Optical Absorption and Scattering Phenomena in 'Jubileum' Plums in Relation to Their Colour Properties

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Abstract

Absorption and scattering of laser light pulse passing through the fruit determine among others, the optical properties of the product. Efforts have been made in the recent past to utilize innovative techniques such as time-resolved reflectance spectroscopy (TRS) to study the quality aspects of different fruit such as nectarines. These optical properties have been well related to firmness, sugars, acids and other quality attributes. TRS measurements were performed on 'Jubileum' plums at two different wavelengths: 670 nm and 758 nm. The fruit were harvested in Norway and brought to Italy under protected conditions. After sorting the fruit by size, TRS measurements were made and the fruit were randomized for different examinations of quality aspects. It was observed that the absorption coefficient (μ_a) increased for both wavelengths as ripening progressed towards the melting stage of the fruit. The μ_a values at 670 nm were higher than those at 758 nm. The higher rate in the μ_a was distinguishable from the third day onwards as the fruit ripened. Similarly, it was interesting to note that the internal colour measured after destructing the fruit related well with the TRS absorption coefficient (μ_a), i.e., a decrease in the CIE L* (towards darker region) and b* (towards blue) value along with an increase in a* (towards red) from third day of storage.

INTRODUCTION

Optical methods such as time-resolved reflectance spectroscopy (TRS) have been used in the recent past to study the different quality aspects in nectarines (Eccher Zerbini et al., 2006; Jacob et al., 2006; Vanoli et al., 2007). The method is potentially feasible for non-destructive probing of fruit tissues to a depth of 2 cm and more. The use of TRS has been well-explored in various postharvest studies to discriminate mealiness in apples (Valero et al., 2001), to detect brown heart in pears (Eccher Zerbini et al., 2002), to relate with pectin composition in apples (Vanoli et al., 2006), etc. The technique uses pulsed laser light injected into fruit at a particular wavelength and detection of their temporal distribution in form of remitted photons that comes out of the fruit at a certain distance. The optical parameters, i.e., absorption coefficient (μ_a) and scattering coefficient (μ_s') are obtained by interpretation using the theoretical model of light propagation. The working principal and procedure using TRS have been described in detail (Cubeddu et al., 2002).

A change in the background skin colour often depicts the maturity stage of a fruit. Many growers consider this an appropriate index for deciding the harvesting date in plums. However, extensive purple blush as seen in 'Jubileum' plums at early stages of fruit development can confuse a harvester leading to pick not optimally mature fruit. Skin and flesh colour may be useful indicators of ripening but many plum cultivars develop pigmentation early in growth; hence, the colour of fruit has little significance in determining the harvest date (Abdi et al., 1997; Bhutani and Joshi, 1995). In this

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experiment, TRS measurement was employed on 'Jubileum' plums that were brought from Norway to Italy. The cultivar is large, oval and dark blue with medium shelf life (less than 2 weeks at 4°C) and susceptible to fungal decay during storage (Vangdal et al., 2007). The objective of this research was to develop a suitable non-destructive technique to categorize the fruit into various maturity classes based on their optical properties, and at the same time, to relate with their internal colour changes during ripening.

MATERIALS AND METHODS

Plums of the cultivar 'Jubileum' were picked on 2 September 2007 at the experimental orchard of Planteforsk Ullensvang Research Center in Western Norway. After harvest, 300 fruit were brought to the CRA-IAA institute at Milano, Italy, on the same day. The fruit were arranged according to their mass and then divided equally into 2 classes: size 'A' and size 'B'. Each size contained 150 fruit, of which size 'A' fruit had higher mass than size 'B' fruit (size A > 54 g ≤ size B). TRS measurement was performed on all fruit respective of their size class at the beginning of storage. The measurement was made at 670 and 758 nm in order to obtain the optical coefficients, μ_a and μ_s' at respective wavelengths. Within the size classes, fruit were ordered according to decreasing value of μ_a 670 nm. The randomization procedure was adopted in order to obtain a comparable sample (30 fruit) that contained high, medium and low μ_a 670 nm fruit for every examination. The fruit were stored at 20°C and 50-60% RH. Including the analysis at harvest, altogether 5 times TRS measurements were conducted per size class. Fruit examination was performed every day at approx. 24h interval. At every examination, the allotted sample (30 fruit) was taken out of the storage room and monitored for μ_a and μ_s' at both wavelengths. However, on the third day of examination, 2 fruit from size A and B having the lowest μ_a 670 nm values had to be discarded due to initiation of rotting. TRS instrumental set-up for μ_a and μ_s' measurement has been described by Tijskens et al. (2007). Skin and flesh colour of the fruit (CIE: L*a*b* values) were measured using a Spectrophotometer CM-2600d (Minolta Co., Ltd., Osaka, Japan). Data were statistically analyzed using Excel spreadsheet (MS-Office 2003, Microsoft, Redmond, USA).

RESULTS AND DISCUSSION

The correlation coefficient of the measured parameters is presented in Table 1. Considering the whole batch of fruit (n=296) measured during storage, the absorption coefficients (μ_a) at wavelengths 670 and 758 nm were highly correlated (r=0.83) when compared to the scattering coefficients (μ_s') at respective wavelengths (r=0.61). The average μ_a value at 670 nm was higher than at 758 nm. Bigger fruit (Size A) had lower μ_a when compared to smaller (size B) fruit. At both wavelengths, μ_a of fruit increased during storage (Fig. 1a). On the other hand, the scatter coefficient (μ_s') decreased from the initial value (at harvest) except for bigger fruit measured at 670 nm (Fig. 1b). On an average, the scattering coefficient (μ_s') was higher at 670 nm. There was not much difference noticed between the two size classes with respect to their μ_s' value. The changes in the μ_s' were not as distinct as in the μ_a values. The skin colour of fruit changed during the storage. A decrease in the CIE: L* (towards darker region), a* (towards green) and b* (towards blue) of the skin was observed (Fig. 2a, b, c) as the storage period advanced (Salvador et al., 2003). However, in the flesh colour of the fruit, an increase in L* (towards brightness) and b* (towards yellow) value was observed at the onset of storage which abruptly decreased after the third examination (Fig. 2d, f). The value in the flesh a* increased (towards red) as the storage period progressed (Fig. 2e). No relation was found between the L*a*b* values of skin and flesh. The L* and b* value of the flesh remained higher compared to L* and b* value of the skin, while the skin a* value was higher when compared to the flesh a*. Higher values in the absorption coefficient (μ_a) at 670 nm compared to 758 nm could correspond to absorptions by major pigments, particularly chlorophyll (before ripening and at harvest) and anthocyanin (towards ripening). Qin and Lu (2008) suggested that maximum values of μ_a occur at 675 and 535 nm, i.e., the absorption band is mainly influenced by chlorophylls and anthocyanins. In our study,

each fruit was at a different state of ripeness: those towards higher μ_a values were less ripe and more firm, while those in the lower μ_a value range were riper and less firm (firmness data not shown here). As the ripening progressed towards the melting phase, the cell-wall collapsed due to enzyme mediated alterations leading to concentration of vacuolar anthocyanin in the fruit flesh (Usenik et al., 2008), which was marked by increase in flesh a* value and μ_a 670 value (Fig. 2e). The absorption due to chlorophyll would have been less as most of it would be degraded and reduced to minimum towards the end of storage. The present result is contrary to the results of Tijskens et al. (2006), who reported a decrease in the μ_a value (at 670 nm) of nectarines as the storage period progressed. Compared to nectarines, plums are generally smaller in size. During ripening, plums become more juicy and translucent. Due to relatively smaller size and high translucency, the laser light can easily transmit within the flesh and can get absorbed by the stone and inner side of the fruit peel adhered to the flesh. This perhaps could explain why there was a significant relation between the skin colour parameters and μ_a (Table 1). On the other hand, the lowering of scattering coefficient (μ_s') in general could be due to dissolution of the scattering centres (cellular structures) as the fruit began to ripe.

CONCLUSIONS

The optical coefficients of fruit can be successfully used to track quality changes in plums. The non-destructive method of relating internal colour changes with the fruit's absorption coefficient (μ_a) can help the growers to assess the optimum fruit maturity at harvest, while the wholesalers and retailers can be benefitted by regulating the supply-flow of plums based on the state of fruit ripeness. More research, however, is needed to understand the relations between optical properties, fruit ripening and quality changes.

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Tables

Table 1. Correlation coefficients between the optical and colour parameters of plum (n=148 fruit/size).

	670 nm		758 nm		Skin			Flesh	
Size	μ_a	μ_s'	μ_a	μ_s'	L*	a*	b*	L*	a*
A	-0.18*								
B	-0.66***								
A	0.84***	-0.11^{NS}							
B	0.77***	-0.66***							
A	-0.35***	0.63***	-0.11^{NS}						
B	-0.59***	0.59***	-0.20*						
A	-0.41***	0.21*	-0.33***	0.48***					
B	-0.47***	0.38***	-0.37***	0.46***					
A	-0.57***	0.18*	-0.53***	0.24**	0.55***				
B	-0.62***	0.49***	-0.57***	0.36***	0.57***				
A	-0.47***	0.23**	-0.39***	0.49***	0.94***	0.69***			
B	-0.55***	0.43***	-0.48***	0.43***	0.92***	0.74***			
A	-0.55***	0.33***	-0.55***	0.20*	0.26**	0.47***	0.36***		
B	-0.40***	0.43***	-0.45***	0.04^{NS}	0.15^{NS}	0.47***	0.30***		
A	0.18*	0.13^{NS}	0.16*	-0.09^{NS}	-0.41***	-0.25*	-0.40***	-0.12^{NS}	
B	0.25**	-0.10^{NS}	0.16*	-0.13^{NS}	-0.37***	-0.19*	-0.39***	-0.16*	
A	-0.39***	0.27***	-0.41***	0.09^{NS}	0.06^{NS}	0.24*	0.13^{NS}	0.70***	0.46***
B	-0.19*	0.35***	-0.33***	-0.05^{NS}	-0.05^{NS}	0.28***	0.05^{NS}	0.76***	0.35***

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; NS = Non-significant

Figures

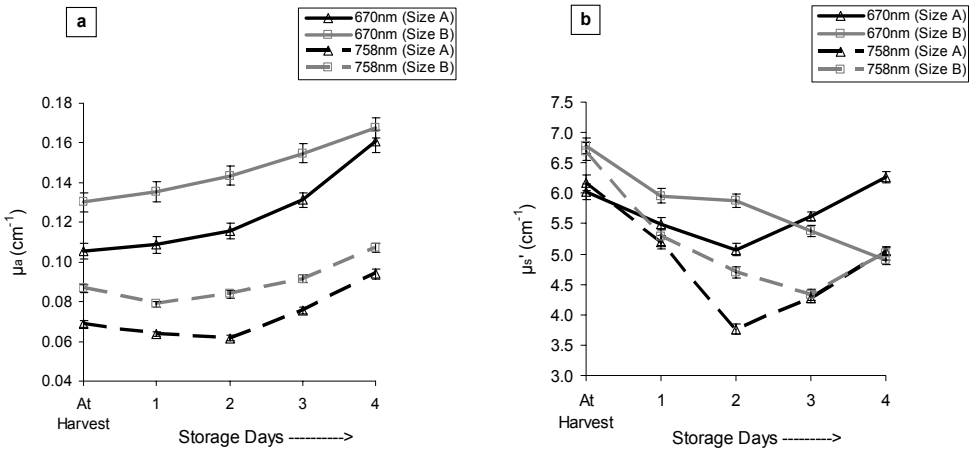

Fig. 1. (a) Change in the absorption (μ_a) and (b) scattering (μ_s') coefficient of plums (mean ± SE) during storage.

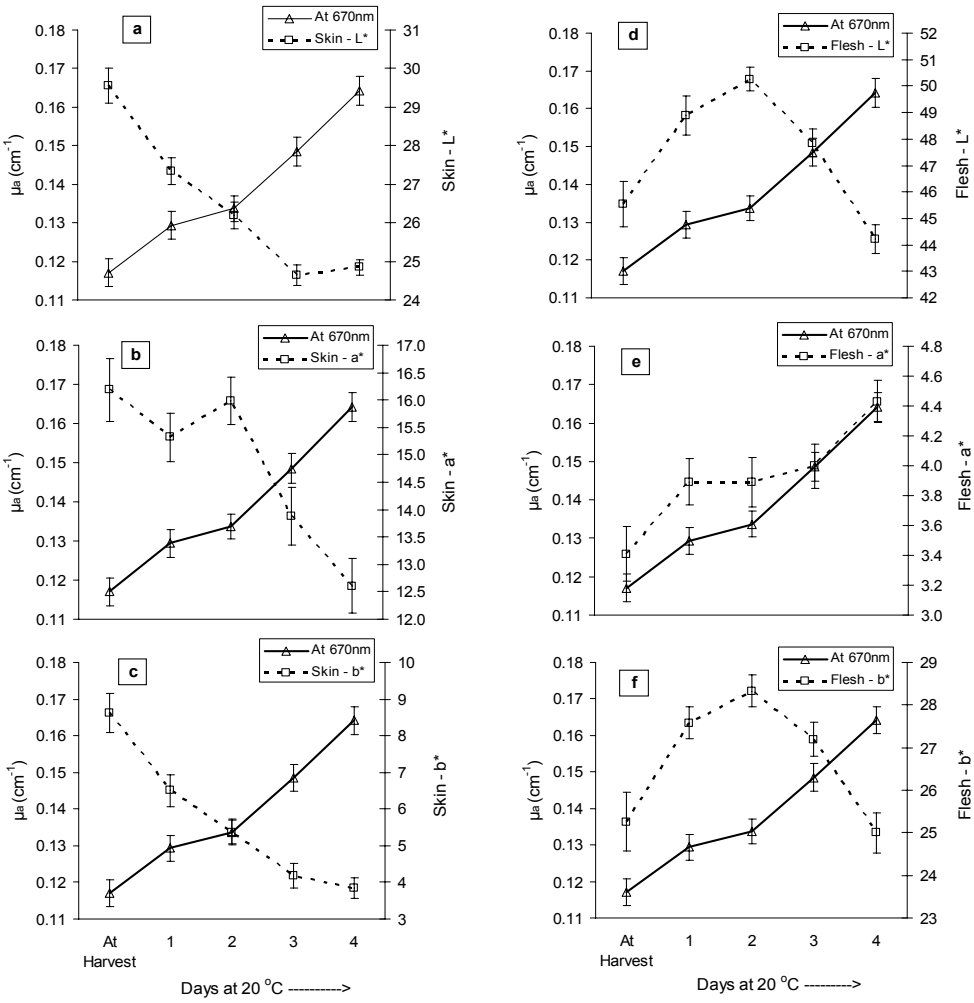

Fig. 2. Change in the skin (left) and flesh colour (right) of plums (mean ± SE) during storage as indicated by their L*a*b* value in relation to the μ_a at 670 nm.