Portable Sensor Equipment for Fruit Maturity Monitoring in Apple Orchard

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Abstract
To improve the prediction of optimum harvest date, more exact and rapid sensing of apple fruit maturity development is required. Destructive methods are currently used to determine the optimum harvest date. Because of high variability of individual fruits, the accuracy of this method is limited. Spectrophotometry in VIS wavelength range can sensitively detect pigment content. Robust miniaturised spectrophotometer technique could be promising for practical use in fruit production and marketing.

Research tests were carried out with two apple cultivars during twelve dates of the season 2004. Specific portable equipment with miniaturised spectrometer module and glass-fibre probe was used for measurements of fruit on tree. The light transmission through a part of fruit tissue could be measured in wavelength range from 500 to 1000 nm.

According to fruit maturity progress, the spectral signatures showed an increase of light intensity around 680 nm due to decreasing chlorophyll content. The chlorophyll decrease was very clear indicated by the red-edge index. A decrease of light intensity between 500 and 570 nm was recorded due to increasing blush colour pigments. The progression of blush colour could be demonstrated by means of an anthocyanin index. The two cultivars showed typical differences in variance of fruit maturity development. The results could be useful for development of more objective and precise monitoring the optimum harvest date of apple fruit.

INTRODUCTION
During harvest period, climacteric fruits such as apples show typical changes in several parameters. The optimum harvest date for apples to be stored is indicated if the climacteric state occurs, i.e. the respiration rate and the ethylene evolution show a distinct rise. But, the monitoring of respiration rate is very expensive. Therefore in practice, several times samples of fruits are randomly picked, and non-destructive tests are carried out. Mostly, the following three parameters are determined: the starch index, the Magness-Taylor firmness, and the total soluble solids content (Brix value). Based on these parameters, the Streif index is calculated (De Jager and Roelofs, 1996). The Streif index shows typical values for each apple cultivar. Because of high variability of individual fruits, the accuracy of determination of optimum harvest date is limited. Sufficient experience is required to get useful results (Höhn et al., 1999).

Non-destructive objective methods such as optical measurements could be very helpful to monitor fruit maturity progress and optimum harvest date. In particular, the measurement of spectral signature of fruit provides access to several different components within the fruit and could be very promising for non-destructive evaluation of maturity stage. Zude-Sasse et al. (2002) found significant correlation between spectral parameters
in visible wavelength range and chlorophyll content of apple fruit. By using a sensing probe for partial light transmittance, a higher correlation with fruit maturity progress was calculated than for diffuse light reflectance. The red-edge appeared to be a useful parameter to characterise the maturity stage. Merzlyak et al. (2003) investigated the diffuse light reflectance of apple fruit in visible wavelength range from 400 to 800 nm. They used five apple cultivars, all picked in mature condition. They obtained significant correlation between different reflectance indices and fruit chlorophyll, carotenoid and anthocyanin content. Rohrbach et al. (2004) used portable equipment with robust miniaturised spectrometer modules and glass-fibre probe to carry out field tests with ‘Elstar’ apples during maturation on the tree. The glass-fibre probe was designed for measurement of partial light transmission through fruit cell tissue. The resulting spectral signatures showed clearly continuous decrease of chlorophyll absorption peak with maturity progress. Accordingly, the red-edge diminished approximately linearly over the time.

The portable spectrophotometer equipment was used to monitor the changes of ground and blush colour of two apple cultivars during the season 2004. The objective of this paper is to demonstrate the performance of partial light transmittance measurements to monitor the development of identical fruits on the tree. In particular, this non-destructive sensing technique could improve the accuracy of determination of the optimum harvest date.

**MATERIALS AND METHODS**

Test were carried out with ‘Elstar’ and ‘Pinova’ apples in an commercial orchard of region Werder near Berlin during twelve dates of the season 2004. Ten trees per cultivar were randomly selected, and ten fruits of each tree were labelled for identification. A measuring location was marked on each fruit. Initially once a week, later twice a week, measurements of these locations were taken by using the spectrophotometer. After each measuring date the labelled ten fruits from one of the trees were picked and analysed in laboratory for starch conversion index, fruit flesh firmness and Brix value.

A recently developed portable equipment with a commercial miniaturised spectrometer module Type ZEISS MMS1 NIR enhanced and specific glass-fibre probe for partial light transmission was used for measurements of fruit on the tree (Truppel et al., 2005). This equipment consists of a light portable part and a stationary part. The portable part contains an electronic control unit, the spectrometer unit with glass-fibre probe, and a radio transceiver. It is carried by the operator in a backpack. The stationary part contains the other transceiver and a PC. The front-end of the glass-fibre probe contains a concentric grouping of miniature lamps and a central collecting glass-fibre. By using this sensor probe, the light transmission through a part of fruit tissue could be measured in wavelength range from 500 to 1000 nm. The equipment allowed single-handed operation in orchard (Fig. 1). In this way, one hand was free to keep the fruit to be measured in fixed position. The measured data were wireless transmitted from operator to remote stationary PC.

Two criteria were derived from spectral signature measured on the fruits: the red-edge index and an index of anthocyanin increase.

The red-edge index $I_{RE}$ was calculated as the inflection point on the long-wave flank of chlorophyll absorption range around 680 nm.

The index of anthocyanin increase $I_{AI}$ was defined separately for each cultivar:
for ‘Elstar’ according to
\[ I_{AI,E} = \frac{(R_{570}-R_{630})}{(R_{570}+R_{630})} \] (1)
and for ‘Pinova’ according to
\[ I_{AI,P} = \frac{(R_{515}-R_{630})}{(R_{515}+R_{630})} \] (2)
where: \( I_{AI,E} \) and \( I_{AI,P} \) are the indices of anthocyanin increase for ‘Elstar’ and ‘Pinova’, respectively; and \( R \) is the reflectance for the wavelength in the subscript in nm.

RESULTS AND DISCUSSION

For ‘Elstar’ apples, the starch conversion started abruptly and was widely completed within 24 days, while for ‘Pinova’ apples, it showed a gradual increase and took about 40 days. During the same period, the fruit flesh firmness decreased for ‘Elstar’ apples from 88 to 69 N/cm², and for ‘Pinova’ apples from 120 to 89 N/cm². However, neither starch conversion nor firmness showed consistent characteristics, because the fruits were picked each date from different trees. The Brix value of juice changed less, with gently inclined characteristics.

According to fruit maturity progress, the spectral signatures of fruit changed significantly in visible wavelength range. The average spectral signatures taken from ten identical fruits of an ‘Elstar’ tree at four dates during the period from August 16 to September 30, are shown in Fig. 2. On the one side, distinct increase of light intensity around 680 nm occurred due to decreasing chlorophyll content. On the other side, relative decrease of light intensity was recorded between 500 and 570 nm due to increasing anthocyanin content. The average spectral signatures of ten identical fruits of an ‘Pinova’ tree measured at five dates during the period from August 16 to October 11 exhibit similar behaviour (Fig. 3). The decrease of chlorophyll content is nearly equal to that of ‘Elstar’, while the light absorption due to anthocyanin is restricted to the wavelength range below 520 nm. For that reason, the indices of anthocyanin increase were defined in different way.

Figure 4 shows on average of the ten ‘Elstar’ apples, the courses of the red-edge index, and the index of anthocyanin increase over the test period. The red-edge has consistent sigmoid characteristics starting from 707.5 nm at August 16 and arriving 694.7 nm at September 30. The index of anthocyanin increase showed less consistent sigmoid characteristics. Nevertheless, it could be helpful to characterise the increase of blush colour. Similar results were obtained for ‘Pinova’ apples (Fig. 5). However, the red-edge index started from 708.0 nm at August 16 and arrived 694.6 nm at October 11. That indicates clearly the more slow maturation of ‘Pinova’ apples. The index of anthocyanin increase showed also less consistent sigmoid characteristics. Because the blush colour was not evenly distributed over the fruit surface, certain deviations of the measured location on the fruit could be the reason for that.

Summarising the results of these tests, both spectral indices could more precisely characterise the fruit maturity progress than the conventional parameters. This demonstrated the high potential of spectral measurement to quantitatively determine the fruit maturity progress.
Literature Cited


Figures

![Fig. 1 Use of the glass-fibre probe for fruit measurement on the tree](image-url)
Fig. 2 Change of spectral signature of ‘Elstar’ apples during development on the tree

Fig. 3 Change of spectral signature of ‘Pinova’ apples during development on the tree
Fig. 4 Change of red-edge and of anthocyanin increase for ‘Elstar’ apples during development on the tree (day n° 1 was August 9, 2004)

Fig. 5 Change of red-edge and of anthocyanin increase for ‘Pinova’ apples during development on the tree (day n° 1 was August 9, 2004)
Équipement de sonde portable pour la surveillance de la maturité des pommes dans les vergers

Mots-clés : fruit de pomme, progrès de maturité, surveillance, spectromètre de VIS/PIR

Résumé

Pour améliorer la prévision de la date optimale de la récolte, une perception plus exacte et plus rapide de maturité de la pomme est exigée. Des méthodes destructives sont actuellement employées pour déterminer la date optimale de la récolte. En raison de la variabilité élevée des fruits individuels, l'exactitude de cette méthode est limitée. La spectrophotométrie dans la gamme de la longueur d'onde VIS peut sensiblement détecter la teneur en pigments. Une technique fiable de spectrophotomètre miniaturisé pourrait être prometteuse pour une utilisation pratique dans les filières fruits.

Des essais de recherches étaient effectués avec deux cultivars de pomme sur douze dates de la saison 2004. Un équipement portable avec un module de spectrophotomètre miniaturisé et sonde en fibre de verre était utilisé pour mesurer les fruits sur l’arbre. La transmission de la lumière à travers une partie du fruit pourrait être mesurée dans une gamme de longueur d’onde comprise entre 500 et 1000 nm. Suivant le degré de maturité des fruits, les spectres ont montré un accroissement de l’intensité de la lumière autour de 680 nm due à la diminution de la chlorophylle. La baisse en chlorophylle était indiquée très clairement par l’index de bord rouge. Une diminution de l’intensité de la lumière entre 500 et 570 nm était enregistrée dû à une augmentation dans les pigments de la couleur de la rougeur. L’évolution de la couleur de la rougeur pourrait être démontrée au moyen d’un index de l’anthocyanine. Les deux cultivars ont montré des différences spécifiques de maturation des fruits. Les résultats pourraient être utiles pour développer une surveillance plus précise et plus objective de la date optimale de récolte des pommes.