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Use of Vis/NIR Spectroscopy to Assess Fruit Ripening Stage and Improve Management in Post-Harvest Chain

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ABSTRACT

Fruit "quality" is a concept encompassing sensory and mechanical properties, nutritive values, safety and defects. Fruit quality has declined, determining consumer dissatisfaction, largely due to the wrong harvest date; in addition, quality is badly defined since the parameters mainly considered are fruit size and skin color. Other attributes such as flesh firmness, sugar content, acidity and aroma, are perceived by the consumer as fruit global quality, are seldom considered by the farmer and by other individuals along the chain. Up to now, several studies have been carried out on fruit quality assessment by using traditional methods, which are affordable and fast, but do not consider other quality traits, as antioxidant power, aroma volatile emission, soluble sugars and organic acids content. The assessment of these parameters is time consuming and requires sophisticated equipments (i.e. HPLC, GC-MS). Moreover, destructive analyses can be performed only on a limited number of fruit. In recent years, extensive research has been focused on the development of non-destructive techniques for assessing internal fruit quality attributes allowing extending the assessment to a high number of fruit, to repeat the analysis on the same samples monitoring their physiological evolution, and to achieve real-time information on several fruit quality parameters at the same time. Among the non-destructive techniques, visible/Near Infra Red spectroscopy (vis/NIR) can be efficiently used for determining traditional fruit quality traits and concentration of the main organic acids and simple sugars. In addition, this technique allows defining a new maturity index strictly related to fruit ethylene emission and ripening stage. This index, called "Absorbance Difference" index (I_{AD}), which can be used for precisely determining harvest date, and for grouping harvested fruit in homogeneous classes which show a different evolution of the ripening syndrome during shelf-life.

Keywords: DA-Meter, fruit quality, shelf-life, sugars

Abbreviations: E-nose, electronic nose; **FF**, flesh firmness; $\mathbf{I_{AD}}$, index of absorbance difference; **NIRs**, near infrared spectroscopy; **SSC**, soluble solids content; **TA**, titratable acidity

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INTRODUCTION

Fruit "quality" is a concept encompassing sensory properties (appearance, texture, taste and aroma), nutritive values, mechanical properties, safety and defects. Altogether, these attributes give the fruit a degree of excellence and an economic value (Abbott 1999). The quality of any given fruit can be viewed as the sum of all its sensory, mechanical and nutritional parts or properties. While fruit quality is thought to be an important component of consumer appeal, it can only be speculated to what extent this expectation holds true. Indeed, even trying to come up with an overall concept about fruit quality has thus far proven more complicated than expected, especially given the fact that the production-marketing chain from orchard to consumer table involves more than one individual (grower, packer, wholesaler, retailer, stocker, shopper and the consumer, or the person usually referred to as the one who ultimately eats the fruit). Each of these individuals expects different attributes of fruit, such as high yield, high flesh firmness for easy manipulation, long shelf-life, and so forth, and may confuse these with "fruit quality." Quality can thus be a context-sensitive concept, so that determining what traits to measure and how to measure them in laying out a framework of minimum parameters and values to rate fruit quality traits is an important issue. In addition, there is now an increasing appreciation that "quality" means also nutritional properties (e.g. vitamins, minerals, dietary fibre) of fruit and health benefits (e.g. antioxidants) are becoming important factors in consumer preference. Experimental, epidemiological and clinical studies evidenced that the diet carries out an important role in the prevention of the chronic-degenerative diseases, as tumours, cardiovascular diseases and atherosclerosis. It is supposed, in fact, that the consumption of fruit and fresh vegetables exerts a protecting role against the development of such pathologies (Doll 1990; Ames *et al*. 1993; Dragsted *et al*. 1993; Anderson *et al*. 2000).

For most of the fruits already in marketing circuits,

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quality has been defined and characterized so that it has the same meaning for all individuals marketing fruit via computer. People use their sense perception to judge quality and integrate the derived sensory inputs into a final judgment about the acceptability of a given fruit. In order to have the same meaning for a given quality among individuals dealing with the same tasks (such as researchers or marketing people), instruments are essential to reduce variations and provide precise and objective data.

However, fruit quality at harvest, during storage and consumption is traditionally assessed on a limited number of traits (e.g. soluble solids content, flesh firmness, acidity, starch) that, besides representing to some extent internal fruit quality, are widely used mainly because of their simplicity and are assessed with simple devices such as penetrometers and refractometers, and enable decisions to be made in real time. For example, the harvesting date of kiwifruit fruits is based on the amount of soluble solids (6.2° Brix) (Testolin *et al.* 1994; Costa *et al.* 1999; Andreotti *et al.* 2000; Costa *et al.* 2000) and more recently on dry matter, which must reach at least 15% (Montefiori *et al.* 2003**)**. Yet these determinations are destructive and, as a result, are carried out on a limited number of fruit samples. This raises the question as to how representative the sample lot is of the totality of harvested fruits, which is further complicated because it has been shown that quality of fruits from a single vine are highly variable (Smith *et al.* 1994). Another example might consider peach and nectarine: in these species, fruits are usually picked on the basis of fruit size and skin blush and it is also a rule of thumb to harvest peach fruits at high flesh firmness values to overcome any damage during sorting, transport and the other further handling operations the fruit is subject to before reaching the table. Yet high flesh firmness can also signal incomplete fruit ripening and, hence, insufficient quality level at eating time. As a consequence, the definition of the proper harvest time is essential, as fruit maturity at harvest greatly influences peach fruit market life potential and quality. Reaching proper "on-tree ripening" and determining the precise harvest date thus take on marked importance when it comes to achieve the quality levels required by an increasingly more demanding market (Shewfelt 1998).

It has however to be said that fruit quality standard was enhanced in the last recent years, although consumers were not always satisfied of the quality of the fruits at the point of sale (Crisosto *et al.* 2005). In fact, although fruit quality is recognized as a very important aspect and it is known that the ripening stage at harvest influences the quality at consumer level, fruit quality in the practice is determined by simple analyses of traditional fruit quality traits, that, although cheap and fast, are not precise and do not consider other fundamental aspects of quality, as antioxidant power, volatile aroma emission, soluble sugars and organic acids content, which will characterize with a much higher precision the ripening stage of the considered fruits (**Fig. 1**). A more accurate definition of fruit quality would require sophisticated analyses (i.e. HPLC, gas chromatography -GC-, mass spectrometry-MS-, GC-MS) that are not usually run because they should be carried out only in well equipped laboratories with trained personnel. In any case, simple or more complex destructive analyses can be performed only on samples of a limited number of fruit, often not fully representative of the entire lot (Costa *et al.* 2002, 2003).

In recent years, extensive research has been focused on the development of non-destructive techniques for assessing internal fruit quality attributes in Japan, New Zealand Australia, USA and Italy. These new approaches make it possible to determine quality traits on a large number of fruits, to repeat assays on the same samples and to monitor their physiological changes through pre-harvest ripening and during storage, to select the sample most representative of the variability of the studied population, to determine different attributes with the same measurement and, hence, to increase the amount of useful information obtained (Kawano 1994 a and b; Abbot 1999). The methods being used commercially, or that are still under research, are based on electromagnetic (NIRs, NMR, nuclear magnetic resonance), electrochemical (e-nose or electronic nose) and the electromechanical (impact) principles (Clark *et al.* 1997; Di Natale *et al.* 1997; Schulz *et al.* 2000; Di Natale *et al.* 2001; Ruiz-Altisent *et al.* 2006; Nicolaï *et al.* 2007).

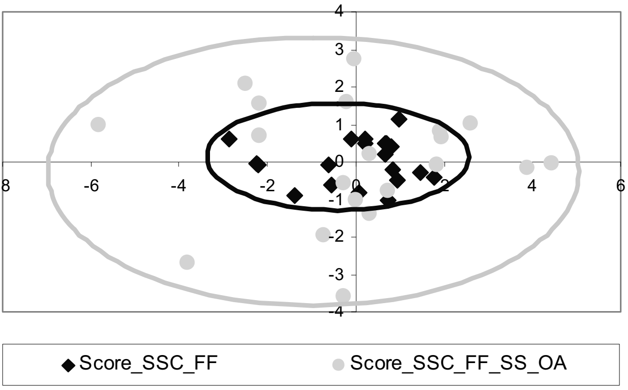

Fig. 1 Principal component analyses comparison as affected by soluble solid content (SSC) and flesh firmness (FF) (rhombuses) alone or together with simple sugars (SS) and organic acids (OA) (circle).

Among these methods those using optical properties such as NIRs are the most adopted in the practice.

NEAR INFRARED SPECTROSCOPY (NIRs)

Optical properties indicate the response of fruit matter to visible light (400-700 nm) and the near-infrared (700-2500 nm) wavelengths and allow the study of molecular structure and dynamics resulting from the absorption, emission and scattering of light. NIRs is used for identification of molecules containing hydrogen atoms and for quantitative analysis of water, alcohol, amine and other compounds containing C-H, N-H and/or O-H groups. NIRs use three operating modes: "reflectance", "interactance" and "transmittance". The one to be used depends upon detector position and configuration and light intensity. When the fruit is exposed to the light, part of it is reflected, part transmitted and part is absorbed. Those that exploit electromagnetic properties are among the most widely employed while those that use NIRs are being increasingly employed in different fruit storage and handling facilities for sorting and grading fruits (Kawano 1994a, 1994b; Peirs *et al.* 2000). Indeed, many of these novel tools are linked to graders and can work at the same speed. Then, too, some of the NIRs instruments are portable, non-destructive to the fruit and make it possible to determine the evolution of various ripening parameters in the field with the fruit still on the tree or even to track changes that can occur during the initial stages of cold storage (Costa *et al.* 1999, 2002).

As far as the optical configuration is concerned, two different options are described. In the first one, the bifurcated optical configuration (**Fig. 2A**), the light is generated by a tungsten halogen lamp, and is carried to the sample by at bundle of optical fibres. From the sample other optical fibres are used to selectively reflect the light back to the spectrometer. At the end of the bifurcated cable, the probe is lean on directly to the skin of the fruit. This system can only be used in the 380 to 1650 nm wavelength range (Lammertyn *et al.* 2000).

In the second configuration (**Fig. 2B**), fruits are irradiated directly determining a higher light intensity than the first model. In this optical configuration, all optical fibres are used to bring back the light to the spectrometer. In addition, the probe does not lean on the fruit, to avoid measurement of surface reflections and to allow light penetration into the fruit, a rubber ring is positioned around the probe head. In both cases the light reflected by the fruit is separated into single wavelengths; each transformed into an electric signal via an optic transducer. An ADC (Analog to

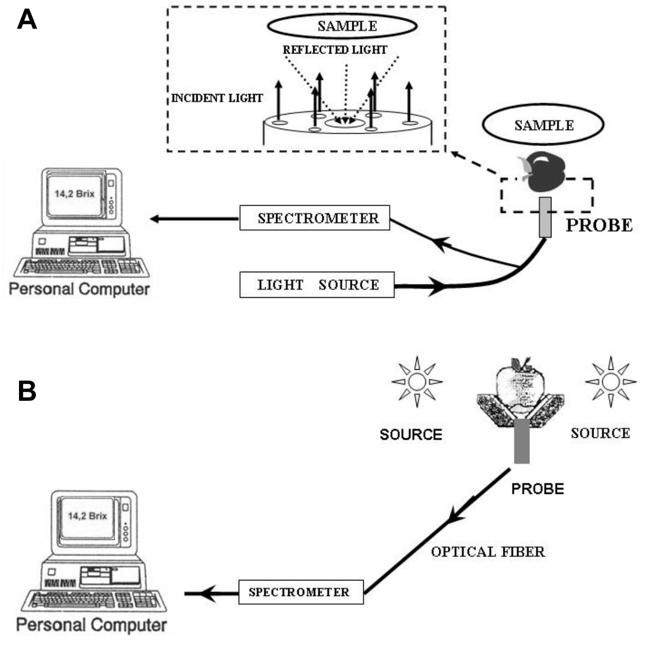

Fig. 2 The optical configuration with bifurcated optical fibre (**A**). The optical configuration with external light source (**B**).

Digital *Converter)* electronics unit is used to amplify and digitise the spectral signal. Data acquisition and spectra storage is achieved with a PC (McGlone *et al.* 2001).

All non-destructive methods in general, help increasing the amount of information obtained. The NIRs system, in particular, compared with conventional analytical methods, allows to carry out analysis within 1 second time, and does not require any sample preparation for liquids, solids or gases. Since no reagents are used, the cost per analysis is very low. NIRs determinations allow establishing physical properties and biological effects that can be calculated from spectra of samples. Moreover the detection limits can be very low.

These non-destructive devices allow establishing multiple parameters on several species. Nicolaï *et al.* (2007) reported in a recent review on NIRs spectroscopy, the possibility to determine up to 4 quality parameters of fruits and vegetables with only one reading. On some fruits species it has also been shown the possibility to establish a higher number of fruit quality traits simultaneously. In **Table 1** the traditional parameters such as soluble solids content (SSC), flesh firmness (FF) and acidity (TA) as well as simple sugar and organic acid values predicted with NIRs are reported. As reported in **Table 1**, the value obtained with the prediction and the RMSEP (Root mean standard error of prediction) ranged on low or acceptable values confirming the efficiency of such technique as also reported by many authors (Nicolaï *et al.* 2007). It has however to be underlined that, although the possibility to obtain several quality traits with only one reading and with a good degree of precision is demonstrated, these results are obtained after several data processing step as standardisation, normalisation and transformation of the row data obtained. Thereafter, the chosen algorithm and variability of fruit set determine the model accuracy and robustness. In fact, to illustrate the importance of the model robustness, the scatter plots of the comparison of the measured spectral data set versus predicted values of the chosen parameters (normally soluble solids content or acidity) can show very low dispersion of the data (**Fig. 3**). Finally, the calibration transfer in the practice is a delicate step also considering that fruit temperature and other factors (cultivar, area of production, etc.) might affect the final results.

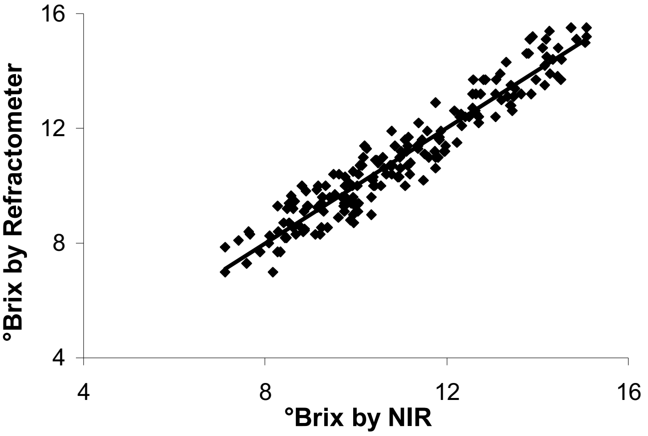

Fig. 3 Scatterplot of the calibration curve for SSC data. The model is used to control the robustness of the prediction.

Although these devices potentially allow to establish several parameters and to define with high precision the ripening stage reached by the fruits, their limit is represented by the need to repeat calibration on a high number of fruits depending upon the temperature at which fruits are maintained, the fruit calibre, the ripening stage and, to some extent, also the area of production. As a result of this, calibration must be verified and updated and much time is necessary to repeat and continuously adjust calibration, vanishing the vantages offered by such technique.

DA-METER

To overcome the problem of the repeated calibration, the Authors belonging to the Department of Fruit Tree and Woody Plant Sciences of the University of Bologna developed a simple device which allows to define the ripening stage reached by the fruits in a more simple a rapid way (**Fig. 4**). The instrument named DA-Meter is a portable, user-friendly vis/NIRs device capable to measure a new parameter, the Index of Absorbance Difference (I_{AD}). The DA-Meter is formed by 6 diode LEDs, all positioned around the photodiode detector, 3 diode LEDs emit at 670

Table 1 Parameters obtained with a unique NIRs reading. For each parameter it is necessary to have obtained a calibration model. S.D. is defined as Standard Deviation. RMSEC is defined as the root mean square error for calibration, RMSEP is defined as root mean square error for prediction.

	Unit	Min.	Max	S.D.	Average	R^2	RMSEC	RMSEP
Soluble Solids Content	°Brix	9.70	18.90	2.30	13.25	0.90	0.90	1.10
Firmness	N	5	71	21.3	39.5	0.60	13.7	14
Acidity	g/l Malic Ac.	4.61	12.10	1.84	8.68	0.90	0.45	0.88
Sucrose	g/l	48.81	97.17	11.75	67.50	0.93	2.96	5.00
Glucose	g/l	14.45	25.72	3.22	18.10	0.70	1.73	2.16
Fructose	g/l	12.40	19.75	1.91	15.07	0.84	0.73	1.11
Sorbitol	g/l	3.08	8.28	1.51	4.94	0.65	0.95	1.16
Citric Ac.	g/l	2.15	8.22	1.44	4.77	0.95	0.34	0.71
Malic Ac.	g/l	5.25	10.22	1.39	7.04	0.65	0.84	1.14
Quinic Ac.	g/l	2.57	4.43	0.45	3.35	0.60	0.28	0.23
Succinic Ac.	g/l	1.12	2.70	0.52	1.72	0.95	0.10	0.33

Fig. 4 The DA-Meter portable instrument. The dimensions of the instrument are 15 cm by 8 by 5 (length, width, thickness).

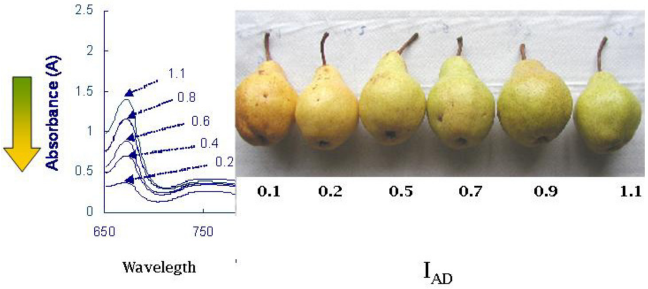

Fig. 5 Absorbance spectra of individual "Bartlett" pears collected throughout the last stages of fruit development. For each spectrum, arrows indicate the corresponding I_{AD} value.

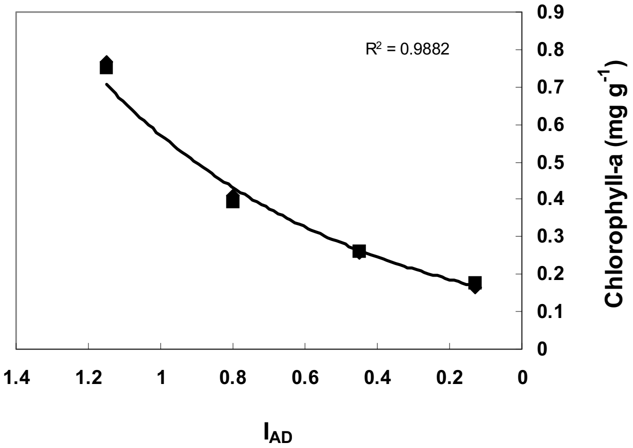

Fig. 6 Correlation between I_{AD} and chlorophyll-*a* amount in outer mesocarp of "Stark Red Gold" nectarines. Modified from Ziosi *et al.* 2008.

nm wavelength and the other 3 emit at 720 nm. The fruit, in a very short span of time, is illuminated alternatively with the 2 monochromatic light sources, and for each the amount of light re-emitted by the fruit measured. The environmental light is subtracted, measured with all the diode LEDs turned-off, and is assumed to be constant for all the measurement length. Light is detected by a photodiode positioned centrally to a diode crown, converted to a digital signal through an ADC converter (Analog to Digital *Converter*), and I_{AD}, derived via a microcontroller. Based on fruit absorbance spectra, the I_{AD} is calculated as $I_{AD} = A_{670} - A_{720}$ where A_{670} and $A_{720,}$ near the chlorophyll-*a* absorbance peak were the A values at the wavelengths of 670 and 720 nm, respectively.

In **Fig. 5** the absorbance spectra of individual "Bartlett pears collected throughout the last stages of fruit development are reported. For each spectrum, arrows indicate the corresponding I_{AD} value. It is clear from the figure that fruits of different ripening stages are characterized by different I_{AD} values. The instrument and the I_{AD} were patented by the University of Bologna (2005). In **Fig. 6** the strict correlation between I_{AD} and chlorophyll-*a* amount in the outer mesocarp of "Stark Red Gold" nectarines is shown; moreover, the I_{AD} decreases throughout fruit development and ripening. As a consequence, the DA-Meter allows to group fruits on the basis of their ripening stage in homogeneous classes. The DA-Meter does not allow itself to determine parameters such as SSC of FF or TA normally used to define fruit quality. This because these parameters do not define clearly the ripening stage and, when the fruits are grouped in classes of homogeneous ripening, these traits can be simply determined with traditional instruments (penetrometer, refractometer, etc). The DA-Meter do correlate with important parameters which modify with fruit ripening, such ethylene production, climacteric stage and, to some extent, flesh firmness, a parameters difficult to determine with non-destructive devices. In addition, the DA-Meter practically does not require any calibration and it can be used along all the productive chain, from the orchard on the fruits still attached to the tree up to the point of sale.

HOW CAN THE DA-METER IMPROVE MANAGEMENT IN THE POST-HARVEST CHAIN?

Assessment of the harvest time

The DA-Meter can be used to asses harvest time, since it allows the ripening stage evolution to be followed. The instrument, being portable and allowing the I_{AD} determination without any destruction of the fruits, can be used on a selected number of fruits "on the tree". Normally, harvest of many fruit commodity is established on the basis of practical parameters. For instance, peach and nectarine fruits are picked on the basis of fruit size and skin colour at high flesh firmness values to overcome any damage during sorting and further handling operations. The I_{AD} follows the ripening stage evolution and allows choosing the proper harvest time by correlating it with the parameters normally used to establish the picking time. Peaches and nectarines are climacteric fruit characterized by a sharp rise in ethylene biosynthesis at the onset of ripening, associated with changes in sensitivity to the hormone itself, and changes in colour, texture, aroma and other biochemical features. As a consequence, it is important that fruits are picked from the tree when ethylene emission starts in order to allow fruits to ripe in a proper way and reach the best quality traits for consumption.

The I_{AD}, however, also correlates with the traditional fruit quality traits, such as SSC, FF and TA (**Table 2**), although it is quite evident that a classification of the fruits on the basis of these parameters might lead to some misunderstanding; in fact, fruits of the first two classes of Stark Red Gold do not differ for flesh firmness and acidity while are statistically different for SSC (**Table 2**).

Indeed, the robustness of I_{AD} is confirmed by the fact

Table 2 Ethylene production, SSC, FF, and TA of, 'Stark Red Gold', fruits graded at harvest according to the I_{AD} (class 0: pre-climacteric; class 1: onset of climacteric; class 2: climacteric). Different letters indicate significant differences at P<0.05 according to the Newmann-Keuls's multiple range test. Modified from Ziosi *et al.* 2008.

	Class	**I_{AD}**	**Ethylene production ($nl\ l^{-1}\ h^{-1}\ g^{-1}FW$)**	**FF (N)**	**SSC (°Brix)**	**TA ($g\ l^{-1}$ malic acid)**
Stark	0	1.2-0.9	0.00 ± 0.00 c	52.0 ± 2.0 a	12.3 ± 0.3 b	10.6 ± 0.6 a
Red	1	0.9-0.6	0.66 ± 0.10 b	47.0 ± 2.0 a	13.3 ± 0.3 a	10.5 ± 0.5 a
Gold	2	0.6-0.3	3.50 ± 0.44 a	25.0 ± 4.0 b	13.6 ± 0.2 a	7.7 ± 0.5 b

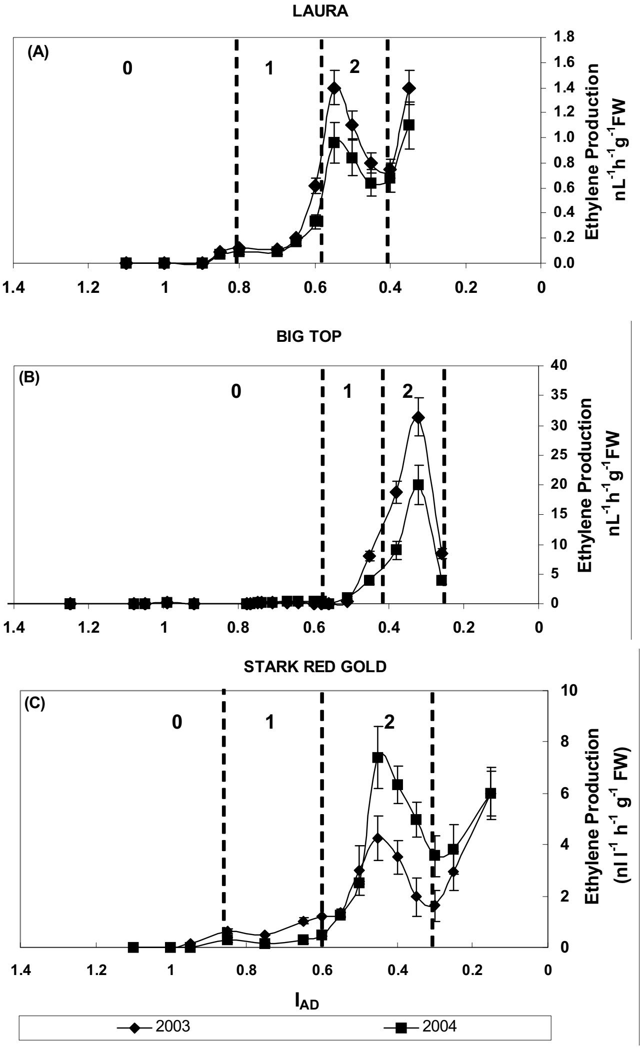

Fig. 7 Changes in ethylene production, as a function of the I_{AD}, during ripening of "Laura" (**A**), "Big Top" (**B**) and "Stark Red Gold" (**C**) fruit in the seasons 2003 and 2004. Dashed lines indicate the I_{AD} ranges belonging to pre-climacteric (0), onset of climacteric (1), and climacteric (2) stages of ripening. Modified from Ziosi *et al.* 2008.

that, being correlated with ethylene, the hormone that plays a key role in peach fruit ripening by coordinating the expression of ripening-related genes responsible for flesh softening, colour development, and sugar accumulation (Ruperti *et al.* 2002; Trainotti *et al.* 2003, 2006), any modification of such parameters correlate with the I_{AD}. As a further confirmation of the high correlation between I_{AD} and quality parameters in peach and nectarine, the I_{AD} results strongly correlated with transcript levels of ripening related genes, such as 1-aminocyclopropane-1-carboxylate oxidase (ACO1), pyruvate decarboxylase (PDC), a bZIP transcription factor (bZIP), polygalacturonase (PG), 1-aminocyclopropane-1-carboxylate synthase (ACS1), pectinesterase inhibitor (PEI) which were up-regulated during ripening (Ziosi *et al.* 2008). On the contrary expansin 2 (EXP2), a dehydration-induced protein RD22-like (RD22), catalase (CAT), an unknown protein (UK), a putative sorbitol transporter (ST) were down-regulated during ripening. This underlines that the classes made by the DA-Meter are clearly distinct and characterized by a very uniform ripening stage.

Another advantage of the DA-Meter use is also represented by the fact that when the ripening stage to perform the harvest is assessed, this value is constant in subsequent years. In fact, in a specific experiment carried out in peach and in apricot, it was pointed out that in all the years in which the trials were carried out, the I_{AD} values were the same. They always coincided with the ethylene peak although the absolute values were slightly different in intensity. In **Fig. 7** changes in ethylene production, as a function of the I_{AD}, during ripening of 3 nectarine cultivar are reported: "Laura" (A), "Big top" (B) and "Stark Red Gold" (C). It is clear that the I_{AD} represents a tool for classifying fruit as belonging to different climacteric stages of ripening.

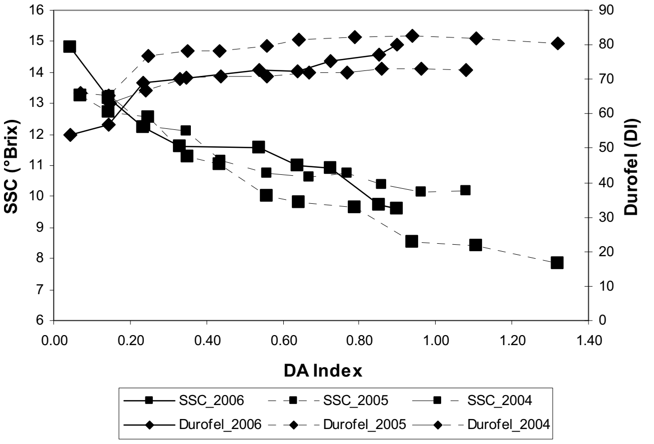

Fig. 8 Changes in soluble solids content (SSC) and elasticity (DI - Durofel Index), as a function of the I_{AD}, during ripening of "Orange Red" apricots. Modified from Costa *et al.* 2008.

It is important to underline that while the I_{AD} value is constant year after year, the levels of the traditional parameters, such as SSC or FF changes. In fact, trials carried out in 2004, 2005, and 2006 on apricot cultivars in order to verify the capability of the I_{AD} to monitor ripening-related changes, show that the index was related to SSC and DI (durofel index), which are the physic-chemical parameters mainly used to establish the optimal harvest time (Lurol *et al.* 2007). The trials showed that SSC and FF values were variable in different seasons, although the I_{AD} value chosen to perform the harvest resulted constant. In all the years, the relationship I_{AD}/SSC and I_{AD}/DI was similar. In fact, in "Orange Red" apricot fruit characterized by I_{AD} higher than 0.8, SSC was below 10.0 °Brix; in the I_{AD} 0.8-0.5 range, SSC was between 10.0 and 11.0 °Brix, while fruit with I_{AD} lower than 0.5 had SSC higher than 11.0 °Brix. As far as the traditional index used (DI) is concerned, it remained unchanged until the I_{AD} reached 0.3 and decreased thereafter (**Fig. 8**). Present results show that the I_{AD} is able to monitor changes in fruit quality occurring during apricot fruit ripening, as previously reported in peach (Ziosi *et al.* 2008).

Consumer acceptability

As far as the consumer acceptability is concerned, here some results of trials carried out on apricot and peach cultivars are reported. Apricot fruit belonging to cvs. "Orange Red" and "Bergarouge" were subdivided into three classes (unripe, intermediate, ripe) according to decreasing values of the I_{AD} and, for each sample, the consumer was asked to indicate their degree of liking/disliking by using a nine-point hedonic scale (1-dislike extremely to 9-like extremely). In "Orange Red" apricots, fruit graded according to the I_{AD} were differentially appreciated by the consumer: in fact, class 2 fruit showed the highest percentage of consumer acceptance (87 and 76% after short and long storage, respectively); while class 0 ones had the highest percentage of consumer disliking (58 and 59% after short and long storage, respectively). High consumer acceptance (51 and 44% after short and long storage, respectively) was recorded also for class 1 fruit, although lower than that expressed for class 2 ones (**Table 3**). Similar results were obtained in "Bergarouge" fruit graded at harvest according to the index (**Table 4**), demonstrating that the I_{AD} is able to precisely grade apricot fruit into homogeneous classes of ripening characterized by quality traits and consumer acceptance (Costa *et*

Table 3 Percentage of consumers liking (score > 5), neither liking nor disliking (score = 5), and disliking (score <5) of 'Orange Red' apricots graded at harvest according to the I_{AD} (class 0: 1.2-0.8; class 1: 0.8-0.5; class 2: 0.5-0.2. Fruits were stored at 8°C for 2 days or at 1°C for 11 days. In both cases, fruit were kept at 20°C for 2 days before the consumer test. Modified from Costa *et al.* 2008.

	Stored at 8°C for 2 days			Stored at 1°C for 11 days		
Score	**Class 0**	**Class 1**	**Class 2**	**Class 0**	**Class 1**	**Class 2**
<5	58	34	4	59	32	13
5	20	15	9	21	24	11
>5	23	51	87	20	44	76

Table 4 Percentage of consumers liking (score > 5), neither liking nor disliking (score = 5), and disliking (score <5) 'Bergarouge' apricots graded at harvest according to the I_{AD} (class 0: 1.5-1.0; class 1: 1.0-0.5; class 2: 0.5-0.2). Modified from Costa *et al.* 2008.

Score	Class 0	Class 1	Class 2
<5	54	27	19
5	18	17	9
>5	29	56	73

Table 5 Percentage of consumers liking 'Big Top nectarine graded at harvest according to the I_{AD} (class1=1.0-1.4; class 2: 0.8-01.0; class 3= 0.6-0.4). Consumers acceptance expressed as an arbitrary score from 1=dislike extremely to 5-like extremely).

	Class 1	Class 2	Class 3
Colour	3.8	3.7	4.1
Firmness	3.1	3.3	3.7
Sweetness	2.7	3.0	3.5
Taste	2.9	3.2	3.6
Total score	2.8	3.1	3.6

al. 2008).

Similar results were obtained on peaches and nectarine. Also in this specie the consumer preference was related to the different I_{AD} values reached by the fruits at harvest (**Table 5**). These results showed that the ripening uniformity of the fruits graded on the basis of the I_{AD} index is quite robust and allow the consumer to clearly distinguish the fruit classes according to their ripening.

Shelf-life forecasting

Shelf-life forecasting might represent an important aspect for improving management in post-harvest chain as well as the acceptability of the fruits the consumers are purchasing at the point of sale. In fact, the shelf-life is strictly correlated with the characteristics the fruits have at harvest, which also contribute to define the storage strategy. Specific trials carried out on peach and nectarine showed that Laura nectarine fruit belonging to classes 1 (0.8-0.6 I_{AD}) and 2 (0.6-0.4 I_{AD}) showed significant differences in ethylene production and quality traits at harvest. In fact, in class 1, ethylene production was detectable but markedly lower than in class 2; class 1 fruit also showed significantly higher FF and TA relative to class 2, while no differences in SSC were recorded (**Table 6**). In control nectarines of both classes, ethylene production increased and reached the climacteric peak at 12 (class 2) or 36 h (class 1) (**Table 7**). In class 1 fruit, FF did not change up to 12 h, and then gradually decreased during the following trial period. In class 2, FF felt down within 36 h after harvest (**Table 7**).

In another experiment carried out on "Laura" nectarine and "Fayette" peach, the shelf-life duration was arbitrary computed as the number of hours necessary to reach the FF value of 1 kg/cm^2 which was considered proper for consumption. The fruits of the two cultivars were divided at harvest in two I_{AD} classes (1= 0.8-0.6 and 2= 0.6-0.4 for "Laura" and 1= 0.8-0.5 and 2= 0.5-0.2 for "Fayette" fruits). These two classes require 12 to 60 hours respectively for "Laura" and 20 to 60 hours for the two "Fayette" fruit classes. It is interesting to point out (**Fig. 9**) that the fruits of both cultivars were also characterized by a different softening trend during the experiment span of time (**Fig. 9**). As a conclusion, it appears possible to forecast the shelf-life duration on the basis of the I_{AD} values determined at harvest potentially allowing the fruit marketing distribution to exhibit fruits of the same ripening stage in separate containers at the point of sale.

As a conclusion the vis/NIRs technique could represent a powerful tool to precisely assess fruit ripening stage and

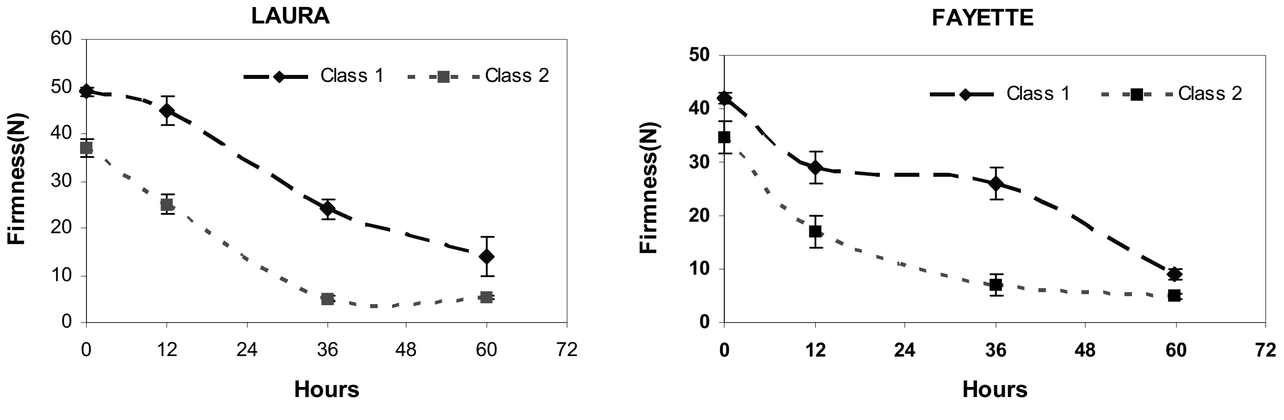

Fig. 9 Shelf-life duration (expressed as hours necessary to reach 1 kg/cm^2 penetrometer reading) of "Laura" and "Fayette" nectarine fruits kept at room temperature. Modified from Ziosi *et al.* 2008.

Table 6 Ethylene production, FF, SSC and TA of class 1 and class 2 'Laura' nectarines at harvest. Modified from Ziosi *et al.* 2008.

Class	I_{AD}	Ethylene (nl h^{-1} g^{-1}FW)	SSC (°Brix)	FF (N)	TA (g l^{-1} malic acid)
1	0.8-0.6	0.1 ± 0.1	10.1 ± 0.2	49.0 ± 1.0	13.0 ± 0.6
2	0.6-0.4	0.7 ± 0.5	10.3 ± 0.2	37.0 ± 1.0	11.0 ± 0.5

Table 7 Ethylene production and FF of class 1 and class 2 'Laura' nectarines kept at 25°C up to 60 h after harvest. Modified from Ziosi *et al.* 2008.

		Class 1			Class 2		
		12 h	**36 h**	**60 h**	**12 h**	**36 h**	**60 h**
Ethylene	C	1.0 ± 0.3	1.5 ± 0.2	1.1 ± 0.2	2.3 ± 0.5	2.0 ± 0.3	2.5 ± 0.5
FF	C	40.0 ± 3.0	28.0 ± 2.0	14.0 ± 4.0	25.0 ± 2.0	5.0 ± 1.0	5.0 ± 0.3

improve management in the post-harvest chain. The DA-Meter in particular is easy to use and can be adopted by several individuals all along the productive chain from the field to the point of sale.

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