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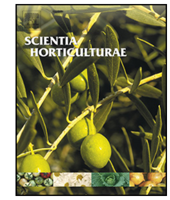

Skin color and chlorophyll absorbance: Indices for establishing a harvest date on non-melting peach

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ABSTRACT

The aim of this research was to develop an objective method to determine the best harvest date for non-melting peach cultivars. For this purpose the absorbance of chlorophyll (I_{AD}) on the skin of 'Andes Du-1', 'Loadel' and 'Bowen' peach cultivars was assessed. The on-tree fruit development was monitored for two consecutive seasons, one month before harvest. The correlation between I_{AD} of the skin and the flesh firmness was positive and highly significant (r = 0.9). Also, I_{AD} and h° correlation was found to be positively and significantly associated (r = 0.75 to 0.91). The greatest observed correlations were between I_{AD} and flesh firmness, and the lowest correlations were between soluble solids concentration (SSC) and the other indices. The relationship between the h° of the skin and the h° of the flesh was high and significant, reaching r = 0.89, 0.84, and 0.88, for 'Andes Du-1', 'Loadel, and 'Bowen', respectively. However, the relationship between the two variables was not linear, so the data was adjusted to segmented regressions. The relationship between I_{AD} and the *Munsell Book of Color* defined the five categories of I_{AD}, ranging from less than 0.180 I_{AD} units for the category holding the ripest fruit (2.5Y 8/10) to the category of I_{AD} greater than 1.545 units (10Y 8/10) for the less ripe fruit. The I_{AD} has shown being an informative ripeness index for evaluating non-destructively the evolution of ripeness during the last phase on-tree, and particularly this index is associated with the flesh firmness.

1. Introduction

One of the main challenges of a peach orchard is how to determine the optimal harvest time (Tijskens et al., 2007), as the proper peach harvest maturity level is the key factor to assure a high-quality product (Infante, 2012). The maturity level of peach at harvest is naturally heterogeneous: fruit are at different stages of development and maturity because the bloom time can span two or more weeks (Shinya et al., 2013). Further, the peach on the tree canopy are exposed to uneven light and temperature conditions, which is dependent on spacing and position, so each fruit will ripen at different times and rates (Marini et al., 1991).

The ground color of the skin has been used on peach as an indicator of maturity, comparing it with standardized color charts (Eccher Zerbini et al., 1994). Other parameters to determine the beginning of the harvest time for the industry have been the fruit size and soluble solids concentration (SSC) (Kader, 1997). However, these parameters are greatly affected by environmental conditions, thus they are not always reliable indices (Infante et al., 2011a). Additionally, the color of peach skin it is not always a reliable index because in some cases, it has not been shown to relate to the real maturity of the fruit in terms of physiological ripeness (Ferrer et al., 2005). In this regard, Lewallen and Marini (2003) note that the ground color is not always satisfactory to define fruit maturity, as fruit with the same color have wide variability in flesh firmness, acidity, and SSC.

For the above reasons, there is a need to define indices that can be measured easily in the orchard in a non-destructive way and that can be tightly associated with the parameters that reflect the maturity stages of peach, such as the flesh firmness. The index related to the absorbance of chlorophyll (I_{AD}), calculated as I_{AD} = A670–A720, which is near the peak of absorbance of chlorophyll-a (Ziosi et al., 2008), allows an indirect determination of the concentration of chlorophyll in the skin (Lurie et al., 2013). This is also related to ethylene biosynthesis (Ziosi et al., 2008). Together, these are the parameters that, to a large extent, can determine the maturity of the peach.

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The I_{AD} has been proven to predict the state of maturity on melting fleshed peach cultivars (Ziosi et al., 2008; Bonora et al., 2013; Lurie et al., 2013), but there have been no studies that validate this index on non-melting peach genotypes. Non-melting peach cultivars are harvested according to the ground color of the skin, which is then compared with color charts. The equivalence of an I_{AD} value to a standardized color may allow getting a more objective physiological parameter of ripeness instead of only the visual comparison of the skin of the fruit with a chart of colors.

In terms of both sensory quality and consumer acceptance, the SSC is an informative parameter for establishing quality levels, or even thresholds, of peach (Crisosto and Crisosto, 2005); however, this parameter is solely valid for the fresh peach industry. When dealing with non-melting fleshed cultivars destined for canning, the SSC is rarely useful because the final product is enriched with extra sugar, in the form of syrup, where are cooked. With canning peach, the flesh texture and the color of the flesh are quite valuable parameters to define quality (Infante, 2012). For this reason, a non-destructive parameter that could be associated with flesh color would be quite valuable for the industry.

In this research, the I_{AD} of the skin of three non-melting peach cultivars was monitored on-tree for approximately one month before harvest. This index was then associated with maturity parameters that are important as either harvest or quality parameters for peach destined for canning. In consequence, the objectives of this research were to evaluate the evolution of some non-destructive indices that are most tightly related with fruit ripeness during the last phase on-tree, and particularly with flesh firmness; and also to define the relationships between different ripeness parameters that change during this phase on peach.

2. Materials and methods

2.1. Plant material

The trial was conducted during two consecutive seasons (November 2010 and December 2011) in two orchards located in the VI Region (34°19′49.68″S; 70°50′1.88″W) and the Metropolitan Region (33°48′12.57″S; 70°45′6.17″W), both of which are located in the Central Valley of Chile. The plant material corresponds to the non-melting peach cultivars 'Andes Du-1', 'Loadel', and 'Bowen', grafted onto 'Nemaguard', which were planted in a north-south orientation and irrigated by drip lines.

2.2. Monitoring peach ripening

Trees were randomly selected in a uniform field area of the orchards. To assess fruit maturity, in the first season, 30 fruit were collected weekly, and in the second season, 20 fruit were collected twice weekly. Each time, the sampling occurred about four weeks before the time of harvest, picking the fruits from three neighbor trees. The fruit were transferred to the lab, and the I_{AD} was assessed in the equatorial zone of each cheek with a DA-meter (Sinteleia, Bologna, Italy). The ground color of the skin was assessed with a Minolta portable colorimeter model CR- 400 (Minolta, Tokyo, Japan), with a source illuminant D65 and an observer angle of 0° using the CIELab system, calibrated with a white standard. The SSC was determined by a thermo-compensated portable refractometer (Atago, Tokyo, Japan), and the flesh firmness was analyzed with a FTA GS -14 texture-meter (Guss, Strand, South Africa) on each cheek before the skin removal, using a 7.9-mm diameter probe with a penetration distance of 10 mm at 5 mm s $^{-1}$ speed. Harvest was performed when the ground color changed from yellow-green to yellow (*Munsell Book of Color*, 1958), which was associated with flesh firmness between 35 and 44N. During the second season, the color and the I_{AD} of the flesh were also assessed, measured after removing the skin on each cheek.

On 'Andes Du-1', a descriptive evaluation of the evolution of the ground color was performed using a Munsell color chart. For this purpose, five weeks before harvest, 20 fruit per tree were scored twice a week. The ground color determination was always performed by the same assessor, and under regular daylight conditions.

2.3. Data analysis

We performed correlations and linear and nonlinear regressions. The linear regression models described the relationship between the I_{AD} and the other variables, under the framework of General Linear and Mixed Models, during the period in which the I_{AD} decreased linearly, approximately 10 to 15 days before harvest. The I_{AD}, the cultivar, and their interaction were considered as fixed effects, and the seasons were the random effect. Segmented model nonlinear regressions were used to describe the relationship between the hue (h°) of the skin and the h° of the flesh. The parameters of the regressions (i.e., inflection point and slope) were statistically significant ($\alpha = 0.05$). Akaike Information Criterion (AIC) (Akaike, 1974) and Bayesian Information Criterion (BIC) (Schwarz, 1978) were used. An analysis of the classification and regression tree (CART) was performed to identify the rank of I_{AD} for each color category. Lastly, the InfoStat statistical program (National University of Córdoba, Argentina) version 2013 was used in all the statistical analysis.

3. Results

Significant linear correlations between the I_{AD} of the skin and the maturity variables were observed during the on-tree development phase, except for SSC (Table 1). The correlation between I_{AD} of the skin and flesh firmness was positive and highly significant ($r \approx 0.9$). Also, the I_{AD} and the h° of the skin were positively and significantly associated, with r values between 0.75 and 0.91. The strongest observed correlation was between the I_{AD} of the skin and flesh firmness, reaching a higher score than the relationship between the h° of the skin and the flesh firmness. In contrast, the association between SSC and the other indices were found to be not significant, which is in agreement with previous results with peach (Cantín et al., 2009). Chroma, as h° and I_{AD}, is correlated with firmness in all three cultivars, but it is weakly associated with SSC. On non-melting peach cultivars, which are commonly destined

Table 1
Pearson's correlation coefficients (r) among maturity parameters assessed non-destructively on the skin (h° and I_{AD}) and the soluble solids content (SSC) and the flesh firmness of three non-melting peach cultivars. Data was registered during the last phase of fruit development on-tree on two consecutive growing seasons.

Cultivar		I_{AD}	Chroma	h°	SSC
Andes Du-1	Chroma	-0.27^{*}	–	–	–
	h°	0.88^{*}	0.13^{NS}	–	–
	SSC	-0.04^{NS}	0.19^{*}	-0.02^{NS}	–
	Firmness	0.94^{*}	-0.30^{*}	0.80^{*}	0.04^{NS}
Loadel	Chroma	-0.67^{*}	–	–	–
	h°	0.75^{*}	-0.17^{NS}	–	–
	SSC	-0.15^{NS}	0.05^{NS}	-0.27^{*}	–
	Firmness	0.92^{*}	-0.67^{*}	0.64^{*}	0.05^{NS}
Bowen	Chroma	-0.88^{*}	–	–	–
	h°	0.91^{*}	-0.77^{*}	–	–
	SSC	-0.02^{NS}	-0.00^{NS}	-0.07^{NS}	–
	Firmness	0.90^{*}	-0.84^{*}	0.83^{*}	0.09^{NS}

[ns] Not significant.
[*] Level of significance $p \le 0.05$.