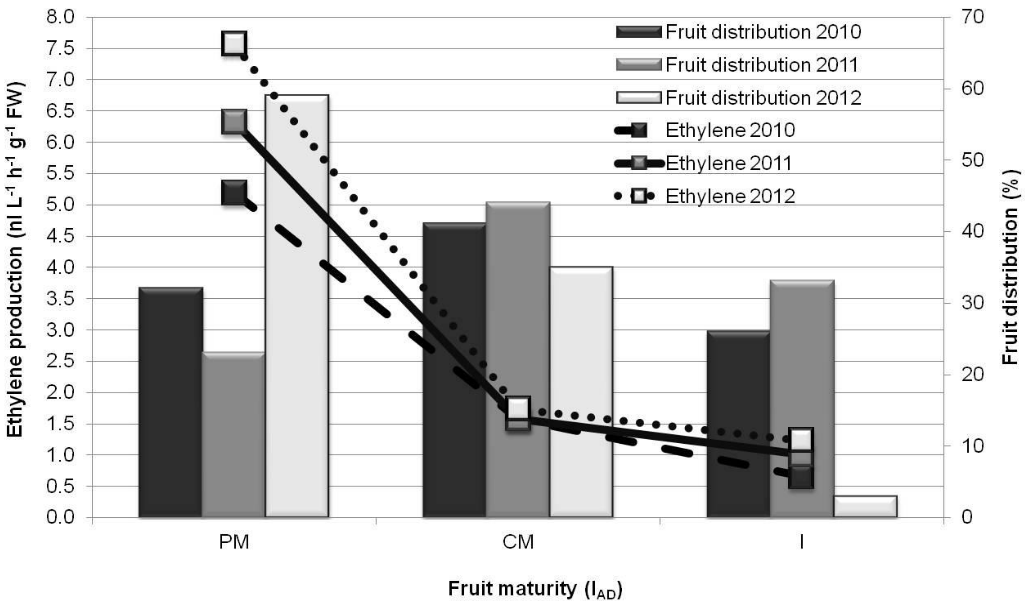

Figure 2: Ethylene production and fruit distribution in the three maturity classes (PM-Physiological Maturity; CM-Commercial Maturity; I-Immature).

7.9 Tables

Table 1: Ripening period of the white and yellow fleshed color varieties.

Flesh color	Variety	Ripening period
white	Patty®	early
	Maurà®	mid-season
	Kevina®	late
yellow	Royal Majestic®	early
	Diamond Princess	mid-season
	Kaweah®	late

Table 2: Ethylene production per maturity class and corresponding I_{AD} class, per each white and yellow fleshed variety, in year 2012.

Fruit flesh color	Variety	Fruit maturity class	I_{AD} class	Ethylene production ($nl\ L^{-1}\ h^{-1}\ g^{-1}$ FW)	
white	Patty®	PM[z]	0.3-0.5	1.55	a[y]
		CM	0.5-0.8	0.28	b
		I	0.8-1.0	0.09	c
	Maurà®	PM	0.0-0.2	1.72	a
		CM	0.2-0.6	0.36	b
		I	0.6-0.8	0.14	c
	Kevina®	PM	0.4-0.8	0.71	a
		CM	0.8-1.0	0.47	b
		I	1.0-1.2	0.30	c
yellow	Royal Majestic®	PM	0.4-0.6	7.57	a
		CM	0.6-0.8	1.74	b
		I	0.8-1.0	1.23	c
	Diamond Princess	PM	0.0-0.4	5.03	a
		CM	0.4-0.9	1.91	b
		I	0.9-1.2	0.66	c
	Kaweah®	PM	0.0-0.3	3.13	a
		CM	0.3-0.8	1.32	b
		I	0.8-1.0	0.72	c

[z]= Fruit maturity stages: physiological maturity (PM), commercial maturity (CM) and immature (I)

[y]=Small letters should be read vertically and represent significant differences between maturity class (PM, CM and I) within the same variety at $p<0.05$.

Table 3: Fruit maturity (I_{AD}), flesh firmness (FF), soluble solid content (SSC) at harvest (H) and after three days of shelf-life (S3) for the three yellow fleshed varieties, in year 2011 and 2012.

Variety	Fruit maturity class	I_{AD} class	Year	Fruit ripening (I_{AD})		FF (Kg/cm^2)		SSC (Brix)	
				H	S3	H	S3	H	S3
Royal Majestic®	PM[z]	0.4-0.6	2011	0.52 a[y]***b***[x]A[w]	0.34 a***b***B	3.7 a*a*A	0.5 a*a*B	10.41 a*a*B	11.46 a*a*A
			2012	0.53 a***b***A	0.40 a***b***B	4.0 a*a*A	0.4 a*a*B	10.28 a*a*B	11.19 a*a*A
	CM	0.6-0.8	2011	0.69 a*a*A	0.50 a*a*B	3.9 a*a*A	0.7 a*a*B	10.13 a*a*B	10.77 a*a*A
			2012	0.67 a*a*A	0.43 a*a*B	4.5 a*a*A	0.4 a*a*B	9.97 a***b***B	10.59 a***b***A
Diamond Princess	PM	0.0-0.4	2011	0.32 a***b***A	0.18 a***b***B	4.1 a***b***A	0.6 a***b***B	12.77 a*a*A	12.55 a*a*A
			2012	0.29 a***b***A	0.12 a***b***B	4.0 a*a*A	0.6 a***b***B	12.14 b*a*A	11.96 b*a*A
	CM	0.4-0.9	2011	0.62 a*a*A	0.34 a*a*B	5.9 a*a*A	2.2 a*a*B	12.89 a*a*A	12.79 a*a*A
			2012	0.61 a*a*A	0.28 a*a*B	4.0 b*a*A	1.0 b*a*B	11.63 b***b***A	11.50 b***b***A
Kaweah®	PM	0.0-0.3	2011	0.21 a***b***A	0.05 a***b***B	3.1 b***b***A	0.7 a***b***B	12.96 b*a*A	12.70 b*a*A
			2012	0.19 a***b***A	0.08 a*a*B	4.4 a***b***A	0.5 a***b***B	14.10 a*a*A	13.73 a*a*A
	CM	0.3-0.8	2011	0.50 a*a*A	0.15 a*a*B	6.6 a*a*A	2.8 a*a*B	11.88 b***b***A	11.86 b***b***A
			2012	0.46 a*a*A	0.10 a*a*B	6.4 a*a*A	2.6 a*a*B	13.70 a***b***A	13.15 a***b***B

[z]= Fruit maturity classes: physiological maturity (PM) and commercial maturity (CM).

[y]=Small letters should be read vertically and represent significant differences between years, for fruit of the same matiruty class (PM and CM), within the same variety, at harvest (H) and after three days of shelf-life (S3), at $p<0.05$.

[x]= Cursive, bold small letters should be read vertically and represent significant differences between maturity classes (PM and CM), in the same year, within the same variety, at harvest (H) and after three days of shelf-life (S3), at $p<0.05$.

[w]= Capital letters should be read horizontally and represent significant differences between harvest (H) and after three days of shelf life (S3), for fruit of the same maturity class (PM and CM), variety and year, at $p<0.05$.

Table 4: Fruit ripening (I_{AD}), flesh firmness (FF), soluble solid content (SSC) at harvest (H) and three days after harvest (S3) for the three white fleshed varieties, in year 2012.

Variety	Fruit maturity class	I_{AD} class	Fruit ripening (I_{AD})		FF (kg/cm^2)		SSC (°Brix)	
			H	S3	H	S3	H	S3
Patty®	PM[z]	0.0-0.5	0.44 b[y]A[x]	0.33 aB	4.2 aA	0.5 bB	11.40 aB	12.43 aA
	CM	0.5-0.8	0.64 aA	0.37 aB	4.5 aA	1.1 aB	10.94 aB	12.12 aA
Maurà®	PM	0.0-0.2	0.17 bA	0.13 bA	2.9 bA	0.5 aB	11.51 aA	11.50 aA
	CM	0.2-0.6	0.37 aA	0.22 aB	4.7 aA	1.0 aB	11.45 aA	11.15 aA
Kevina®	PM	0.4-0.8	0.63 cA	0.47 cB	4.9 aA	2.0 cB	12.66 aA	13.00 aA
	CM	0.8-1.0	0.88 bA	0.63 bB	4.9 aA	3.4 bB	12.42 aA	12.90 aA

[z]= Fruit maturity stages: physiological maturity (PM), commercial maturity (CM) and immature (I).

[y]=Small letters represent significant differences between ripening stages (PM and CM), within the same variety, at harvest (H) and three days after harvest (S3), at $p<0.05$.

[x]= Capital letters represent significant differences between harvest (H) and three days after harvest (S3), for fruit of the same ripening stage (PM and CM) and variety, at $p<0.05$.

Table 5: Overall degree of liking and willingness to return buying for each yellow fleshed variety and ripening class. The assessment was performed in year 2012, three days after harvest (S3).

Variety	Fruit maturity class	Overall degree of liking (score 1-5)	Willingness to return buying (% of consumer)	
			Yes	No
Royal Majestic®	PM[z]	3.2	56.5	43.5
	CM	3.1	55.6	44.4
Diamond Princess	PM	4.0	91.8	8.2
	CM	3.3	70.0	30.0
Kaweah®	PM	3.9	58.4	41.6
	CM	3.0	38.4	61.6

[z]= 1 corresponds to "I do not like it at all"; 2.5 corresponds to "It is indifferent"; 5 corresponds to "I like it very much".

[y]= Fruit ripening stages: physiological maturity (PM) and commercial maturity (CM).

[x]= Small letters represent significant differences between fruit ripening stages (PM and CM), within the same willingness to return buying, at $p < 0.05$.

[w]= Capital letters represent significant differences between willingness to return buying (Yes and No) within the same fruit ripening stage, at $p<0.05$.

8.0 General Conclusions

The present work confirmed the importance of a correct management of peach and nectarine ripening, in order to guarantee fruit homogeneity at harvest and the achievement of the minimum quality traits for consumer satisfaction.

As far as the considered relationship between ripening stage and heterogeneity was related to pre-harvest factors (training system, crop load, fruit position, exposure to solar radiation and internal temperature), it has been showed that these factors mainly affected the harvesting window, advancing or delaying it, without influencing ripening trend. In particular, our findings demonstrated that an high crop load caused an extension of the ripening season, delaying the harvest time as compared to standard situation. As far as the training system is concerned, open canopy, such as Tatura trellis or open-vase, reduced the window of the ripening season, inducing an early harvesting, if compared to a palmette training system.

As far as the devices and methods used to perform the different trials, several innovative instruments and methods were used. In particular the tree architectural model (PlantToon®) capable to punctually design the canopy structure was used. The fruit ripening evolution was instead monitored with the DA-Meter, as Index of Absorbance Difference (I_{AD}), while the temperature of the fruit was controlled by thermistors.

It has been pointed out that the combined used of PlantToon® and I_{AD} allowed to precisely describe the tree canopy structure and the exact position of each fruit as well the quality traits and ripening evolution. The different maturity stage reached by the fruit resulted mainly affected by height from the ground and inner or outer position in the canopy.

The combined use of I_{AD} and thermistors instead indicated also that the inner canopy fruit, as those located in the lower part of the canopy which normally are shaded, accumulated less heat, showing a ripening delay, if compared with sunlit fruit of the canopy top. Our findings also confirmed the difficulties in separating the effect of solar radiation from that of internal temperature on fruit maturity, because of the synergic combination of these two factors.

From our work, it also emerged the possibility to easily manage fruit ripening heterogeneity. In fact, the I_{AD} allows to sort fruit into ripening homogeneous classes, that showed a proper shelf life potential.

All these information were used to create a model for forecasting harvesting date, yield and fruit quality characteristics (desired ripening stage, distribution in classes of ripening, etc). The predictive model was validated in the present work and it was able to fulfill the experimental hypothesis. In fact it allows to forecast the harvesting date with an error of ± 3 days and yield with an error of 1-10%. Grower can use this model by collecting simple data from the field (monitoring fruit ripening and growth).

As a final remarks, the innovative devices used in this research allow a precise reconstruction of the tree structure and of the ripening evolution; the collected information allow the creation of a database for a "fruit production programming". This method can be used in field as a "decision support system" to tune up the management cultural operation to reduce the fruit ripening heterogeneity; in packing house, where the I_{AD} can be also used to further group fruit in classes of uniform ripening; it can be also applied during storage, where the use of the I_{AD} allow to follow ripening evolution on detached fruit. The "fruit production programming" is also a potent instrument to track fruit from the "field to the fork" with the final objective to fulfill consumers expectations.

9.0 Literature cited:

Abel S., Theologis A., 1996. Early genes and auxin action. *Plant Physiology*.111: 9-17.

Ahumada O. and Villalobos J. R., 2009. Application of planning models in the agri-food supply chain: A review. *European Journal of Operational Research.* **196**(1): 1-20.

Alexander L. and Grierson D., 2002. Ethylene biosynthesis and action in tomato: a model for climacteric fruit ripening. *Journal of Experimental Botany.* 53: 2039-2055.

Anderson J.L., Richardson E.A. and Kesner C.D., 1986. Validation of chill unit and flower bud phenology models for 'Montmorency' sour cherry. *Acta Horticolturae.* 184: 71–75.

Anon, 2004. Fruit and Tree Nuts: Situation and Outlook Yearbook, TFS- 271. United States Department of Agriculture, Economic Research Service.

Bellini E., Giannelli G., Giordani E. and Sabbatini I., 2004. Miglioramento della qualità e de1 valore commerciale nelle nettarine. *Frutticoltura*. 1: 25-30.

Bertone E., Venturello A., Leardi R. and Geobaldo F., 2012. Prediction of the opti- mum harvest time of 'Scarlet' apples using DR-UV–vis and NIR spectroscopy. *Postharvest Biology and Technology*. 69: 15-23.

Bonghi C., Ramina A., Ruperti B., Vidrih R. and Tonutti P., 1999. Peach fruit ripening and quality in relation to picking time, and hypoxic and high CO_2. *Postharvest Biology and Technology.* 16: 213-222.

Boote, K.J., Jones J.W. and Pickering N.B., 1996. Potential uses and limitations of crop models. *Agronomy Journal.* 88: 704-716.

Bruhn C.M., Feldman N., Garlitz C., Hardwood J., Ivan E., Mar- shall M., Riley A., Thurber D. and Williamson E., 1991. Consumer perceptions of quality: apricots, cantaloupes, peaches, pears, strawberries, and tomatoes. *Journal of Food Quality*. 14: 187-195.

Brummell D.A. and Harpster M.H., 2001. Cell wall metabolism in fruit softening and quality and its manipulation in transgenic plants. *Plant Molecular Biology*. 47: 311-339.

Carbo´ J. and Iglesias I., 2002. Melocotonero: las variedades de mas interes. Ed.: Institut de Recerca y Tecologia Agroalimentaries, Barcelona. P. 285.

Caruso T., Di Vaio C., Guarino F., Motisi A. and Nuzzo V., 2003. Peach varieties for intensive plantations in southern Italy, 44- 51 p. In: Marra FP, Sottile F (Eds.). Proc IV Cong Nazionale sulla Peschicoltura Meridionale. Panuzzo Prontostampa, Caltanisseta, Italy.

Caruso T., De Michele A., Sottile F. and Marra F.P., 1998. La peschicoltura siciliana nel contesto italiano: ambiente, cultivar e tecniche colturali. Proceedings ogf the 2nd Convegno sulla Peschicoltura meridionale. Paestum, 2-3 luglio: 83-88.

Caruso T., Inglese P., Sidari M. and Sottile F., 1997. Rootstock influences seasonal dry matter and carbohydrate content and partitioning in above ground components of ‘Flordaprince’ peach trees. J. Amer. Soc. Hort. Sci. 122:673–679.

Chalmers DJ, Van Den Ende B.and Van Heek L., 1978. Productivity and mechanization of the Tatura trellis orchard. *Horticoltural Sciences*. 13: 517-521.

Cole S. W., 1849. The American Fruit Book, John P. Jewett, New Jork.

Corelli Grappadelli L. and Sansavini S., 1989. Ligth interception and photosynthesis related to planting density and canopy management in apple. *Acta Horticulturae*. 243: 159-174.

Costa G., Noferini M., Fiori G.and Orlandi A., 2003. Non-destructive technique to assess internal fruit quality. *Acta Horticulturae*. 603: 571-575.

Crisosto C.H., Crisosto G.M., Echeverria G. and Puy J. 2006. Segregation of peach and nectarine (*Prunus persica* (L.) Batsch) cultivars according to their organoleptic characteristics. *Postharvest Biology and Technology*. 39: 10-18.

Crisosto C.H. and Crisosto G.M., 2005. Relationship between ripe soluble solids concentration(RSSC)and consumer acceptance of high and low acid melting flesh peach and nectarine (Prunus persica L. Batsch) cultivars. *Postharvest Biology and Technology*. 38: 239-246.

Dagar A., Weksler A., Friedman H., and Lurie S., 2012. Gibberellic acid (GA_3) application at the end of pit ripening: effect on ripening and storage of two harvests of “September Snow” peach. *Scientia Horticulturae*. 140: 125-130

Dani M. 2007. Connection between the light availability and the peach fruit quality. VI. Alps-Adria Scientific Workshop Obcrvellach, Austria, 337-340.

DeBuse C., Lopez G and DeJong T., 2010. Using spring weather data to predict harvest date for Improved French prune. *Acta Horticulturae* (in press).

DeJong TM, Day K.R. and Doyle J.F. 1994. Te Kearney Agricultural Center perpendicular ‘V’ (KAV-V) orchard system for peaches and nectarines. *Horticultural Technology*. 4: 362-367.

Eccher Zerbini, P., Spada, G.L., Liverani, C., 1994. Selection and experi- mental use of colour charts as a maturity index for harvesting peaches and nectarines. *Advances in Horticultural Sciences*. 8: 107-113.

Farina V., Lo Bianco R. and Inglese P. 2005.Vertical distribution of crop load and fruit quality within vase- and Y-shaped canopies of ‘Elegant Lady’ peach. *HortScience*. 40: 587-591.

Feng-Lil H., Fei W., Qin-Ping W., Xiao-wei W. and Qiang Z., 2008. Relationships between the distribution of relative canopy light intensity and the peach yield and quality. *Agricultural Sciences in China*. **7**(3): 297-302.

Ferguson I.B., Snelgar W., Lay-Yee M., Watkins C.B. and Bowen J.H., 1998. Heat shock response in apple fruit in the field. *Australian Journal of Plant Physiology*. 25: 155-163.

Fisher D.V., 1962. Heat units and number of days required to mature some pome and stone fruit in various areas of North America. *Proceedings of the Amererican Society for Horticultural Sciences*. 80: 114-124

Flores F., Ben Amor M., Jones B., Pech J.C., Bouzayen M., Latché A. and Romojaro F., 2001. The use of ethylene-suppressed lines to assess differential sensitivity to ethylene of the various ripening pathways in Cantaloupe melons. *Physiol Plantarum*. 113: 128-133.

Flores F., El-Yahyaoui F., de Billerbeck G., Romojaro F., Latche ´ A., Bouzayen M., Pech J.C. and Ambid C., 2002. Role of ethylene in the biosynthetic pathway of aliphatic ester aroma volatiles in Charentais Cantaloupe melons. *Journal of Experimental Botany*. 53: 201-206

Génard M, Gibert C., Bruchou C., Lescourret F. and Agroparc S., 2009. An intelligent virtual fruit model focussing on quality attributes. *Journal of Horticultural Science & Biotechnology*. ISAFRUIT Special Issue. 157: 157-163.

Gènard M. and Gouble B., 2005. ETHY: a theory of fruit climacteric ethylene emission. *Plant Physiology*. 139: 531-545.

Goldschmidt E.E. And Lakso A.N., 2005. Fruit tree models: scopes and limitations. In: Information and Communication Technology (ICT) Development and Adoption: Perspectives of Technological Innovation, (E. Gelb, A. Offer, eds.), European Federation for Information Technologies in Agriculture, Food and the Environment (web only)

Haji T., Yaegaki H. and Yamaguchi M., 2003. Softening of stony hard peach by ethylene and the induction of endogenous ethylene by 1-aminocyclo- propane-1-carboxylic acid (ACC). *J. Jpn. Soc. Hortic. Sci.* 72: 212-217.

Hale G., Lopresti J., Bonora E., Stefanelli D. and Jones R., 2012. Using non-destructive methods to correlate chilling injury with fruit maturity. Proceedings of the International Symposium on Post-Harvest, Malaysia.

Herrero-Langreo A., Fernández-Ahumada E., Roger J.M., Palagós B. and Lleó L., 2011. Combination of optical and non-destructive mechanical techniques for the measurement of maturity in peach. *Journal of Food Engineering*. **108**(1): 150-157.

Hilaire C.and Mathieu V., 2004. Le Point sur la qualite gustative des peches et nectarines. Infos-Ctifl 201, 27–31.

Hiwasa K., Kinugasa Y.,Amano S., Hashimoto A., Nakano R., Inaba A. and Kubo Y., 2003. Ethylene is required for both the initiation and progression of softening in pear (Pyrus *communis* L.) fruit. *Journal of Experimental Botany*. 54: 771-779.

Iglesias I., Carbó J., Bonany J., Casals M., Dalmau R. and Montserrat R., 2005. Innovación varietal en melocotonero: especial referencia a las nuevas variedades de nectarina. Fruticultura Profesional: Especial Melocotonero III 152:6-36.

Iglesias, I., and Echeverría G., 2009. Differential effect of cultivar and Harvest date on nectarine co-lour, quality and consumer acceptance. *Scientia Horticulturae.* 120: 41-50.

Infante R., 2012. Harvest maturity indicators in the stone fruit industry. Stewart Postharvest Review. June: 1-6.

Jimènez C.M. and Dìaz B.J., 2003. A Statistical Model to Estimate Potential Yields in Peach before Bloom. *Journal of the American Society for Horticultural Sciences*. **128** (3):297-301.

Kader A.A.,1999. Fruit Maturity, Ripeninh, and quality reltionships. Proc. Int. Symp. On Effect og Pre and Post Harvest Factors on Storage of Fruit. *Acta Horticolturae* 485: 203-208.

Kondo S., Meemak S., Ban Y., Moriguchi T. and Harada T., 2009. Effects of auxin and jasmonates on 1-aminocyclopropane-1-carboxylate (ACC) synthase and ACC oxidase gene expression during ripening of apple fruit. *Postharvest Biology and Tecnology*. 51: 281-284.

Lavilla T., Recasens I., Lopez and Puy J. 2002. Multivariate analysis of maturity stages, including quality and aroma, in 'Royal Glory' peaches and 'Big Top' nectarines. *Journal of the Science of Food and Agriculture*. 82: 1842-1849.

Layne REC and Bassi D., 2008. The peach: botany, production and uses. 1st ed. Wallingford: CABI.

Lescourret F. and Génard M., 2005. A virtual peach fruit model simulating changes in fruit quality during the final stage of fruit growth. *Tree physiology*. **25**(10): 1303-15.

Lewallen K.S., 2000. Effect of light availability and canopy position on peach fruit quality. Master of science in Horticulture Thesis, Faculty of the Virginia Polytechnic Institute and State University.

Lewallen, K. S. and Marini R. P., 2003. Relationship between flesh firmness and ground color in peach as influenced by light and canopy position. *Journal of the American Society for Horticultural Science*. 128: 163-170.

Liverani A., Giovannini D. and Brandi F., 2002. Increasing fruit quality of peaches and nectarines: the main goals of ISF-FO (Italy). *Acta Horticolturae*. 592: 507-514.

Lleó L., Roger J.M., Herrero-Langreo A., Diezma-Iglesias B. and Barreiro P., 2011. Comparison of multispectral indexes extracted from hyperspectral images for the assessment of fruit ripening. *Journal of Food Engineering*. 104: 612-620.

Loreti F., Massai R. and Morini S., 1989. Further observations on high density nectarine plantings. *Acta Horticulturae* .243: 353-360.

Lurie S., Friedman H., Weksler A., Dagar A. and Eccher P., 2013. Maturity assessment at harvest and prediction of softening in an early and late season melting peach. *Postharvest Biology and Technology*. 76: 10-16.

Magnanini E., Bonora E. and Vitali G., 2010. PlantToon - drawing and pruning fruit trees. In: Proceedings of the 6th International Workshop on Functional-Structural Plant Models. Davis, CA, September 12-17. Pp. 255.

Marcelis L.F.M., Heuvelink E. and Goudriaan J., 1998. Modelling biomass production and yield of horticultural crops: a review. *Scientia Horticulturae*. 74: 83-111.

Marini R.P., Sowers D. and Marini M.C., 1991. Peach fruit quality is affected by shade during final swell of fruit growth. *Journal of the American Society for Horticultural Science*.. 116, 383–389.

Marsh K.B., Richardson A.C., and Macrae E.A., 1999. Early and mid season temp erature effects on the growth and composition of Satsuma mandarins. *Journal of Horticultural Science and Biotechnology*. 74: 443-451.

Mimoun M.B. and DeJong T.M., 1999. Using the Relation Between Growing Degree Hours and Harvest Time to Estimate Run-Times for Peach: A Tree Growth and Yield Simulation Model. Department of Pomology, University of California, Davis.

Mora M., Echeverría G., Predieri S. and Infante R., 2008. Results of a consumer survey conducted in Chile-Italy and Spain on marketpotential of peach and nectarines. Atti del VI convegno nazionale sulla peschicoltura meridionale, Caserta, 6-7 marzo 2008, 336-339.

Nuzzo V., Dichio B., Palese AM., and Xilayannis C., 2000. Sviluppo della chioma ed intercettazione radiativa in piante di pesco allevate a Y trasversale ed a vaso ritardato nei primi tre anni dall'impianto. V giornate scientifiche SOI. Pp. 319-320.

Nyasordzi J., Friedman H., Schmilovitch Z., Ignat T., Weksler A., Rot I. and Lurie S., 2013. Utilizing the I_{AD} index to determine internal quality attributes of apples at harvest and after storage. *Postharvest Biology and Technology*. 77: 80-86.

Pavel E.W. and DeJong T.M., 1993b. Estimating the photosynthetic contribution of developing peach (*Prunus persica* L.) fruits to their growth and maintenance carbohydrate requirements. *Physiologia Plantarum.* 88: 331-338.

Predieri S., Liverani A., Gatti E. and Versari N., 2008. Italian consumers preferences according to peach fruit organoleptic characteristics. Atti del VI convegno nazionale sulla peschicoltura meridionale, Caserta, 6-7 marzo 2008, 318-325.

Prusinkiewicz P., 1998. Modeling of spatial structure and development of plants: a review. *Scientia Horticulturae*. 74: 113-149.

Reig, G., Alegre S., Iglesias I.and Echeverría G., 2012. Fruit Quality, Colour Development and Index of Absorbance Difference (I AD) of Different Nectarine Cultivars at Different Harvest Dates. IRTA-Estació Experimental de Lleida pp. 1117-1126.

Rupasinghe H.P.V., Murr D.P., Paliyath G. and Skog L., 2000. Inhibitory effect of 1-MCP on ripening and superficial scald development in 'McIntosh' and 'Delicious' apples. *J Hortic Sci Biotechnol.* 75: 271-276.

Sansavini S. and Neri D., 2005. Forme di allevamento e potatura del pesco. Manuale di Peschicoltura. Bologna: Edagricole-Calderini, pp. 115-144.

Sansavini S., Corelli Grappadelli L., Costa G., Lugli S., Marangoni B., Tagliavini M., Ventura M., Abeti D., Ferali S., Marani G., Mascalzoni G., Molducci Proni R., SamaA., Spada G.,Vitali S., Turroni P., Minguzzi A. and Randi M., 2000. Ricostituzione degli impianti e nuovi indirizzi produttivi della peschicoltura romagnola. In: Proceedings of the XXIII Convegno Peschicolo, Ravenna, pp. 62–74.

Sansavini S., Costa G., Gucci R., Inglese P., Ramina A. and Xiloyannis C., 2012. General arboricolture . Patrona ds pp. 536.

Sansavini S., Corelli L., and Giunchi L., 1985. Peach yield efficiency as related to tree shape. *Acta Horticolturae*. 173: 139-158.

Scorza R. and Sherman W.B., 1996. Peaches. In: Janick, J., Moore, J.N. (Eds.), Fruit Breeding, vol. 1. *Tree and Tropical fruits*. John Wiley & Sons, Inc, N.Y. Pp. 325-440.

Smith G.S., Curtis, J.P., Edwards, C.M., 1992. A method for analysing plant architecture as it relates to fruit quality using three-dimensional computer graphics. *Annals of Botany*. 70: 265-269.

Smith, G.S., Gravett, I.M., Edwards, C.M., Curtis, J.P., Buwalda, J.G., 1994. Spatial analysis of the canopy of kiwifruit vines as it relates to the physical, chemical, and postharvest attributes of the fruit. *Annals of Botany*. 73: 99-111.

Tomes M.L., 1963. Temperature inhibition of carotene synthesis in tomato. *Botanical Gazette.* 11: 180–185.

Tonutti P., Casson P.and Ramina A., 1991. Ethylene biosynthesis during peach fruit development. *Journal of the American Society for Horticultural Science*. 116: 274- 279.

Trainotti L., Bonghi C., Ziliotto F., Zanin D., Rasori A., Casadoro G., Ramina A. and Tonutti P., 2006. The use of microarray mPEACH1.0 to investigate transcriptome changes during transition from pre-climacteric to climacteric phase in peach fruit. Plant Science 170, 606–813.

Trainotti L., Zanin D. and Casadoro G., 2003. A cell wall-oriented genomic approach reveals a new and unexpected complexity of the softening in peaches. *Journal of Experimental Botany*. 54: 1821-1832.

Vanoli M. and Buccheri M. 2012. Overview of the methods for assessing harvest maturity- Stewart *Postharvest Review*.

Warrington I.J., Fulton T.A., Halligan E.A. and Silva H.N.D., 1999. Apple fruit growth and maturity are affected by early season temperatures. *Journal of the American Society for Horticultural Science* 124: 468–477.

Weinberg J. H., 1948. Influence of temperature following bloom on fruit development period of ‘Elberta’ peach. *Proceedings of the American Society for Horticultural Science.* 51: 175–178.

Yamada H., Takechi K., Hoshi A. and Amano S., 2004. Comparison of water relations in watercored and non watercored apples induced by fruit temperature treatment. *Scientia Horticulturae*. 99: 309–318.

Ziosi V., Noferini M., Fiori G., Tadiello A., Trainotti L., Casadoro G.and Costa, G., 2008. A new index based on vis spectroscopy to characterize the progression of ripening in peach fruit. *Postharvest Biology and Technology*. 49: 319-329.