TRS-Measurements as a Nondestructive Method Assessing Stage of Maturity and Ripening in Plum (*Prunus domestica* L.)

E. Vangdal[1], M. Vanoli[2], P. Eccher Zerbini[2], S. Jacob[2,3], A. Torricelli[4] and L. Spinelli[4]
[1] Bioforsk Vest Ullensvang, Lofthus, Norway
[2] CRA-IAA, Unità di ricerca per i processi dell'industria agroalimentare (Agricultural Research Council - Research Unit for Agro Food Industry), Milan, Italy
[3] Groupe-ESA, Angers, France
[4] CNR-INFM and CNR-IFN, Politecnico di Milano – Dipartimento di Fisica, Milan, Italy

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Abstract

In plum fruit with dark red or blue blush colour covering the whole fruit, the change in ground colour from green to yellow during maturation and ripening is masked. Hence, the maturity stage is difficult to judge. Time-resolved reflectance spectroscopy (TRS) has been used as a nondestructive method to assess changes in important internal quality factors in 'Jubileum' plums (*Prunus domestica* L.). Absorption coefficients (μ_a) and scattering coefficients (μ_s) were measured at both 670 and 758 nm during 5 days of storage. The changes in soluble solids content, titratable acidity and firmness were as expected. No change in soluble solids content was observed, while the plums became less acid and softer during storage. The TRS-measurements of plums indicated that TRS could give interesting information on internal quality factors in plums as the absorption at 670 nm was closely related to firmness, TA and TSS at the time of picking. Absorption at 758 nm was more closely related to the quality parameters after storage. The study did not indicate that scattering could be used in assessing maturity stage in plum.

INTRODUCTION

Firmness is regarded as the best way to judge the maturity stage of plums (Vangdal, 2008). However, when picking plums the pickers have to judge the fruit by size and colour. Partly blushed plums should be picked when the ground colour changes from green to yellow. 'Jubileum' is a Swedish medium to late ripening plum cultivar with good crop and large dark blue fruit (Werlemark, 1995). The fruit of 'Jubileum' develop blue cover colour more than a week prior to the fruit start softening (Fig. 1). Hence it is difficult to judge the maturity stage by colour, and marketed plums often vary in ripeness.

To solve similar challenges in red nectarines, the TRS-method has been used (Eccher Zerbini et al., 2006; Jacob et al., 2006; Vanoli et al., 2007). In postharvest research TRS-measurements may reveal mealiness in apples (Valero et al., 2001) and internal browning (brown heart) in pears (Eccher Zerbini et al., 2002). The theory and procedures for the TRS-method has been described by Cubeddu et al. (2002). The measured absorption coefficients (μ_a) and scattering coefficients (μ_s) make it possible to assess biochemical changes up to 2 cm into the fruit flesh independent of skin colour.

Nondestructive methods to assess stage of maturity have been sought. In plums Haugen et al. (2003) and Bengtsson et al. (2007) have worked with several methods and sensors, including near infrared spectroscopy (NIR). A portable NIR-equipment has been tested in apricots in Switzerland (Camps, 2007, pers. communication).

In this study 'Jubileum' plums (*Prunus domestica* L.) were brought from Norway to Milan (Italy) for TRS-measurements. The aim of the study was to point out if TRS could be used as a nondestructive method to assess the stage of maturity in fruit of this plum cultivar.

MATERIALS AND METHODS

Fruit Samples

Plum fruit of the cultivar 'Jubileum' (*Prunus domestica* L.) were grown in the experimental orchards at Bioforsk Vest Ullensvang in Western Norway. The plums were picked and transported to CRA-IAA Institute in Milan the same day for TRS-measurements during 5 days of storage at approx 20°C and RH 60-70%. The plums were divided into 5 comparable samples with 60 fruit each, and each fruit was individually labelled. Two fruit had to be discarded due to decay before the experiment was finished.

Analyses

Every day each fruit was weighed and TRS-measurements were performed as described by Tijskens et al. (2007). Laser pulses with wavelengths of 670 and 758 nm were used. At day 0 TRS and mass were recorded for 300 fruit. 60 fruit were removed each day for quality measurements by destructive methods (see below). Hence, at day 1 240 fruit, at day 2 180 fruit, at day 3 120 fruit and at day 4 the last 60 fruit were analyzed by TRS and weighed. The quality measurements included firmness, soluble solids content and titratable acidity. Firmness was measured by an Instron 4301 Universal Testing Machine with an 8 mm diameter cylindrical plunger driven into the fruit at a speed of 200 mm min^{-1}. Measurements were made on two peeled sides of the fruit. Content of soluble solids was measured using a refractometer and titratable acidity by titrating diluted juice samples to pH 8.1 by 0.1 N NaOH.

Statistical Analyses

The correlations between the coefficients of absorption (μ_a) and scattering (μ_s) at both wavelengths and the quality parameters were calculated using the Excel spreadsheet (MS-Office 2003, Microsoft, USA).

RESULTS

As shown in Tables 2 and 3 the correlations between firmness, acidity and soluble solids were as expected. Firm plums (less ripe) had higher content of titratable acids and lower content of soluble solids, while softer plums had lower content of titratable acids and higher content of soluble solids.

Correlations between the Absorption Coefficient (μ_a) and Quality Parameters

The absorption coefficients (μ_a) increased during storage (Table 4), and smaller fruit had higher coefficients than larger ones (data not shown). At day 0 the correlations between the absorption coefficient (μ_a) at 670 nm and the quality factors were statistically significant. The correlations for firmness and acidity were positive, while negative for soluble solids (Table 2). Less ripe plums had higher absorption coefficients at 670 nm than more ripe plums. However, during storage the correlation coefficients decreased, and at day 4 none of the correlation coefficients were statistically significant.

At 758 nm the trends were the same; high absorption coefficients indicated firm and acid plums. However, the correlations were not significant (Table 3).

Correlations between the Scattering Coefficient (μ_s) and Quality Parameters

The scattering coefficients (μ_s) decreased the first two days of storage (Table 4). The measurements of scattering (scattering coefficients (μ_s)) were poorly correlated to quality parameters (Tables 2 and 3). No significant correlations or trends were observed between scattering at both wavelengths and titratable acidity. For firmness no correlation with scattering coefficients (μ_s) was found at 670 nm. At 758 nm, however, the correlation became stronger and positive during storage. Both after 2 and 4 days of storage the correlation coefficients were statistically significant.

Scattering at both wavelengths was positively correlated to soluble solids content. The correlations were stronger on day 0 and 1 and became poorer during storage. At day 0 and 1 scattering measurements both at 670 and 758 nm could indicate the content of soluble solids.

DISCUSSION

During postharvest ripening of plums important biochemical and physical changes affect fruit quality. The changes in soluble solids content, titratable acidity, firmness and water loss are shown in Table 5. The main objective of this study was to look for possible correlations between firmness and parameters from TRS-measurements. The single optical parameter most closely related to firmness was the absorption coefficient (μ_a) at 670 nm.

After 4 days of storage the correlation between firmness and absorption was much weaker. Tijskens et al. (2006) reported a decrease in the μ_a value at 670 nm of nectarines during storage. In plums the absorption coefficients (μ_a) at 670 nm increased as the storage period advanced, while the absorption coefficients (μ_a) at 758 nm decreased the first two days of storage and then increased (Jacob et al., 2010). The difference observed between nectarines and plums may be due to variation in maturity stage at the beginning of storage. The plums were picked in Norway and transported for approximately 10h to Milan. During transport the temperatures probably fluctuated.

In this study it is not possible to identify the effect of single biochemical or physical changes on the optical parameters as measured by TRS.

CONCLUSIONS

TRS-measurements of plums could give interesting information on internal quality factors in plums:

- Absorption at 670 nm was closely related to firmness, TA and TSS at the time of picking.
- Absorption at 758 nm was more closely related to the quality parameters after storage.
- The study did not indicate that scattering could be used in assessing maturity stage in plum.

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Tables

Table 1. Firmness (measured by DUROFEL) at various maturity stages.

Stage of maturity	Firmness (DUROFEL-units)
Immature	>80
Slightly mature	70-80
Tree ripe	60-70
Eating ripe	50-60
Overripe	<50

Table 2. Coefficients of correlation between optical parameters at 670 nm and quality factors in 'Jubileum' plums (n=60).

				Absorption at 670 nm (μ_a)					Scattering at 670 nm (μ_s)				
	TA	TSS	Firmness	day 0	day 1	day 2	day 3	day 4	day 0	day 1	day 2	day 3	day 4
TA		-0.28*	0.33	0.47	0.43	0.35	0.28	0.10	-0.03	0.05	0.15	-0.04	-0.07
TSS	-0.28		-0.23	-0.31	-0.28	-0.18	-0.05	0.04	0.20	0.28	0.12	0.15	0.05
Firmness	0.33	-0.23		0.31	0.25	0.19	0.05	-0.15	-0.04	0.02	0.22	0.14	-0.02

*correlation coefficients > 0.325 $p<0.01$. correlation coefficients 0.25-0.324 $p<0.05$. correlation coefficients <0.25 not significant

Table 3. Coefficients of correlation between optical parameters at 758 nm and quality factors in 'Jubileum' plums (n=60).

				Absorption at 758 nm (μ_a)					Scattering at 758 nm (μ_s)				
	TA	TSS	Firmness	day 0	day 1	day 2	day 3	day 4	day 0	day 1	day 2	day 3	day 4
TA		-0.28*	0.33	0.22	0.12	0.14	-0.01	-0.10	0.08	0.00	0.22	0.01	0.02
TSS	-0.28		-0.23	-0.04	0.06	-0.01	0.13	0.23	0.23	0.24	-0.01	0.09	0.01
Firmness	0.33	-0.23		0.17	0.04	0.11	-0.14	-0.23	-0.04	0.01	0.30	0.18	0.25

*correlation coefficients > 0.325 $p<0.01$. correlation coefficients 0.25-0.324 $p<0.05$. correlation coefficients <0.25 not significant

Table 4. Coefficients of absorption (μ_a) and scattering (μ_s) from TRS-measurements at 670 and 758 nm during 4 days of storage of plums at 20°C.

	Day 0	Day 1	Day 2	Day 3	Day 4
670 nm:					
Absorption coefficient (μ_a)	0.12	0.13	0.13	0.15	0.16
Scattering coefficient (μ_s)	6.34	6.33	5.67	5.82	5.58
758 nm:					
Absorption coefficient (μ_a)	0.08	0.08	0.07	0.08	0.10
Scattering coefficient (μ_s)	6.35	5.70	4.14	4.10	5.03

Table 5. Soluble solids content, titratable acidity, firmness (by Instron) and mass loss in 'Jubileum' plums during storage at 20°C and RH 60-70%.

	Day 0	Day 1	Day 2	Day 3	Day 4
Soluble solids	16.8	16.9	16.8	16.7	16.6
Titratable acidity	2.29	2.27	2.16	2.07	2.02
Firmness	8.78	7.73	5.68	4.57	3.48
Mass loss*	0	2.33	3.55	5.36	7.08

* as percent of mass at day 0.

Figures

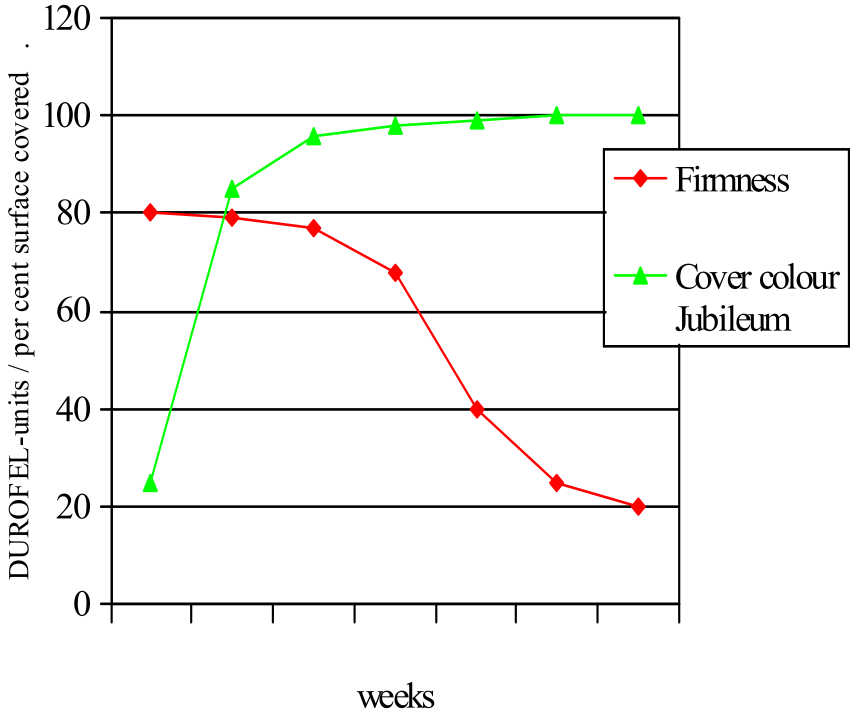

Fig. 1. Softening and cover colour development during ripening of 'Jubileum' plums. Optimum maturity stage for picking at firmness 60-70 (DUROFEL units).