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Spectrophotometric Monitoring of Apple Fruit Maturation on the Tree

During Elstar apple development on the tree, the spectral optical signature in visual and near infrared wavelength range was repeatedly measured in a non-destructive way through a portable handheld spectrophotometer with wireless data transfer to a stationary PC. Changes in body and ground colour were characterised by using the so-called red-edge criterion. Moreover, the spectral optical signature has also potential to characterise the development of blush colour. The results of these measurements could be helpful in determining the different influences of cultivation and weather on fruit maturity development and the optimum harvest date more exactly.

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Keywords

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According to EU quality standards, apple fruits for the market have to be sufficiently developed in order to be able to continue the ripening and to reach the adequate ripeness stage of specific cultivar [1]. Usually, the starch-iodine test is used to determine the sufficient stage of fruit development. Additionally, colour tables are helpful to judge the ground colour of fruit. Further indices of sufficient maturity stage and good quality are the fruit size and the blush colour [2]. If the starch-iodine test is used, the apple fruits have to be picked from the tree and cut in two halves. Samples with sufficient number of fruits have to be taken several times in order to determine the optimum harvest date based on representative data. The single cultivars show different characteristics. Hence, sufficient experience is required to obtain reliable results of starch test as well as of judging with colour tables. Therefore, objective non-destructive methods for maturity determination would be highly desired.

Spectrophotometer measurements in visual and near infrared range would in principle allow rapid and non-destructive quality determination of agricultural products and are introduced in research to evaluate external and internal fruit quality parameters since many years [3, 4, 5]. However, suitably adapted low-cost devices for determination of fruit development under field conditions are currently not commercially available.

Spectrophotometer for field conditions

Recently, a portable single-handed operated spectrophotometer with wireless data transfer to a stationary PC has been developed by ATB, that is designed for studies on apple fruits during development at the tree [6]. The portable part was put into a backpack. From there, a cable is placed along the operator arm to link the electronic control unit with the miniaturised spectrometer module that is attached to the forearm. A glass fibre-bundle connects the spectrometer module with the sensing probe that is guided by hand (*Fig. 1*). A specifically adapted sensing probe has been built up to measure the spectral signature of light reflected from inside the fruit. A circle of six miniature light bulbs and in the centre a light collecting glass-fibre bundle are placed at the front of the probe. When the sensing probe is put onto the fruit, the light of the bulbs penetrates through the fruit skin directly into the fruit flesh. The light is diffusely scattered within the cell tissue of fruit flesh. A part of this light is reflected, gets back through the fruit skin to the glass-fibre bundle, and is measured by the spectrometer. In the course of this partial transmission through the fruit, the spectral signature of this light is more affected by absorbing components of fruit flesh than in the case of diffuse reflection on fruit surface.

Fig. 1: Sensing probe during measurement on a tree

During the measurement, the operator gets oral comments from the audio interface about the measuring run, and he can also give oral comments about the measurement vice versa. These comments are recorded and can be recalled later on. In this way, an expensive

Table 1: Laboratory data of fruits from two trees with different yield after harvest in cw 39 . For analysis there were ten fruits from tree 1 (79 fruits yield) and because of partial decay only five fruits from tree 2 (22 fruits yield); average (AV) and standard deviation (SD) are presented

Parameter	tree 1		tree 2	
	AV	SD	AV	SD
Fruit volume, cm^3	175	31	246	18
Fresh matter, g	145.1	25.3	197.0	18.2
Starch index	9.9	0.3	9.6	0.5
Brix value	14.0	0.7	15.6	2.1
Fruit firmness, N	61.3	9.1	48.5	14.2

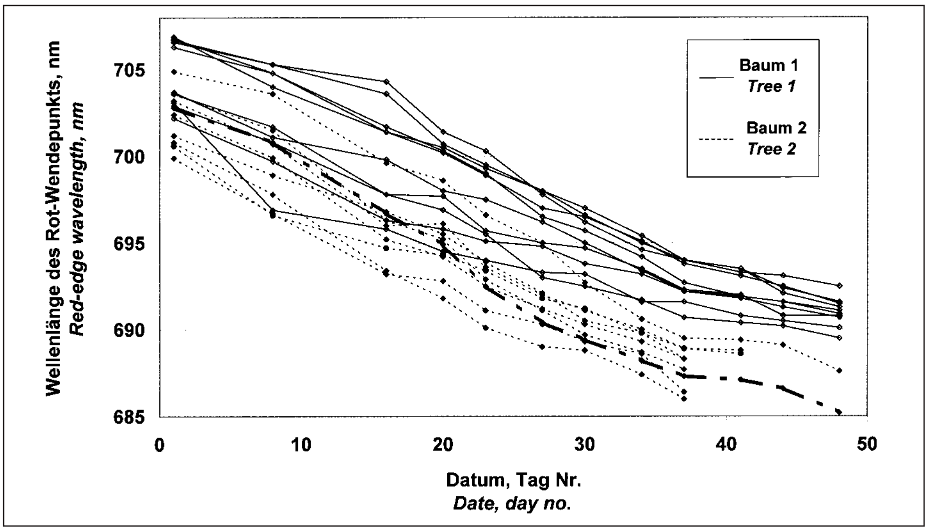

Fig. 2: Red-edge shift of the fruits of two selected trees during fruit development on tree (bold broken line see fruit in Fig. 3)

change of the spectral signature for the example of a typical fruit of the tree number 2. Besides the characteristic light absorption due to chlorophyll around 680 nm, a strong decrease of light intensity between 530 and 580 nm could be observed during the fruit development until cw 35. This change was caused due to the blush colour pigments that showed rapid development on the fruits of tree number 2. For quantitative evaluation of blush colour development, there is potential to derive a suited criterion from spectral signature. In this case, attention should be paid to the specific differences of blush colour development of different cultivars. By using these spectral optical criteria, a more exact monitoring of fruit development and optimum harvest date would be possible.

written protocol of measurement is not required.

Measurements during maturity development

Studies have been carried out on "Elstar" apples in an orchard with two years old trees sited in the region of Werder near Berlin during the harvest season 2003 from calendar week (cw) 32 to 39. During this extremely dry season, the orchard has got continuous drop irrigation. From two rows in an even site of the orchard, nineteen trees were selected, and ten fruits of each tree were labelled for identification. A measuring area was marked on each fruit to facilitate repeated spectral optical measurements during the maturity development at the tree and later on reference analyses in laboratory.

Spectral optical measurements have been carried out from cw 32 to 34 once a week, and thereafter twice a week, i.e. altogether until twelve measuring dates. After each measuring date, the labelled ten fruits of one of a single tree were picked and analysed in laboratory for starch index, Brix value and fruit flesh firmness (*Table 1*). Partly, some premature fruit losses occurred. However, the spectral signatures of the same ten fruits from four trees could be measured during the whole time period.

Data analysis in visual spectral range

In order to be able to judge the fruit development, particularly the data of visual spectral range were analysed. The analysis was focussed on the most important criterion of this range, the so-called red-edge of spectral signature. The red-edge indicates changes of chlorophyll content [5]. During the maturity development, these changes are visible as fading green ground colour. The results of this analysis are shown for the example of two trees with different fruit yield (*Fig. 2*). The red-edge value of the fruits of both trees has a relatively even drift to shorter wavelengths with progress of fruit maturity development. The curves of single fruits vary considerably. But the fruits of the tree number 2 (low fruit yield) have a distinct lead in maturity development compared with those of the tree number 1 (high fruit yield). This lead was found not only at the begin of the measuring series but also due to the steeper decrease of the curves, and it is corresponding with the well-known experience on influence of fruit yield. The laboratory results of analyses of fruit volume, fresh weight and fruit flesh firmness confirm that the fruits of the tree number 2 were totally ripe or overripe at the end of measuring period (cw 39) (*Table 1*).

Additionally, the influence of development of blush colour on the spectral signature has been studied. *Figure 3* shows the

Literature

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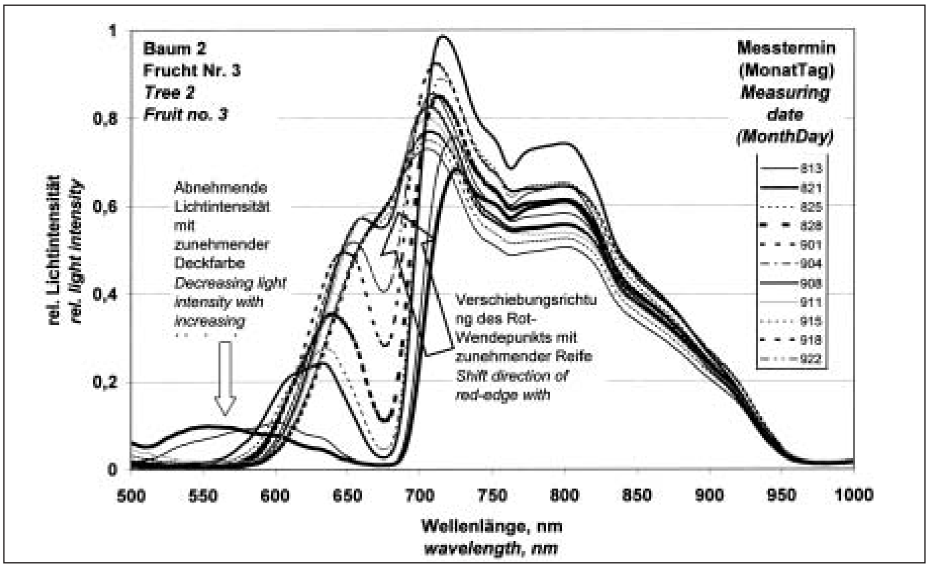

Fig. 3: Change of spectral signature of a single fruit of tree 2 during fruit development on tree