

# Peach ripening: Segregation at harvest and postharvest flesh softening



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## ABSTRACT

The peach melting flesh cultivars 'Ryan Sun' and 'Sweet September' and the non-melting, 'Kakamas' were harvested according to their visually assessed ground color and divided into four, ripeness classes (M1, M2, M3, and M4). The following aspects were determined: fruit mass, soluble solids content (SSC), ground skin hue angle ( $h^\circ$ ) and chroma ( $C^*$ ), the absorbance difference at 670 nm and, 720 nm index ( $I_{AD}$ ), and the texture (fruit firmness measured with a needle, flesh firmness measured, with a 7.9 mm plunger, and uniaxial compression strength). Considering that in peaches, the  $h^\circ$  of the, ground color and the  $I_{AD}$  are maturity indicators closely associated with ripeness and particularly with, flesh firmness, the texture parameters and their relationship to  $h^\circ$  and  $I_{AD}$  were examined. The visual, assessment of the ground color was validated as the criterion for sorting the ripeness levels in peaches, as confirmed by  $h^\circ$  and  $I_{AD}$ . Fruit firmness assessed with the needle and that with the 7.9 mm plunger, were highly correlated with each other and with the  $h^\circ$  and  $I_{AD}$ , whereas the compression strength, exhibited less correlation with the optical properties of the skin. The non-melting 'Kakamas' showed, the poorest correlation between texture and  $h^\circ$  and  $I_{AD}$ . Comparing both optical properties, the  $I_{AD}$ , showed a higher correlation with texture features than the  $h^\circ$ . In a second experiment, fruit from the M3 ripeness class was maintained in a ripening chamber (20 °C, and 80% RH) until the flesh was softened for consumption. During postharvest, the first two principal, components of a principal component analysis explained 85% of the total variance of the texture, components and the optical properties of the skin. PC1 (67.2%) was defined positively by the texture, parameters and  $I_{AD}$ . The  $h^\circ$  of the ground color was negatively related to all texture parameters, and,  $I_{AD}$ . PC2 (17.8%) was associated positively with the juice content, and this parameter proved to be, independent of all others.

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## 1. Introduction

Predicting the potential lifespan of a peach along the commercial chain is crucial to planning the storage, transport, and postharvest handling and selling to guarantee high fruit quality and consumer satisfaction. A first point to be considered is the fruit physiological state at harvest because peach shelf-life performance is heavily determined by its ripeness at this key stage (Ruiz-Altisent et al., 2006). One of the most important challenges for the peach industry is the segregation at harvest of fruit into homogeneous groups in terms of state of ripeness. Tijsskens et al. (2007) highlighted the importance of grading individual fruit at harvest into classes of usability and of selecting fruit with different ripeness stages for different market segments on the basis of a reliable prediction of their softening rate. The goal is to guarantee a flesh firmness adequate to transport and sufficient ripening potential to reach good eating quality. Commercially, a common criterion for distinguishing

immature from mature fruit is the visual evaluation of the ground skin color (Kader, 1999; Zerbinì et al., 1994; Tijsskens et al., 2007). Although separating peaches on the basis of comparable visual appearance is a common and inexpensive method, the segregation of batches with similar postharvest life potential is a major technical challenge. There are two main difficulties in using this simple approach: first, the ground color of the peach in the new cultivars is masked by the covering blush, and second, the flesh typologies of new peach cultivars do not demonstrate equal behavior, particularly the stony hard (Yoshida, 1970) and non-melting flesh cultivars. Unlike the melting flesh cultivars, these genotypes do not exhibit the melting period of softening, which is marked by a strong decline in firmness, increased solubility of both loosely bound pectins and matrix glycans, and decreases in the numbers of tightly bound molecules (Brummell et al., 2004).

Peach flesh firmness has been traditionally determined by the Magness–Taylor pressure test using a 7.9 mm plunger, and this is the most popular method in the peach industry as well as for postharvest studies. When harvest time is near, fruit are sampled at the orchard, and then an appropriate flesh firmness score is associated with a ground skin color. In this way, the skin ground

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color of the fruit becomes a reliable and non-destructive indicator of the flesh firmness and therefore of its potential market life. There are high correlations between surface ground color and physiological maturity in peach and nectarine (Kader, 1999), and the hue angle ( $h^\circ$ ) in particular has been shown to be highly informative and closely associated with ripeness (Ferrer et al., 2005). It has also been observed, however, that the same  $h^\circ$  could be associated with different levels of firmness because the fruit is influenced by the light environment in which it develops (Lewallen and Marini, 2003). This maturity indicator should therefore be used with caution. Recently, the  $I_{AD}$  (difference of fruit absorbance spectra ( $A$ ) at two wavelengths  $I_{AD} = A_{670} - A_{720}$ ), determined non-destructively using a portable device called Delta-A instrument (Sinteleia, Bologna, Italy), has been shown to be a reliable method for assessing ripeness (Ziosi et al., 2008). High correlations between  $I_{AD}$  and ripeness level have been reported for peach (Ziosi et al., 2008), prune (Infante et al., 2011a), and Japanese plum (Infante et al., 2011b). The  $I_{AD}$  of the skin is especially informative in those cultivars where the covering color does not allow the ground color to be viewed. Herrero-Langreo et al. (2012) combined chlorophyll-related optical indexes and low mass impact (LMI) to successfully assess peach maturity using the mean values of sequential harvest dates.

In peach, ripeness is a complex process that cannot be fully characterized by a single determination; there are many parameters that change during ripening. In the fresh peach industry, the most limiting factors of fruit quality along the commercial chain are those dealing with the mechanical properties of the flesh and particularly with the softening speed. The evaluation of different methods to assess flesh firmness at harvest will improve the quality and homogeneity of fresh peaches in the marketplace. In addition, there is no knowledge of the mechanical properties of the newer typologies of flesh or of their evolution on-tree and at postharvest, both of which are cultivar-dependent traits; this lack of knowledge makes it essential to test alternative methods for determining firmness.

The optical properties of the skin, measured either as the  $h^\circ$  of the ground color or as  $I_{AD}$ , are both non-destructive and reliable indicators of the physiological age of a fruit. The proposed hypothesis of this study is that flesh firmness determined by means of a puncture test with a 7.9 mm plunger is not correlated with these indicators in peaches of different flesh typology, thereby making it necessary to evaluate alternative methods of texture assessment.

## 2. Materials and methods

### 2.1. Fruit material

Three peach cultivars, all characterized by the visibility of their ground color, were evaluated: the melting flesh genotypes 'Ryan Sun' and 'Sweet September' and the non-melting 'Kakamas'. Fruit was harvested from a commercial orchard located in the Central Valley of Chile. Fifteen trees of each variety, uniform for production, were selected. The fruit was sequentially harvested every 2–3 days for a total of 240 samples. Fruit ripeness was established visually at the orchard, and fruit was harvested into separate batches, based on the ground color of the skin. Afterwards, the fruit was transported to the lab and was re-classified under white light conditions into four ground color levels that represent the ripeness classes used in this trial: M1 (green), M2 (green yellow), M3 (yellow) and M4 (yellow orange), containing 60 fruit each.

### 2.2. Segregation of ripeness classes

At harvest, for each cultivar and utilizing the ripeness levels previously sorted based on the visually assessed ground color (M1,

M2, M3, and M4), the fruit mass, soluble solids content (SSC), ground skin color,  $I_{AD}$ , fruit/flesh firmness, and uniaxial compression strength were determined.

The SSC was measured with a thermo-balanced PAL-1 refractometer (Atago, Tokyo, Japan). The skin color was measured with a CR-400 colorimeter (Minolta, Tokyo, Japan). The chroma ( $C^*$ ) and hue angle ( $h^\circ$ ) were used to characterize changes in skin color from green to yellow during ripening. The  $I_{AD}$  was measured on the skin of both cheeks of each fruit, and three measurements per cheek were performed. The mean of the six measurements per fruit were used for data analysis. The  $I_{AD}$  was measured with a portable Delta-A instrument (Sinteleia, Bologna, Italy).

Firmness was measured by two methods, based on puncture tests: (1) fruit firmness with a needle that penetrates 5 mm into an intact fruit and (2) flesh firmness with the plunger traditionally used on stone fruit (7.9 mm diameter), penetrating 10 mm into the flesh, with the skin having previously been removed with a scalpel. In both cases, a FTA GS-14 texture analyzer (Güss, Strand, South Africa) was used, whose probe ran at 5 mm s<sup>-1</sup>. Firmness value was calculated as a mean of four measures performed on both cheeks and on both shoulders of each fruit.

The uniaxial compression strength was determined with a wide plunger (21 mm diameter) that deforms the intact fruit; the haul of the plunger runs 1 mm deep from the time the plunger contacts the skin. A FTA GS-14 texture analyzer (Güss, Strand, South Africa) was used, whose probe ran at 5 mm s<sup>-1</sup>.

### 2.3. Monitoring flesh softening during postharvest

The M3 ripeness class was chosen for the postharvest monitoring of texture changes because this class represents the most frequent ripeness level employed by the industry that focuses on the fresh fruit market. Forty fruit per cultivar were harvested and transported to the laboratory. Fruit were placed in a ripening chamber, which was set at 20 °C and 80% relative humidity. Evaluations were performed until fruit dehydration reached 5% fresh weight loss, which was determined by monitoring a sample of 10 fruit maintained in the same conditions exclusively for this purpose. 'Ryan Sun' and 'Sweet September' fruit were maintained in this condition for five days, whereas 'Kakamas' was maintained for four days.

The fruit mass, SSC,  $h^\circ$  and  $C^*$ ,  $I_{AD}$ , fruit/flesh firmness, compression strength, and juice content were determined on the first, third and fifth days for a sample of 10 fruit each time for 'Ryan Sun' and 'Sweet September', and on the first, second and fourth days for 'Kakamas'.

The juice content was quantitatively determined by weighing the free juice absorbed by an ordinary absorbent paper from a flesh sample (2 mm wide and 15 mm long) squeezed by the action of two metallic rolling cylinders (Infante et al., 2009).

### 2.4. Data analysis

In the first experiment, data were submitted to analysis of variance (ANOVA) for each cultivar, and 60 fruit of each ripeness class (M1, M2, M3 and M4) were considered. The means were separated with Duncan's test (<0.05).

A linear regression between  $h^\circ$  and  $I_{AD}$  was performed. The relation between optical and texture (measured with the 7.9 mm plunger, the needle, and by uniaxial compression) parameters was analyzed as a polynomial linear regression.

In the second experiment, focusing on the postharvest performance of the cultivars, the mechanical properties of the fruit/flesh and the optical properties of the skin throughout the postharvest period were submitted to a principal component analysis (PCA), followed by a multivariate analysis of variance (MANOVA) to

cross-validate the postharvest/time PCA results. The differences were determined by Pillai's trace test ( $P < 0.05$ ). For all of the statistical analysis, Infostat (Córdoba, Argentina, 2004) was used.

### 3. Results and discussion

#### 3.1. Segregating ripeness classes at harvest

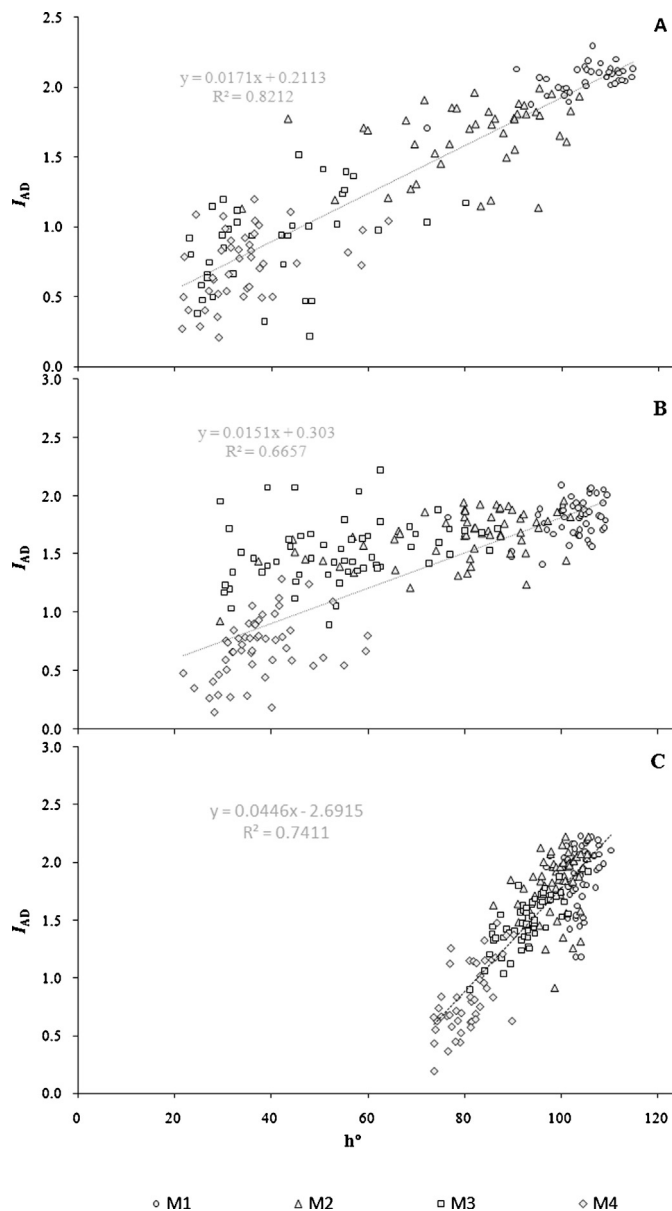
Fruit mass is a parameter associated with on-tree ripening; the riper the peach, the greater the mass should be (Dejong and Goudriaan, 1989). This trend was observed in almost every case (Table 1). Only the ripest 'Ryan Sun' (M4) showed an unexpected mass decrease, possibly indicating a sampling error.

In general, the SSC scores were higher on riper fruit in all three genotypes. The lowest level was observed in M1, significantly different from the SSC observed in the other classes (Table 1), in which this parameter did not vary significantly. This observation is particularly clear for 'Sweet September', which is classified as a low-acid genotype, characterized by an early sugar accumulation during the final phase of fruit development prior to commercial harvest (Yoshida, 1970). As occurs with fruit mass changes in stone fruit species, the SSC is not a sufficiently informative indicator of ripeness on undetached fruit, even if it is clearly associated with the advancement of on-tree maturation (Infante et al., 2011b), as the changes observed during the final phase of ripening are slight and because the potential SSC level that could be reached depends more on the climate, the position in the canopy, and on orchard management than on the genotype (Cantin et al., 2009).

The fruit/flesh firmness measured with the needle or with the 7.9 mm plunger enabled the complete segregation of the four ripeness classes from both melting flesh genotypes. In the case of the non-melting 'Kakamas', the flesh firmness measured with the 7.9 mm plunger was only different in M1; in this genotype, the needle was able to segregate the samples into three groups, with M2 and M3 being statistically equal (Table 1). It is important to highlight that 'Kakamas' had a rather narrow range of fruit/flesh firmness compared with the other two melting flesh cultivars (Table 1), suggesting that for obtaining a comparable M1 firmness class among cultivars, 'Kakamas' should be harvested much earlier than in this experiment. The fruit/flesh firmness is a valuable parameter related to the potential postharvest performance of stone fruits (Zerbini et al., 2006), and it is particularly informative for the melting-flesh genotypes. Moreover, the ground color of the skin in these genotypes is closely associated with the ripeness of the fruit in general and particularly with the flesh firmness (Kader, 1999; Ferrer et al., 2005).

The  $I_{AD}$  of the skin and the  $h^\circ$  of the ground color confirm their value as reliable ripeness indicators in peaches (Ziosi et al., 2008) and enable separation of the three genotypes into the four ripeness classes (Table 1), which show a decreasing trend throughout ripening. For this reason, the  $I_{AD}$  can be considered as a valuable tool for deciding the time to harvest peach, as has been reported before for plum and prune (Infante et al., 2011a,b). The decreasing trend in  $I_{AD}$  observed in peach parallels the massive breakdown of chlorophyll that also occurs in the flesh during ripening (Chalmers and Ende, 1975). Moreover, the Delta-A instrument is able to measure the chlorophyll in the ground color differentially, whereas the colorimeter measures a combination of the ground color and the covering color of the skin through a single determination.

Melting flesh peach cultivars are generally characterized by the simultaneous occurrence of the ground color, which varies from green to yellow in terms of ripeness (Iglesias and Echeverría, 2009; Crisosto, 1994), and the covering color, a reddish tone, which is either genetically determined or induced by exposure to sunlight (Genard and Bruchou, 1992). When the  $C^*$  of the skin is



**Fig. 1.** Regression curves between  $I_{AD}$  and  $h^\circ$  of the melting peach cultivars 'Sweet September' (A) and 'Ryan Sun' (B) and the non-melting 'Kakamas' (C), harvested at four ripeness classes established visually by the ground color of the skin: M1 (green), M2 (green yellow), M3 (yellow) and M4 (yellow orange).

determined in melting peach, the invasion of small spots of the covering color into the ground color zone is a parameter that is not solely associated with ripeness, and therefore its value as a ripeness indicator is low. In this sense, the  $C^*$  of the ground color is not a valid parameter for segregating ripeness classes in 'Ryan Sun' and 'Sweet September'. In contrast, the non-melting genotypes generally show a pure ground color with practically no spots of blush (covering color) invasion, and the  $C^*$  of the skin can be effectively associated with ripeness; in this experiment, it enabled the segregation of the four ripeness classes of 'Kakamas' (Table 1).

#### 3.2. Correlations between parameters

High coefficients of determination were observed in the three genotypes with respect to the linear regression between  $I_{AD}$  and  $h^\circ$ . The observed  $R^2$  values were 0.82, 0.68 and 0.74 for 'Sweet September', 'Ryan Sun' and 'Kakamas', respectively (Fig. 1). The

**Table 1**

Peach ripeness indicators and quality parameters evaluated on fruit harvested in four ripeness classes established visually by the ground color of the skin: M1 (green), M2 (green yellow), M3 (yellow) and M4 (yellow orange). Firmness was measured in the flesh with a 7.9 mm plunger and in the fruit with a needle. The optical properties were determined on the skin ( $I_{AD}$ ) and on the ground color (chroma and hue).

Cultivars	Class	Mass (g)	SSC (%)	Flesh firmness (N)	Fruit firmness (N)	$I_{AD}$	Chroma	Hue
'Ryan Sun'	M1 <sup>a</sup>	120.4 a <sup>b</sup>	11.6a	105.4 d	4.8 d	1.81 d	26.0 b	102.4 d
	M2	150.1 c	13.5 c	98.6 c	4.5 c	1.66 c	24.6 a	79.2 c
	M3	150.2 c	12.7 b	77.6 b	3.4 b	1.14 b	25.5 b	53.8 b
	M4	139.6 b	12.3 b	48.2 a	2.6 a	0.67 a	26.7 c	37.6 a
'Sweet September'	M1	130.8 a	11.8 a	92.4 d	4.8 d	2.06 d	25.0 b	104.8 d
	M2	166.3 b	13.6 b	74.5 c	3.2 c	1.63 c	23.2 a	81.9 c
	M3	228.2 c	13.7 b	51.8 b	2.5 b	0.91 b	23.9 ab	42.7 b
	M4	234.9 c	13.3 b	41.4 a	2.1 a	0.70 a	24.8 b	33.8 a
'Kakamas'	M1	92.8 a	9.0 a	53.0 b	2.6 c	1.93 d	24.5 a	103.8 d
	M2	111.6 b	9.7 b	44.8 a	2.1 b	1.79 c	25.2 b	98.8 c
	M3	121.7 c	10.1 b	44.3 a	2.1 b	1.49 b	26.3 c	93.0 b
	M4	157.4 d	11.7 c	42.2 a	1.9 a	0.85 a	28.5 d	80.5 a

<sup>a</sup> Mean values of  $n=60$  fruits.

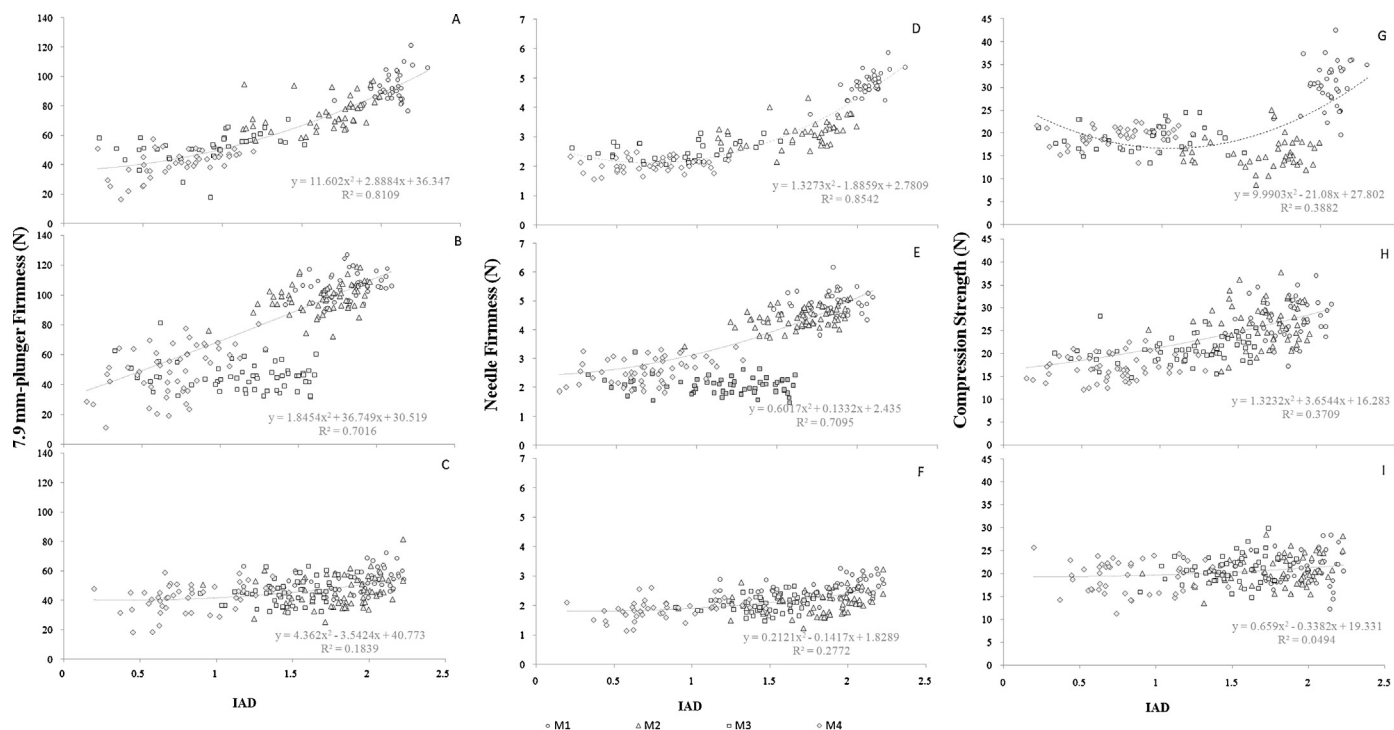
<sup>b</sup> Different letters in the same row per variety indicate significant differences ( $P \leq 0.05$ ).

observed slopes of the functions showed clear differences between the melting flesh genotypes and 'Kakamas', indicating in the former a greater color change with equivalent  $I_{AD}$  changes. However, it should be stated that 'Kakamas', in addition to being a non-melting cultivar, is a particular case because it is a canning peach that exhibits a deep green skin color until advanced maturation that is not associated with ripening, which is not the case of other non-melting genotypes studied in our lab (data not shown). These data confirm the high value of the optical properties of the skin (ground skin  $h^\circ$  and  $I_{AD}$ ) in peach as visual indicators of ripeness and as reliable harvest indexes.

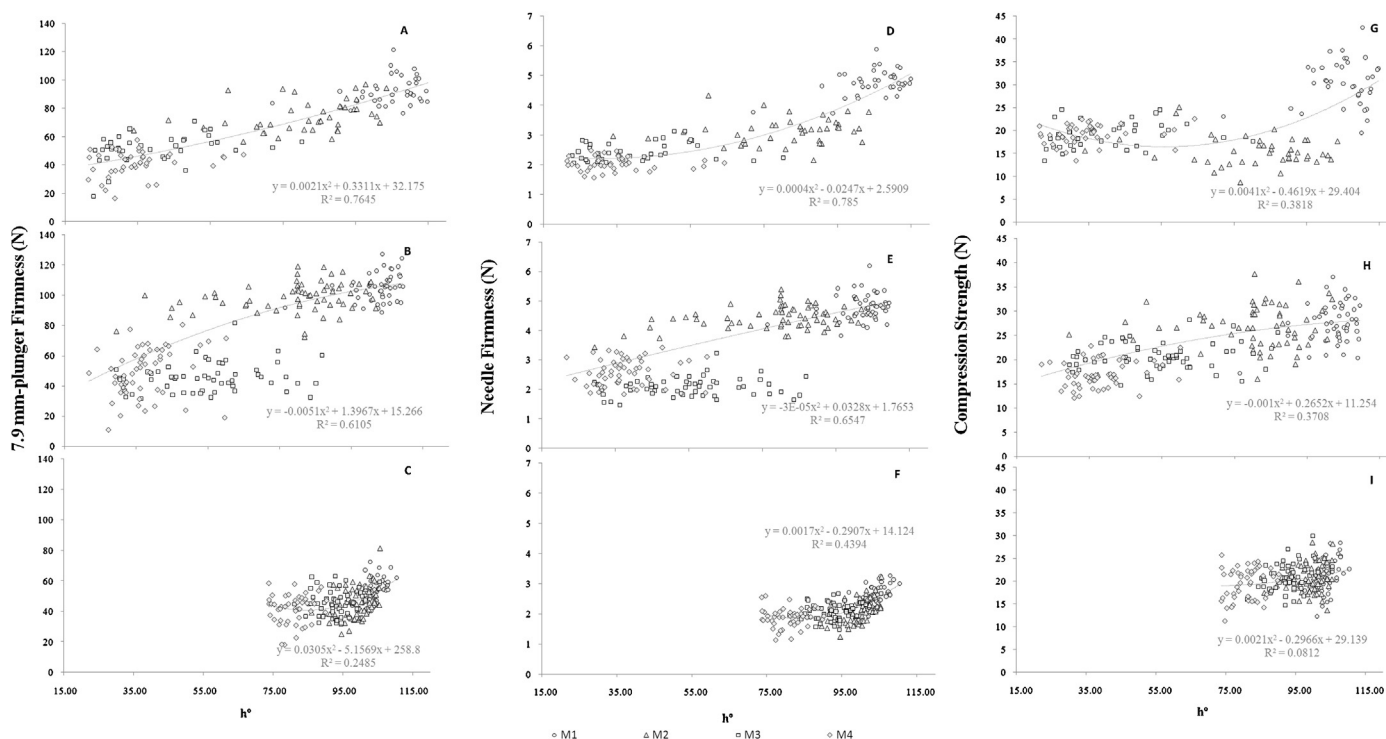
The potential commercial life of a stone fruit is primarily determined by its softening rate, which can be studied by monitoring the flesh firmness from harvest to consumption. The reference measurement for assessing flesh firmness, generally adopted by

growers and packinghouse operators, is the Magness–Taylor penetration force test (Leo et al., 2011), despite not being completely satisfactory.

High determination coefficients were observed when comparing, using a polynomial function, fruit firmness measured with the needle and a 7.9 mm plunger, with  $R^2 = 0.89$ , 0.87, and 0.80 in 'Ryan Sun', 'Sweet September', and 'Kakamas', respectively. This is a foreseeable result because both methods are based on puncture tests, measuring the maximum force reached by the probe. However, there are differences, as the 7.9 mm plunger is assessing solely the maximum force of the flesh, whereas the needle measures a combination of maximum forces of the skin and the flesh. The needle method appears to be a feasible alternative to the 7.9 mm plunger, and in contrast, does not require removal of the skin, thereby allowing firmness to be determined in a less invasive man-



**Fig. 2.** Regression curves between texture parameters – fruit firmness assessed with a needle (A–C), uniaxial compression strength (D–F) and flesh firmness assessed with the 7.9 mm plunger (G–I) – with  $I_{AD}$  of 'Sweet September' (A, D and G), 'Ryan Sun' (B, E and H) and 'Kakamas' (C, F and I) peach, harvested at four ripeness classes established visually by the ground color of the skin: M1 (green), M2 (green yellow), M3 (yellow) and M4 (yellow orange).

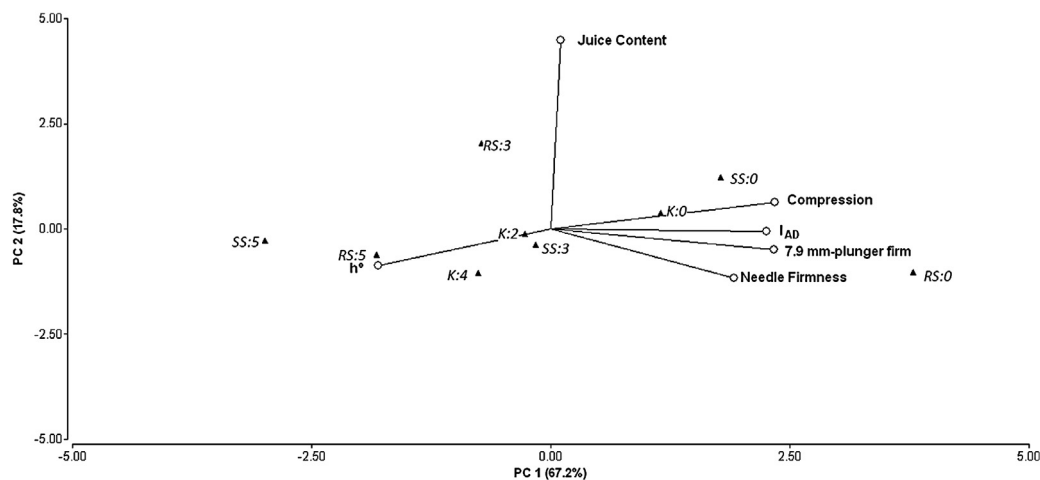


**Fig. 3.** Regression curves between texture parameters – fruit firmness assessed with a needle (A–C), uniaxial compression strength (D–F) and flesh firmness assessed with the 7.9 mm plunger (G–I) – with  $h^\circ$  of the ground color of ‘Sweet September’ (A, D and G), ‘Ryan Sun’ (B, E and H) and ‘Kakamas’ (C, F and I) peach, harvested at four ripeness classes established visually by the ground color of the skin: M1 (green), M2 (green yellow), M3 (yellow) and M4 (yellow orange).

ner. This method could permit a more precise characterization of fruit species with an uneven softening pattern such as peaches, by introducing the probe repeatedly in different areas of a single fruit (shoulders, tip and cheeks).

When the mechanical properties of the flesh—the maximum force, measured either by the 7.9 mm probe or by the needle, and the compression strength—were correlated with the optical properties of the skin  $I_{AD}$  (Fig. 2) or  $h^\circ$  (Fig. 3), different results were observed. In general, the  $I_{AD}$  had a higher  $R^2$  with firmness and compression than did the  $h^\circ$  of the ground color with the same parameters. In addition, the fruit/flesh firmness, as measured with the 7.9 mm probe and with the needle, had a higher  $R^2$  with  $h^\circ$  and  $I_{AD}$  than did the compression strength with the same parameters

(Figs. 2 and 3). The highest  $R^2$  was observed in ‘Sweet September’ in the correlation of needle firmness/ $I_{AD}$  (Fig. 2D), and the lowest in ‘Kakamas’ (Fig. 2). Comparing the two probes based on puncture tests, in all cases, the needle had a higher  $R^2$  than the 7.9 mm probe when correlated with  $I_{AD}$  (Fig. 2A–C) and  $h^\circ$  (Fig. 3A–C) of the ground color. In addition to the higher  $R^2$  observed in the correlations with  $I_{AD}$ , the  $I_{AD}$  data displayed a much more homogeneous distribution throughout the entire range than the  $h^\circ$  of the skin, which is particularly valuable in ‘Kakamas’ (Fig. 2C, F and I), even if this genotype had a weak association between the skin features and firmness. These particular genotypes may require a more detailed analysis to determine which physical principle or probe, be it compression, puncture,



**Fig. 4.** Bi-plot principal component analysis (PCA) of ripeness indicators and quality parameters of peaches ‘Ryan Sun’ (RS), ‘Sweet September’ (SS), and ‘Kakamas’ (K), harvested at the commercial ripeness stage (M3) and then maintained in a ripening chamber (22 °C and 80% RH) until the flesh reached an adequate firmness for consumption. The number of days counted after harvest for each cultivar is indicated in brackets beside the cultivar name.

tension or another, is the most useful for overall characterization of ripeness.

In the flesh firmness range evaluated in this experiment (between 100 and 40 N, as determined by the 7.9 mm plunger), the compression strength appears not to be associated either with  $I_{AD}$  (Fig. 2G–I) or with  $h^\circ$  (Fig. 3G–I), nor are the puncture tests. It was previously reported in Japanese plum that compression strength is a useful parameter that could be easily measured on the same fruit repeatedly, allowing evaluation of a real softening rate over a given time span (Infante et al., 2011b). In contrast, Valero et al. (2007) reported low correlations between flesh firmness scores and measurements from the non-destructive impact response device Sinclair iQTM. These authors highlighted that these results indicated that the device measures a different physical property (tissue elasticity) during ripening, rather than the maximum force measured by the penetrometer.

### 3.3. Monitoring postharvest flesh softening

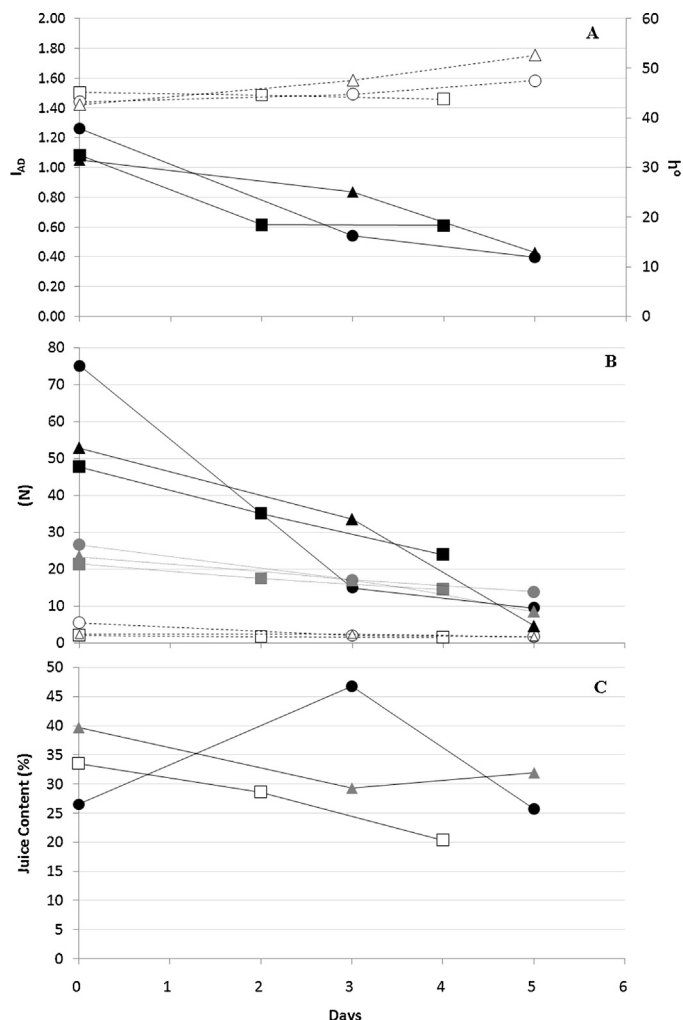
In the PCA, the first two principal components explained 85% of the total variance of the texture components and the optical properties of the skin (PC1 = 67.2% and PC2 = 17.8%) (Fig. 4). PC1 was defined positively by the texture parameters (needle firmness, 7.9 mm firmness and compression strength) and  $I_{AD}$ . The  $h^\circ$  of the ground color was negatively related to all texture parameters and  $I_{AD}$ . PC2 was associated positively with the juice content, and this parameter proved to be independent of all others.

When the curves of each parameter measured at postharvest were compared using a MANOVA test, all three cultivars showed a similar evolution, which rendered it impossible to group the melting genotypes together or other associate the genotypes in any other way (Fig. 5). In general, a decrease was observed in the  $I_{AD}$  and all of the texture parameters (Fig. 5A), with significant differences ( $P < 0.05$ ) being recorded among the varieties during this phase.

The softening rates of the melting flesh genotypes continuous decreased until the fourth to fifth day postharvest, reaching less than 20 N (Infante et al., 2011c), whereas the non-melting genotypes showed symptoms of dehydration or rotting before reaching such flesh firmness scores.

'Ryan Sun' reached its maximum juice content score (46.8% w/w) after three days of shelf life at 20 °C, but after five days, the juice content decreased. 'Ryan Sun' has a flesh characterized by an increase in the release of free juice as the flesh melts (Fig. 5C). Melting fruits soften during ripening, a process primarily associated with the changes in the parenchyma cell walls. These genotypes are more susceptible to developing mealiness after exposure to low temperatures, a symptom of a complex syndrome known as a "chilling injury" (Lurie and Crisosto, 2005). In this case, this drop might not be connected to chilling injury because the fruit was kept at 20 °C, which is over the threshold temperature for the onset of damage. In the case of the non-melting 'Kakamas', the juice content reached 20.4% after four days (Fig. 5C). This difference may not be attributable to either dehydration or mealiness because this difference was already obvious at harvest and because the fruit was not subjected to cold storage. The better explanation may be that non-melting genotypes have a higher capacity for calcium binding in the water-insoluble pectin fraction than fruit from the melting-flesh genotypes (Manganaris et al., 2006).

The  $I_{AD}$  decreased in all genotypes, whereas the  $h^\circ$  of the ground color showed a flat evolution (Fig. 5A), appearing to not be an informative index under these conditions. A similar trend has been observed in Japanese plums close to consumption firmness; in that case, the  $h^\circ$  of the ground color acquired an asymptotic trend over time, precluding the segregation of ripeness classes based on this parameter (Infante et al., 2011b).



**Fig. 5.** Change in the ripeness indicators and quality parameters throughout a postharvest period in peaches 'Ryan Sun' (○), 'Sweet September' (△), and 'Kakamas' (□) maintained in a ripening chamber (22 °C and 80%RH) until the flesh reached an adequate firmness for consumption. On (A), the continuous line represents the  $I_{AD}$  and the segmented line represents the  $h^\circ$ . On (B), the continuous black line represents flesh firmness measured with the 7.9 mm plunger; the continuous gray line represents the uniaxial compression strength of the whole fruit; and the segmented gray line, the fruit firmness measured with a needle. (C) Shows the juice content of the three cultivars. Different letters indicate significant differences between varieties ( $P < 0.05$ ).

In terms of probes for measuring fruit/flesh firmness, although the needle was the most effective method for flesh firmness determination above 40 N (determined with the 7.9 mm-plunger), as was presented earlier (Table 1), it is not sufficiently sensitive below this threshold (Fig. 5B). In fact, the contact area of the needle with the fruit surface is so small that the skin is the only tissue which is really being measured because the flesh is too soft to provide a measurable resistance to a low sensitivity probe, indicated by a flat evolution postharvest.

## 4. Conclusions

Establishing the optimal harvest time in peach is a crucial issue because it regulates the softening rate to a great extent during the postharvest period and thereby determines the potential shelf life of the fruit. The segregation of peaches with different fruit/flesh firmness and compression at harvest, when determined in a flesh firmness range between 100 and 40 N, could be indexed to the  $I_{AD}$  or to the  $h^\circ$  of the ground color. Between the two indicators, the

$I_{AD}$  had a higher correlation when firmness was determined for the whole fruit with the needle than with the 7.9 mm plunger. The uniaxial compression determination exhibited less association with the optical features of the skin.

When peaches approach consumption ripeness, which occurs in the last part of the commercial chain, immediately before acquisition by consumers, the  $h^{\circ}$  of the ground color did not represent a valid indicator of the mechanical properties of the fruit, as this changes only slightly postharvest, whereas  $I_{AD}$  still shows a close association with fruit texture. At this firmness range, the needle is not capable of characterizing firmness changes because the fruit is too soft, whereas the compression strength and the 7.9 mm plunger are still able to characterize these changes.

Our results indicate that ripening behavior is characteristic of each individual cultivar and that this behavior must be monitored with the most informative methods available in terms of the firmness range of the samples. This approach will facilitate the planning of appropriate postharvest procedures that enhance the quality of the product.

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