



## On-tree follow-up of apricot fruit development using a hand-held NIR instrument

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### Abstract

The follow-up of apricot fruit development on tree until harvest is of prime importance as it influences the fruit quality at harvest. Until now, fruit follow-up in the orchard depends mainly on the expert eye of the producer and no objective measurement exists to help the professional to monitor their orchard. In practice, a non-destructive helpful tool would be suitable for use in the field during fruit growing. The present study aimed at developing a hand-held near infrared spectroscopic technique to non-destructively follow the fruit development of two apricot varieties: Bergarouge and Harostar. To start with, a classification approach has been tested to characterize the fruit as a function of a given picking date during growing. Factorial discriminant analysis (FDA) applied to destructive measurements allowed the correct classification of 89% (Harostar) to 92% (Bergarouge) of fruits. Analyses performed on spectral data allowed the correct classification of 96% of fruits whatever the variety. Secondly, partial least squares (PLS) regressions were performed to determine the physico-chemical values during the fruit development. The soluble solids content was determined with a precision of 0.85°Brix and 1.47°Brix to Bergarouge and Harostar varieties, respectively. Firmness was determined with a precision of 2.7% and 6.2% to Bergarouge and Harostar varieties, respectively.

**Key words:** Pre-harvest, soluble solids content, acidity, firmness, orchard, apricot, non-destructive, near-infrared spectroscopy, FDA, PLS, classification, quantitative prediction.

### Introduction

To date, the maturity of apricots in orchard is estimated by means of the subjective judgments of an expert eye. No objective and normalized measurement exist to help the producer. Maturity at harvest is determined only according to the fruit calibre and the background colour of the peel. However, the market requires a minimum level of firmness and a given “soluble solids content – acidity” balance that is specific for a given apricot variety. The development of a measurement method capable of following fruit maturity from green fruits until harvest time would be highly advantageous.

Among the non-destructive methods applied to agri-food products, near infrared spectroscopy (NIR) remains one of the least expensive and most successful methods. Previous studies principally focused on apple, mango and kiwi fruit. In apple, NIR absorbance has been correlated to some sensory attributes<sup>1</sup> and successful in prediction of several physico-chemical quality parameters such as soluble solids content, acidity and firmness<sup>2-6</sup>. NIR has also been used to detect some internal fruit disorders<sup>7</sup> and to characterize apples during storage and a shelf-life period<sup>8</sup>. Several correlations between NIR data and some physico-chemical parameters of mango fruit have been established<sup>9</sup>. Other studies permitted estimation of the internal quality of kiwi fruit<sup>10-12</sup>.

Pre-harvest, visible near infrared spectroscopy has been used to determine the optimal picking date and to predict SSC and firmness of apple<sup>5,13,14</sup>. Also, the negative effect of the natural variability of fruits on predictive models of firmness and SSC of a

given apple variety has been pointed out<sup>5</sup>. In this study, the accent is put on the importance to perform a mathematical model by variety and avoid a too important mix of uncontrolled variability.

In apricots, few studies have been performed and scientific data remain scarce. However, recent studies permitted bringing to light good correlations between near infrared measurements and SSC and firmness values of apricots<sup>15,16</sup>.

Widely developed for post-harvest use, near infrared spectroscopy has found little use pre-harvest, whatever the considered fruit. However, recent development in hand-held equipment is somewhat promising for use of this technique in the field.

The purpose of our study was to develop a non-destructive method, based on near infrared spectroscopy, capable of following apricot maturity on the tree. To commence with, the variation in physico-chemical values has been analyzed to classify apricot fruits according to their maturity. Similar analyzes were performed based on near infrared spectra. Finally, the possibility of determining the physico-chemical characteristics of fruits by means of non-destructive NIR spectroscopy was investigated.

### Materials and Methods

**Apricot fruit:** Two apricot varieties, Bergarouge and Harostar, were analysed in the study. Fruits were picked in the experimental orchard of the Agroscope Changins-Wädenswil (ACW) research station (Switzerland) in 2008. To follow the evolution of fruits on

the tree, four samplings (P1, P2, P3 and P4) were determined (Table 1). P1 corresponded to the green fruits picked about 75 to 77 days after full bloom. P2 and P3 were intermediate stages of fruit growth (88 to 97 days after full bloom) and P4 the harvest time (106-108 days after full bloom). Each sample consisted of 25 fruits per variety picked on four trees. A total of 100 fruits per variety was analysed in this study.

**Destructive analyses:** Firmness ( $F_i$ ) of apricots was measured using a Durofel device fitted with a 0.10 cm<sup>2</sup> probe (Durofel, COPA-Technologie S.A./CTIFL). Two measurements were performed per fruit, first on the coloured side and then on the reverse side. All fruits of the samplings were analysed. The results were expressed in  $DI_{10}$  (Durofel Index, where the Durofel device was fitted with a 0.10 cm<sup>2</sup> probe).

Soluble solids content (SSC) of apricot juice was determined using a refractometer (ATAGO, C.O., LTD, Model PR-1) and expressed in °Brix. A juice per fruit was extracted and analysed.

Titration acidity (TA) was measured by means of a titrimeter (Metrohm, 719S, Titrino). Five ml of juice was titrated with NaOH (0.1 N) and the results were expressed in g/L of equivalent malic acid. A juice per fruit was extracted and analysed.

**NIR spectroscopy:** Spectra were directly acquired, in reflectance mode, on the whole fruit using a Visible-NIR spectrometer. The hand-held NIR device consisted of a commercial single-beam spectrometer (Ocean Optics S-2000, USA) with a standard diffraction grating (650-1200 nm, visible and near infrared). A 10-Watt tungsten halogen lamp generated the light. The reflected light was directed to the spectrometer via a bundle of 7200-µm optical fibre linked to the probe end<sup>17</sup>.

Fruits were analyzed the same day as their picking. Two spectral measurements per fruit were carried out on opposite sides (coloured and reverse (non-coloured) side) along the equator of the fruit.

**Factorial discriminant analysis (FDA):** FDA was used to classify the fruits according to the picking date and consequently their maturity. At first, the FDA was applied to the data resulting from destructive measurements, and secondly, to the spectral data obtained from the non-destructive measure.

FDA was carried out on the spectral data corrected by the standard normal variate method<sup>6</sup>. A given spectrum curve forms a vector  $x_i$  of  $p$  wavelengths. The  $n$  spectra were gathered into a matrix  $X$  dimensioned  $n \times p$ . In FDA, the qualitative groups to be discriminated were the picking dates (P1, P2, P3 and P4).

A criterion of the FDA efficiency is the proportion of correctly classified observations in validation sets. These validation tests were carried out by dividing the data matrix,  $X$ , into a training and a validation set. The FDA model was computed on the calibration set. The observations of the validation set were then classified using the established model. The correctly classified observations were then counted and expressed in percentages. Such validation tests were independently carried out ten times, placing two thirds ( $2n/3$ ) of the observations in the calibration set and the remaining ones ( $n/3$ ) in the validation set. FDA computes a set of discriminant scores, which are linear combinations of the original variables.

The discriminant scores are new “synthetic variables” calculated so they can discriminate the observations. It is important to examine

**Table 1.** Picking dates of ‘Bergarouge’ and ‘Harostar’ fruits. DAFB: days after full bloom.

Sampling	Date	DAFB: Bergarouge	DAFB: Harostar
P1	10 Jun. 08	77	75
P2	23 Jun. 08	90	88
P3	01 Jul. 08	97	95
P4: harvest	11 Jul. 08	108	106

the correlation between the discriminant scores and the predictive variables. For this purpose, the correlation coefficients between the discriminant scores and the original variables (600 steps of wavelength absorbance) were computed. As it is impossible to show 600 values of correlation coefficients, the correlation values were graphically represented as curves giving the correlation coefficient of the absorbance at each wavelength with a given discriminant score. All the statistical procedures were carried out using the Matlab 6.0 environment (The MathWorks, Inc., Natick, MA USA).

Data from destructive measurements as well the fruit calibre and weights were gathered in a common matrix  $Y$  dimensioned  $n \times p$  where  $n$  is the number of measurements and  $p$  the measured parameters:  $F_i$ , SSC, TA, calibre and weight.

In the same way to spectral data, FDA was applied to this data matrix  $Y$ . In this case; the groups to be discriminated were the picking dates (P1, P2, P3 and P4). The results were evaluated as previously described to spectral data.

**Partial least square regression (PLS):** In the study, PLS aims at building predictive models of data obtained from destructive analyses by using non-destructive spectral data. In order to minimise the overlapping effect of absorption bands and the variations due to radiation scattering, a second derivative was applied to spectral data<sup>4</sup>. Then, to obtain efficient and robust models, the smallest number of latent variables was used in the models<sup>18</sup>. Cross-validation procedures have been applied by placing (2/3) of spectra as the calibration set and the remaining (1/3) as the validation set. The accuracy of the predictions was discussed according to the correlation coefficient value ( $R$ , Eq.1), the root mean square error of calibration (RMSEC, Eq.2) and the root mean square error of cross-validation (RMSECV, Eq.2):

$$R = 1 - \frac{\sum (y_{pred} - y_{act})^2}{\sum (y_{pred} - y_{mean})^2} \quad (1)$$

$$RMSEC(CV) = \sqrt{\frac{\sum (y_{pred} - y_{act})^2}{n}} \quad (2)$$

$n$  is the number of spectra,  $y_{act}$  the actual value,  $y_{mean}$  the mean value and  $y_{pred}$  the predicted value of the data obtained from the destructive test.

## Results and Discussion

**On-tree fruit variability:** Data presented in Table 2 permitted a view of the overall variability of fruit during growing. The variability has been estimated by calculating the coefficient of variation (CV) expressed in percent. Two global trends appeared. First, the variability of ‘Harostar’ fruit was higher than that of ‘Bergarouge’ and second, the more we get closer to the harvest-time, the more the variability increases. Such variability makes difficult to perform an accurate follow-up of fruit. In order to minimize the effects of

the variability, the potential complementary information of the different measures from destructive analyses is investigated.

**Classification of fruit using destructive measurements:** In preliminary analyses, physico-chemical values obtained from destructive measurements were analysed by FDA in order to highlight the difference due to the picking date. Fig. 1 shows that in a first time the evolution of ‘Bergarouge’ fruits until P3 (1<sup>st</sup> Jul. 2008) sample is mainly dependent on the SSC-TA balance. As expected, SSC increased with time while TA decreased. Until P3, Fi was constant. After P3, SSC and TA remained steady while a rapid decrease of Fi occurred.

A similar course of values from destructive measurement has been noticed for ‘Harostar’ fruits (Fig. 2). However, the evolution in time of Bergarouge variety occurred step by step while that of Harostar variety was continuous. Consequently, the classification of the samples was slightly better for ‘Bergarouge’ (92% of correct classification in average, Table 3) than for ‘Harostar’ (89% of correct classification in average, Table 3). Such differences can be explained by the greater variability of destructive measurements of Harostar variety compared to Bergarouge one (Table 1). Nevertheless, the identification of the fruits according to the picking date remained good whatever the variety.

SSC and Fi are two well-known parameters of fruit quality. They are currently used to estimate the fruit quality mainly after harvest, during storage, shelf life or during commercial exchanges<sup>3,8</sup>. The results showed that SSC and Fi provide complementary information to follow the apricot development, SSC being important during the fruit growing (P1 to P3) and Fi during the final steps of development (P3 to P4). There appears to be a rupture in the course of development around P3. This period could correspond to the end of fruit growing (cell multiplication) and to the beginning of fruit development (cell enlargement). In apricots, this last step is well known to be very short in duration, being about 10-15

days. However, it is still difficult to exactly determine the transition moment between growth and development. In this way, the two periods of evolution of SSC and Fi could help to define this critical period. According to the FDAs, at least 96% (Bergarouge) and 88% (Harostar) of fruits, which have made the transition to P4, were identified.

**Classification of fruit using NIR spectroscopy:** A collection of 200 spectra has been constituted per variety (2 spectra x 25 fruits x 4 picking dates). Fig. 3 shows the average spectra of ‘Bergarouge’ and ‘Harostar’ fruits as a function of the picking dates. Two regions in the vicinity of 970 nm and 1100 nm present notable differences. Such absorbencies are currently due to the fruit water content. In both cases, spectra allow a chronological classification according to the picking dates. In the vicinity of 970 nm, the intensity of the absorbance increased in a continuous way from P1 until P4. The peak of absorbance in the vicinity of 1100 nm was non-existent until P2, appeared in P3 and intensified in P4.

FDA applied on spectral data allowed to classify 99% of the fruits according to the picking dates. Fruits from P1, P2 and P3 were classified with 100% accuracy and these of P4 with an accuracy of 96% for both cultivars. Factorial maps according to the first two factorial scores present a similar pattern of fruit evolution in time for both varieties (Fig. 4). Furthermore, relevant wavelengths of the first factorial score are closed (Fig. 4). Concerning Bergarouge, the first factorial score allowed ranking the fruit of P1, P2 and P3 in a chronological way, these of P4 being discriminated from P3 with the second factorial score. About ‘Harostar’, the first factorial score allowed discriminating the first two samples P1 and P2 from P3 and P4. The second factorial score allowed discerning P1 from P2 and P3 from P4.

The wavelengths important to the discrimination according to the first factorial score were located in the vicinity of 710, 845 and 895 nm and three larger bands in the vicinity of 955-990, 1050-1150

**Table 2.** Mean values (m) of Fi, SSC and TA and coefficient of variation (CV, %). Bg: Bergarouge, Hs: Harostar.

Picking date	Statistics	Fi (DI)		SSC (°Brix)		TA (g/L)	
		Bg	Hs	Bg	Hs	Bg	Hs
P1	μ	91.88	93.36	7.60	8.73	24.50	25.78
	CV (%)	2.36	2.37	5.83	10.10	8.04	20.13
P2	μ	95.68	95.84	8.42	10.30	15.01	28.74
	CV (%)	1.97	1.56	7.24	8.90	10.14	16.03
P3	μ	94.92	93.04	9.18	11.40	11.11	17.54
	CV (%)	2.70	5.19	9.78	17.68	12.08	14.72
P4: harvest	μ	89.96	84.96	8.83	10.37	9.34	20.21
	CV (%)	2.62	8.65	10.73	16.93	15.73	17.99

**Table 3.** Confusion matrices of FDA aiming at discriminating the picking dates of Bergarouge and Harostar varieties.

Variety	Sampling	P1	P2	P3	P4: harvest	% Correct classification	% Mean of correct classification
Bergarouge	P1	22	0	0	0	100	92
	P2	0	21	3	0	87	
	P3	0	2	22	1	88	
	P4: harvest	0	1	0	24	96	
Harostar	P1	21	3	0	1	84	89
	P2	2	22	1	0	88	
	P3	0	0	23	0	100	
	P4: harvest	1	2	0	22	88	

and 1180-1200 nm. Between 800 and 1200 nm, absorbance is related to the 2<sup>nd</sup> overtone of NH and OH chemical bonds, the 3<sup>rd</sup> overtone of CH chemical bond and the combination of the OH chemical bond. In practice, the regions in the vicinity of 800-1000 nm have been correlated to SSC variations while water absorption bands have been located in the 970 and 1180 nm regions<sup>5</sup>. Absorptions at 970 nm and around 1180 nm were particularly important to measure the fruit follow-up during pre-harvest. This was certainly due to fruit growing until P3 and fruit development between P3 and P4.

As stated previously, P3 seems to be a key step in the fruit evolution. Absorbance in near infrared range using such a hand-held spectrometer could be a useful tool to non-destructively determine this crucial step. At least 96% of fruit of P4 samples were correctly identified. Furthermore, the non-destructive approach could allow the fruit follow-up in orchards without picking the fruit.

Other studies, focused on apple, analyzed fruit evolution on the tree to determine an optimal picking date. Using a visible near infrared spectroscopic technique, the optimal picking date has been determined with a precision comprising between 4 to 9 days, depending on the apple variety<sup>13,19</sup>. Wavelengths in the vicinity of 1100 and 1250 nm, identified as relevant in classifying apricots according to the picking dates, have been previously identified as relevant in determining the optimal picking date of apple<sup>13</sup>.

**PLS prediction of soluble solids content and firmness:** SSC and Fi were sufficient to follow fruit evolution until harvest date. The present analyses attempted to determine the values of these two parameters (SSC and firmness) by means of hand-held near-infrared spectroscopy. Globally, the PLS models were more efficient for the Bergarouge variety than for Harostar one (Table 4).

SSC has been determined with a 0.85°Brix precision for 'Bergarouge' while it was around 1.47°Brix for 'Harostar'. In the same way, Fi was correctly predicted for both varieties but the accuracy remained better for Bergarouge with a 2.7% precision compared to 6.2% for Harostar. Fig. 5 shows the actual vs. predicted values of physico-chemical parameters of PLS models. With regard to 'Harostar', prediction of SSC-values met difficulties for data higher than 14°Brix, while prediction of SSC for 'Bergarouge' appears correct whatever the range of the values. The difficulties observed with 'Harostar' model are probably due to the small numbers of fruit presenting high SSC values (>14°Brix) in the analyzed data set. The range of SSC-values should therefore be enlarged to reach an efficient and accurate model of SSC prediction for Harostar variety.

Previous studies showed the ability of near infrared spectroscopy to determine SSC and Fi of apricots picked at commercial maturity<sup>15</sup>. In these studies, SSC and Fi were also determined for Bergarouge and Harostar varieties. The authors

showed that SSC was determined with a precision of 1.00°Brix and 0.97°Brix for 'Bergarouge' and 'Harostar', respectively. In the same study, they were able to predict the Fi with a precision of 24% and 6.2% for 'Bergarouge' and 'Harostar', respectively. This study brings to light variability of the prediction accuracy according to the variety of apricot considered.

Thus, the results showed that prediction of SSC of 'Harostar' was less accurate during pre-harvest (RMSECV=1.47°Brix) compared to post-harvest (RMSECV=1.00°Brix). Concerning Fi, the accuracy of the prediction was similar during pre- and post-harvest (RMSECV=6.2%). Prediction of SSC of Bergarouge variety was slightly more accurate during pre-harvest (RMSECV = 0.85°Brix) than during post-harvest (RMSECV = 1.00°Brix). Finally, prediction of Fi during pre-harvest was in particular more accurate (RMSECV = 2.7%) than after harvest (RMSECV = 24.1%).

The results showed that the efficiency of the predictive models performed during pre-harvest was comparable to those obtained after harvest (excepted for the Fi prediction of 'Bergarouge'). In this way, the development of such models with a hand-held near infrared spectrometer could be a useful tool to follow fruit development in the orchard by means of a non-destructive method.

## Conclusions

Follow-up of fruit maturity was carried out by physico-chemical methods and hand-held non-destructive near infrared spectroscopy. First, analyzed spectra permitted the classification of fruits according to various picking dates during the fruit development until harvest. While physico-chemical methods classified the fruit with 89-92% precision, near infrared spectra permitted a classification of 99%. Secondly, the experiment allowed the prediction of physico-chemical parameters with good precision. RMSECV of SSC prediction ranged from 0.85°Brix to 1.47°Brix and RMSECV of Fi ranged from 2.7% to 6.2%. The accuracy of the two approaches using such a hand-held near infrared technology is promising. Further studies are now necessary to develop such models to a greater number of apricot varieties and to perform a validation over different harvest years.

Also, the fruit development was clearly separated into two stages since the evolution of SSC and Fi was found to be complementary according to the picking date. In this way, further studies analysing fruit evolution around the P3 stage might lead to a better understanding of the fruit physiology.

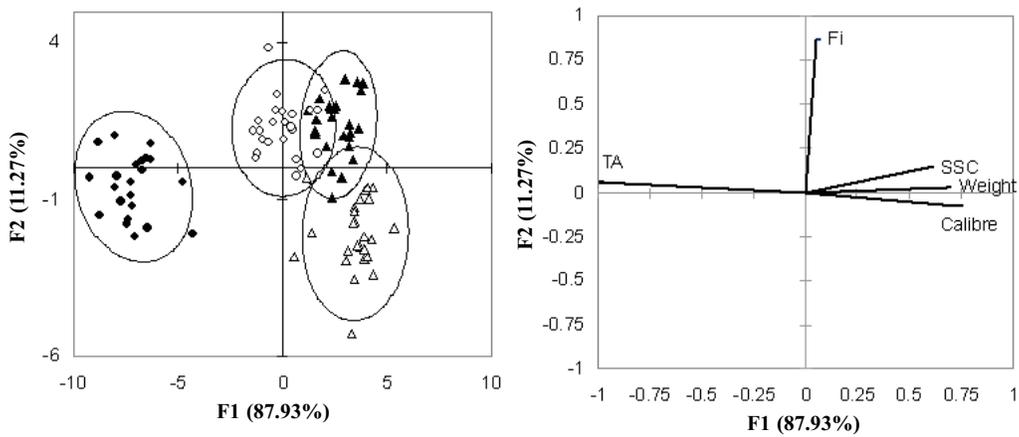
Finally, a non-destructive and semi-continuous monitoring the progress of fruit maturity has been shown to be feasible. Such a follow-up could be less expensive and less time consuming than one using conventional and destructive methods. In future studies, it will be necessary to determine the potential of this approach to determine an optimal harvest date or to monitor a differential harvest.

## Acknowledgments

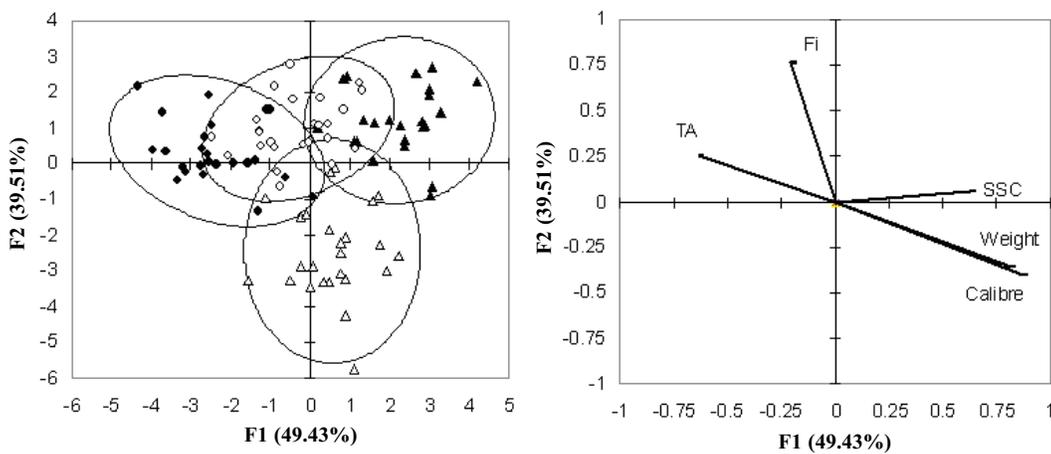
This work was financially supported by the European Action COST 924 (*Enhancement and Preservation of Quality and Health Promoting Components in Fresh Fruits and Vegetables*) and the State Secretariat for Education and Research SER (Switzerland).

**Table 4.** PLS-values of SSC and Fi prediction. R: correlation coefficient, RMSEC: root mean square error of calibration, RMSECV: root mean square error of cross-validation, LV: number of latent variables.

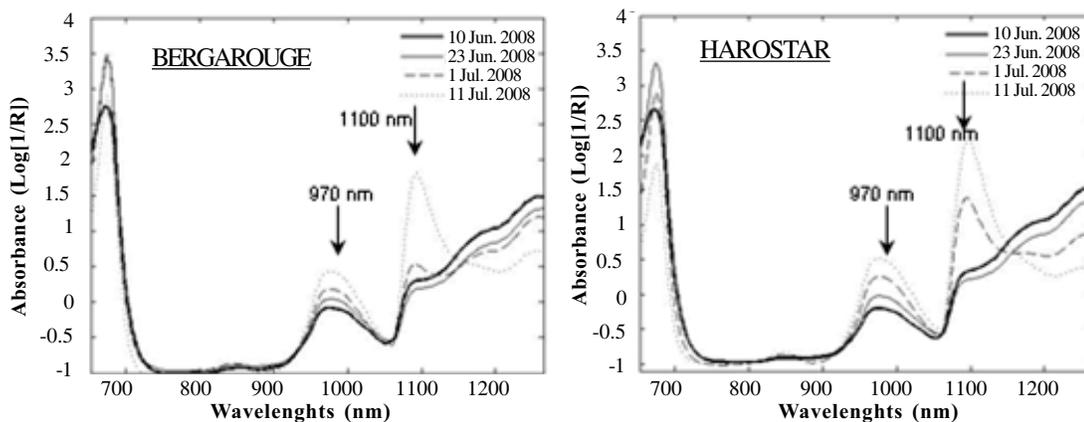
	Parameter	R	RMSEC	RMSECV	LV
Bergarouge	SSC	0.84	0.51°Brix	0.85°Brix	4
	Fi	0.85	1.8%	2.7%	4
Harostar	SSC	0.86	1.04°Brix	1.47°Brix	4
	Fi	0.87	3.1%	6.2%	4



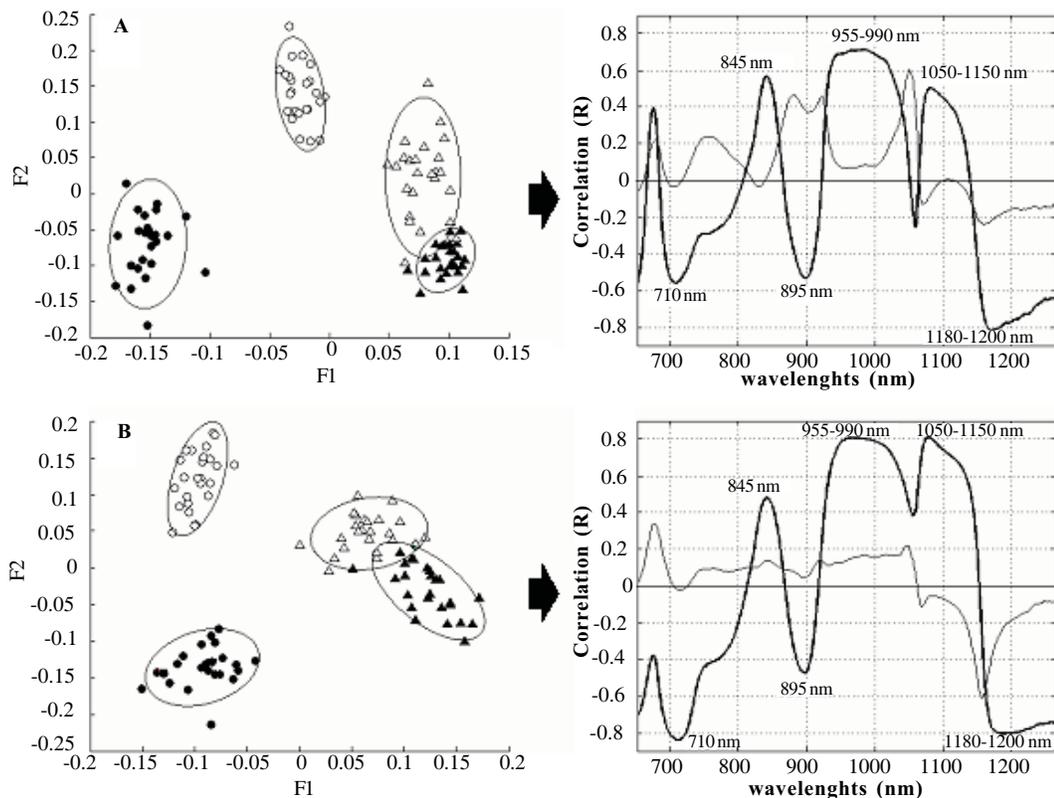
**Figure 1.** FDA performed on destructive data of Bergarouge variety. FDA map according to the first two factorial scores (F1 and F2) where the discriminated groups are the picking dates P1 (10 Jun. 2008: ●), P2 (23 Jun. 2008:○), P3 (1 Jul. 2008: ▲) and P4 (11 Jul. 2008: Δ).



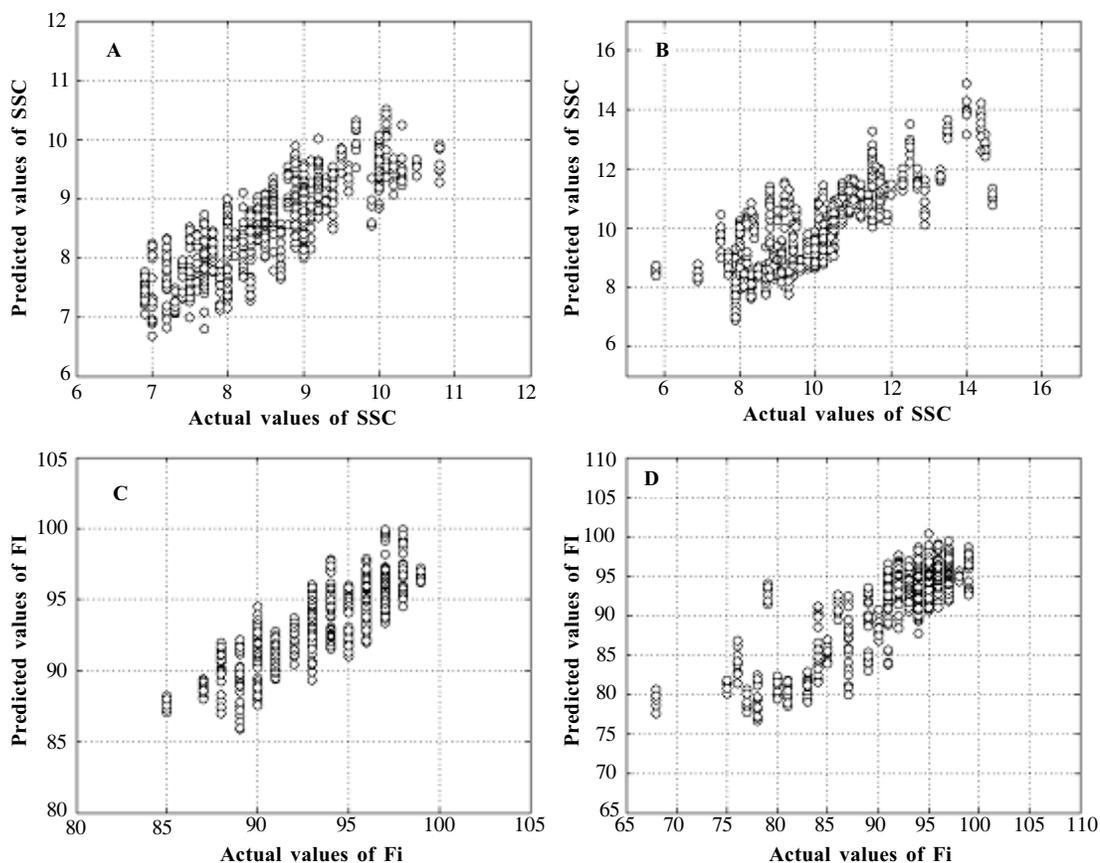
**Figure 2.** FDA performed on destructive data of Harostar variety. FDA map according to the first two factorial scores (F1 and F2) where the discriminated groups are the picking dates P1 (10 Jun. 2008: ●), P2 (23 Jun. 2008:○), P3 (1 Jul. 2008: ▲) and P4 (11 Jul. 2008: Δ).



**Figure 3.** Average NIR spectra of fruit according to the picking dates. P1 (10 Jun. 2008), P2 (23 Jun. 2008), P3 (1 Jul. 2008) and P4 (11 Jul. 2008) of Bergarouge and Harostar varieties.



**Figure 4.** FDA performed on spectral data of Bergarouge (A) and Harostar (B) varieties. Left side: FDA map according to the first two factorial scores (F1 and F2) where the discriminated groups are the picking dates P1 (10 Jun. 2008: ●), P2 (23 Jun. 2008: ○), P3 (1 Jul. 2008: △) and P4 (11 Jul. 2008: ▲). Right side: Correlation between the first two factorial scores of the FDA and the measured absorbance.



**Figure 5.** Determination of SSC and Fi-values by PLS regression. Actual vs. predicted values of SSC and Fi of Bergarouge (A and C) and Harostar (B and D) varieties.

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