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Non-destructive spectralscopic analysis for fruit ripeness

Fruit for the trade must be free of residues and clean. Additionally the products must have the correct ripeness for consumption. Variety-specific taste-giving characteristics are only expressed in fruit which has reached a sufficient maturity on the tree, on the other hand over-ripe fruit cannot be stored.

In order to exploit the full taste potential of an apple variety, harvesting must be at the optimal variety and season related time. Additionally, very precise and objective methods are required for determining ripeness. These requirements can be met by sensors using spectral analysis in the visible wavelength range.

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Optimum harvest time varies with variety, season and location *(fig. 1)*. Sensors are being developed for finding the right harvesting window in each case. Such sensors must satisfy strict information-giving, reproducibility and robustness requirements and be affordable for the horticultural branch.

The rapid development of cost-efficient optical components offers in this case new possibilities for introducing spectral analysis into practical horticulture. In the ATB's modular constructed instrument [2] is a robust monolithic spectrometer with which the spectral light transmission T is investigated through the fruit tissue at integration times of 400 ms. The coupled white light is influenced by the wavelength specific absorption A ($A = \log^{10} 1/T$) in the fruit tissue [2, 3]. The absorption A is correlated with concentration c of the respective connections:

$A = \varepsilon \cdot c \cdot l$

with ε = special absorption coefficient

l = tracklength in tissue

Along with other fruit pigments absorbing the visible wavelength range is above all chlorophyll, the content of which in fruit represents a sensitive indicator of ripeness [4].

Informative ability of non-destructive chlorophyll analysis

Changes in chlorophyll content, visible as faded green ground colour of fruit during the ripening process, is traditionally used for subjective judgement of ripeness. Fruit producers utilise this visual impression for judging fruit ripeness in-store [1].

The buying reactions of consumers are also closely related to fruit colour, in that a certain taste is expected according to variety-specific colour characteristics. State-appointed quality controllers as well as company inspectors currently have access to only a few simple methods for determining ripeness and associated fruit quality. Using new sensor technology based on chlorophyll identification through spectral analysis in the visible wavelength range [2, 3, 4] could determine the ripeness of apples in trade without destroying the fruit. Additionally, information is then available regarding the physiological age of the fruit which depends on adequate or unsuitable storage conditions [4]. Thus, e.g., it is possible to differentiate between apples from a modern controlled-atmosphere store and those from cool store [5].

The determination of chlorophyll content with the help of non-destructive spectral analysis can be utilised for judging ripeness with sufficient precision *(table 1)*.

There are two methods for determining chlorophyll content from spectra: one on the basis of the progression of the turning point on the longwave flank of the chlorophyll absorption band (IP) [6], and then on the basis of the absorption with multivariate evaluation of the total illustrated spectral area (PLS analysis) [5]. For this, spectral data is preconditioned involving a subtraction of the average value and a division of the standard error. Main component analysis and presentation of a calibration model takes place with

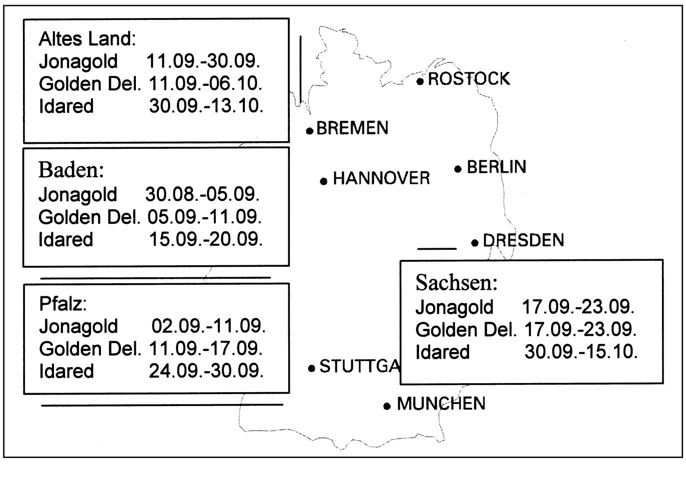

Fig. 1: Regional differences of the optimum harvest date for three apple cultivars . Within a region, given production conditions result in differences between 3 and 21 days

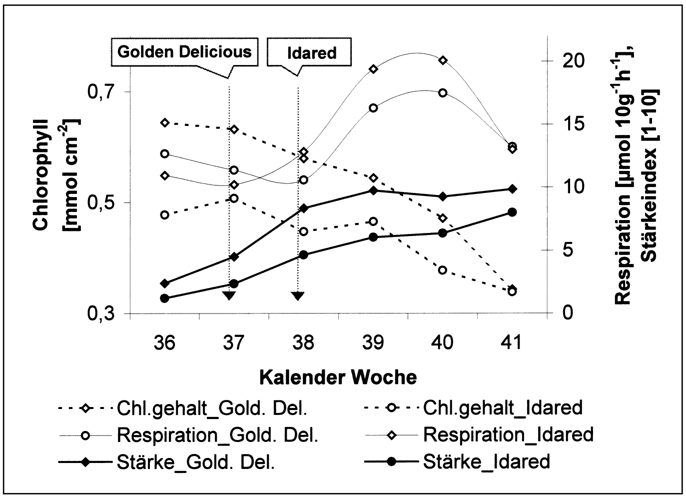

Fig. 2: Fruit respiration rate, starch index and chlorophyll content during fruit development in season 2000. Vertical arrows indicate the optimum harvest date of the two cultivars

Calendar week 2000	Chl a (mmol/100 cm²)	IP (nm)	Pred.Chl a (mmol/100cm ²)
Idared			
36	47,8	693.8	47.9
37	50.8	692.9	50.7
38	44.8	692.5	46.7
39	46.5	692.2	43.3
40	37.8	691.7	38.6
41	35.9	691.2	36.4
Golden Delicious			
36	64.5	697.1	66.4
37	63.2	695.6	55.3
38	57.9	696.8	54.4
39	54.4	694.6	47.8
40	47.1	693.6	47.1
41	34.3	692.7	38.4

Table 1: Chemical analysis of chlorophyll content (Chl a) in the fruit skin of 'Idared' and 'Golden Delicious' apples during fruit development period (weekly) and data of chlorophyll red-edge (IP) and chlorophyll content predicted by PLS regression analysis (Pred. Chl a) from non-destructive transmission recordings.

an Eigenvector PLS-Toolbox (Eigenvector Research Inc., USA) placed upon the program Matlab 5.2 (Math Works Inc., USA). The precision in evaluating turning point progression is $R^2 = 0.65$ with „Idared“ and $R^2 = 0.80$ with „Golden Delicious“. And when evaluating with PLS analysis 0.91 and = 0.83 respectively. The standard error of calibration and the cross validation standard error equal, according to the leave-one-out method, RMSEC/RMSECV=0.99/5.4 for „Idared“ and RMSEC/RMSECV=1.8/13.4 for „Golden Delicious“.

Recording the spectra took place always in the equatorial area of the fruit in order to avoid necrotic points with resultant locally reduced chlorophyll content. Measurement took place without observation of the fruit side, i.e., development state of the red overcolour. In order to determine whether non-observation of the fruit side can be permitted, measurements were carried out on ripe and overripe „Jonagold“ apples on the red and green fruit sides respectively. A main component analysis was conducted over the wavelength range 650 nm to 680 nm. Only the absorption of chlorophyll can be measured in this range in which the absorption bands of overcolour-creating fruit pigments are invisible. Analyses based on the first two main components showed the separation of both apple ripeness grades. The spectra of the red and green sides did not appear separate. Also, the turning point of the longwave chlorophyll flank appeared unchanged with different overcolour intensities. On average, the turning point was measured on the red fruit side of ripe apples at 689.6 nm and overripe at 684.1 nm and on the green side 688.3 nm and 684.4 nm respectively. As a result, the intensity of the overcolour had no influence on the spectral determination of fruit ripeness via chlorophyll content. This means considerable simplification for the utilisation in practical farming in that when being measured the fruit doesn't have to be turned according to covercolour intensity.

Comparing non-destructive measurement with other methods of ripeness evaluation

Apples belong to the climacteric fruit characterised by an increased respiration rate shortly after optimum harvesting point [1]. Measurement of respiration for determining fruit ripeness is thus a very sensitive, but also very effortful, technique in that the CO_2 development has to be followed in micromolar concentrations. In fruit production the harvesting point of apples therefore is often determined via with the simpler method of measuring the starch index after cutting through the axis of the fruit and staining the starch with KJ/J_2 solution. A further method is the penetrometer test which, however, shows hardly any alteration in readings at optimum harvest point and is influenced by the fruit temperature and manual conditions.

The non-destructive and objective determination of chlorophyll content through the new sensor technology could close this gap. *Figure 2* shows the progression of fruit development and the optimum harvest point for two apple varieties determined by measuring respiration rates. The starch index as well as the spectral value of chlorophyll analysis showed changes in the progression of ripening. The method of spectral analysis chlorophyll determination is thus an interesting tool for the judging of fruit ripeness.

Literature

Books are signefied with •

[1] • *Friedrich, G. et al.*: Physiologie der Obstgehölze. Springer-Verlag, Berlin, 2. Aufl., 1986

[2] *Herold, B. et al.*: Zerstörungsfreie Bestimmung des Entwicklungsstadiums von Obst. Landtechnik 55 (2000), H. 3, S. 224-225

[3] *Chen, P. et al.*: Light transmittance through a region of an intact fruit. Transactions of ASAE 23: (1980), no. 2, pp. 519-522

[4] *Zude-Sasse et al.*: Comparative study on maturity prediction in "Elstar" and "Jonagold" apples. Gartenbauwissenschaft 65 (2000), H. 6, S. 260-265

[5] *Zude-Sasse, M. et al.*: An Approach to non-destructive Apple Chlorophyll Determination. Postharvest Biology and Technology 2001, im Druck

[6] *Lichtenthaler, H.*: Spektroskopische Eigenschaften von Pflanzen und ihre Nutzung zur Fernerkundung der Vegetation. Fridericiana 49 (1994), S. 25-45