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Comparative Study on Maturity Prediction in 'Elstar' and 'Jonagold' Apples

Vergleichende Studie der Reifevorhersage bei 'Elstar' und 'Jonagold' Äpfeln

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Summary

Fruit development was observed in apple cvs. 'Elstar' and 'Jonagold' by recording the relative fruit growth, respiration, fruit firmness and starch degradation. Results were obtained by measurements on 60 fruits every week over a period of 4 months. Additionally spectral reflectance in the visible range was recorded non-destructively on fruit skin and associated tissue in order to determine the chlorophyll content decrease during fruit ripening. Maturity determination was improved by using spectral reflectance data. Prediction of fruit development stage was further enhanced by separating the analysis for unripe and ripe fruits.

Zusammenfassung

Die Fruchtentwicklung wurde für die Apfelsorten 'Elstar' und 'Jonagold' mit Hilfe von Messungen des relativen Fruchtwachstums, der Respiration, der Fruchtfleischfestigkeit sowie des Stärkeabbaus aufgezeichnet. Wöchentliche Messungen erfolgten über einen Zeitraum von 4 Monaten an 60 Äpfeln. Veränderungen der spektralen Lichtreflexion an der Fruchtschale und dem schalennahen Gewebe wurden zerstörungsfrei aufgezeichnet, um den reifebedingten Chlorophyllabbau zu bestimmen. Die traditionelle Reifebestimmung der Früchte konnte durch die Berücksichtigung der spektralen Reflexionsveränderungen verbessert werden. Darüber hinaus war die Möglichkeit zur Vorhersage des Stadiums der Fruchtentwicklung erhöht bei einer getrennten Betrachtung für unreife und reife Früchte.

Introduction

The determination of optimum harvest date has become more severe since storage facilities are getting precisely controlled requiring adequate fruit material. The respiration rate is an excellent tool to observe the stage of fruit development in climacteric fruits such as apples. A disadvantage of respiration measurements appears from the expensive sensitive analytical equipment. The widely accepted Streif index (firmness/ [starch index • Brix], STREIF, 1983) may provide valuable information about the appropriate picking date in apples and pears. The Streif index is mainly influenced by the starch degradation, which is described by a starch index efficiently. Particularly the logarithmic value enables sufficient discrimination of various maturity stages.

De Jager and Roelofs (1996) proposed that incorporation of fruit colour might further improve the Streif index. The reasonable suggestion was not proved, since the former use of L*a*b*-values only insufficiently describes the colour changes during fruit development. In addition colour cards related to the fruit colour in different maturity stages are commonly used to obtain information about the optimum harvest date (SMITH, 1985). This method is inexpensive and non-destructive. However, the subjective reference might lead to economic disadvantages. The consumers in fact make their decision to buy a fruit from their own subjective impression of the fruit skin colour mainly. Therefore the observation of colour changes represents an accepted tool to estimate the market quality (BINENKO *et al.*, 1989; DRAHORAD, 1998).

Recently developed accurate and inexpensive spectrometers may determine the ground and blush colour non-destructively (MERZLYAK *et al.*, 1999). The blush colour is influenced by environmental conditions resulting in alternating colours on the fruit, while the ground colour is more homogeneous on the fruit surface. The ground colour of the fruit skin and associated tissue is due to the chlorophyll content.

In the present work the above mentioned traditional methods are applied to determine the stage of fruit development. Non-destructively spectral light reflectance measurement in visible range was investigated to improve the optimum harvest date determination as well as prediction of fruit quality in ripe 'Elstar' and 'Jonagold' apples.

Material and Methods

The fruits were harvested at the research station of the Humboldt University Berlin, Section Fruit Science. The trees Elstar/M26 and Jonagold/M26 were planted in 1992 with a spacing 4.0 m x 1.5 m. All trees yielded similar mass (kg/tree) and number of fruits (fruits/tree). During the measuring period (21. 07. 1999 to 11. 11. 1999) 30 fruits were harvested representatively from 20 trees each cultivar at intervals of 7 days. Temperature and relative humidity were recorded in the orchard as well as during the transport of fruit material.

On individual fruits measurements of fresh weight (g/fruit), circumference (mm/fruit), volume (ml/fruit), dry weight (g/fruit), fruit firmness (N/cm^2) measured at 200 mm/min, total soluble solids (Brix), starch index (scale 1-10), ground colour (difference of reflectance

value at 720 nm and 680 nm) and respiration rate (µmol CO_2/g min) were carried out. The reflectance spectra in the range from 400 nm to 1100 nm were recorded by a miniaturised spectrometer module (MMS 1, Zeiss, Jena) working with a diode array detector. Glass fibres were used to lead the light of a 20 W halogen lamp to the fruit surface and to receive the reflected light collected by using an integrating sphere.

Reflectance spectra and respiration rate were analysed at the picking day, while other measurements were performed one day later. Respiration rate (R) was measured by CO_2 evolution cumulatively in a closed system (equation 1, altered from EBERT, 1988). Q_{10} values were calculated in the range from 10 to 15 °C and from 15 to 19 °C (equation 2, BURTON, 1988).

The Streif index (see above) and logarithmic values were calculated. An additional maturity index (MI) incorporating the light reflectance analysis was calculated (equation 3). Error bars denoted in the figures indicate the SD calculated with Microsoft Excel. Principle component analysis were performed with MATLAB (Math Works, Inc., www.mathworks.com) and the PLS-Toolbox of Eigenvector (www.eigenvector.com) on autoscaled data.

$$(1)\quad R\left[\frac{\mu mol \cdot CO_2}{g \cdot min}\right] = \frac{\Delta CO_2\left[\frac{\mu mol}{mol}\right] \bullet (V_c - V_a)[l] \bullet 60}{(t_1 - t_2)[h] \bullet 22{,}41\left[\frac{mol}{l}\right] \bullet freshweight\,[g]}$$

$$(2)\quad Q_{10}\left[\frac{R_2}{R_1}\right]^{\frac{10}{T_2 - T_1}} \qquad R_2 = \sqrt[\frac{10}{T_2 - T_1}]{Q_{10} \bullet R_1}$$

R_1=Respiration rate 1; R_2=respiration rate; V_c=Cuvette volume; V_a=Apple volume; t_1=time 1; t_2=time 2; T_1=temperature 1; T_2=temperature 2

$$(3)\quad MI = \frac{firmness \bullet (reflection_{720\,nm} - reflection_{680\,nm})}{starchindex}$$

Results

Fruit respiration

Temperature response of fruit respiration rate was determined in the range from 10 °C to 19 °C (Figure 1). The fruit temperatures in the following investigations varied between 12 °C and 16 °C. Respiration rate were corrected with related Q_{10} value of 1.2 for both cultivars. In 'Elstar' a high respiration rate compared to 'Jonagold' was measured.

In the closed measuring device the CO_2 concentration increases during the measuring interval. Additional study was performed on the cumulative respiration rate measurements in closed system concerning the influence of increasing CO_2 concentration on respiration rate. 'Jonagold' (Figure 2) and 'Elstar' were not affected by increasing CO_2 concentrations up to 1800 ppm. The respiration rate sensitively depends on the stage of fruit development. Decreasing respiration rates were recorded in both cultivars from July until the end of September. The climacteric respiration peak occurred at the end of September in 'Elstar' (data not shown) and with a delay of 10 days in the beginning of October in 'Jonagold'. Thus, fruits harvested in the period from 21.07.99 to 22.09.99 (period 1) are defined as unripe, while fruits harvested in the period from 22.09.99 to 11.11.99 (period 2) are denoted as ripe.

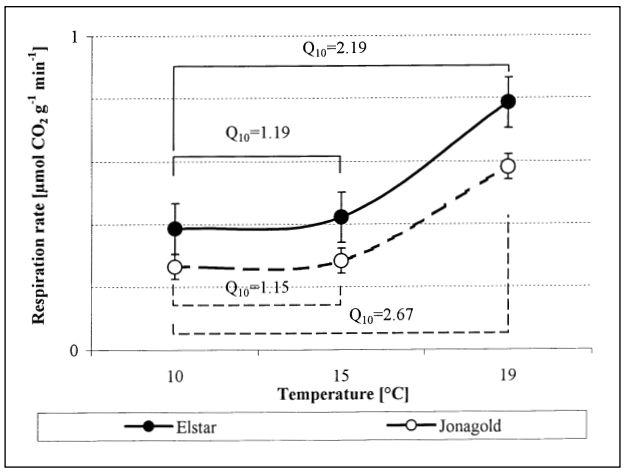


Fig. 1. Influence of fruit temperature on respiration rate of 'Elstar' and 'Jonagold' apples.
Einfluß der Fruchttemperatur auf die Respirationsrate bei 'Elstar' und 'Jonagold' Äpfeln.

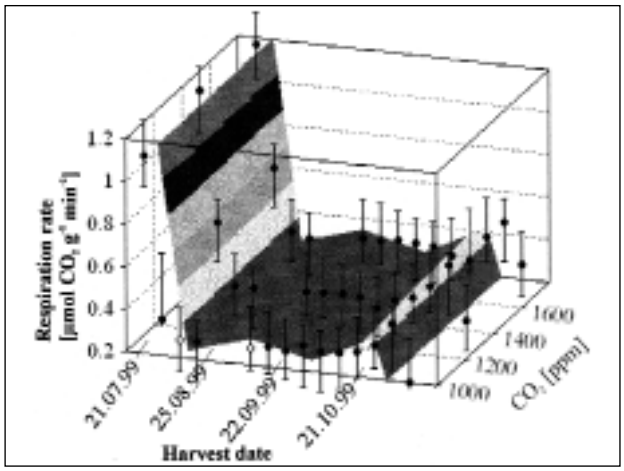


Fig. 2. Influence of the stage of fruit development and CO_2 concentration in the cuvette atmosphere during measuring procedure on the respiration rate of 'Jonagold' apples.
Einfluß des Stadiums der Fruchtentwicklung sowie der CO_2-Konzentration in der Meßküvette während der Messung auf die Fruchtrespirationsrate bei 'Jonagold' Äpfeln.

Fruit size, starch, TSS, firmness and reflectance data

The fruits developed the typical pattern for 'Elstar' and 'Jonagold' (Table 1). Fruit fresh weight, fruit volume and dry weight increased until early October. Starch degradation was enhanced around optimum harvest date at the end of September in 'Elstar' and with a delay of 10 days in the beginning of October in 'Jonagold', while fruit firmness sharply decreased in ripe fruits. Total soluble solids (refractometer readings) were slightly affected by picking date and hence did not sufficiently indicate optimal harvest time. The course of Streif index and suggested maturity index appeared sigmoidal from July to November for the 2 cultivars (Figure 3). The

Table 1. Fruit development of 'Elstar' (Table 1a) and 'Jonagold' (Table 1b) apples described by fruit parameters.
Beschreibung der Fruchtentwicklung bei 'Elstar' (Tabelle 1a) und 'Jonagold' (Tabelle 1b) Äpfeln mit Hilfe von Fruchteigenschaften.

a

Date 1999	Fresh weight [g/fruit]	Dry weight [g/fruit]	Volume [ml/fruit]	Circumference [mm/fruit]	TSS [Brix]	Firmness [N/cm²]	Starch-index [1-10]
21.07.	051.8±11.6	07.2	063	158.7±12	10.6±0.8	99±15	1.1±0.2
04.08.	067.3±14	11.9	092	177.8±13	10.6±0.6	74±15	1.2±0.3
11.08.	066.9±11	08.9	081	176.7±10	10.7±0.6	77±08	1.4±0.2
18.08.	084.9±19	12.4	102	190.0±14	11.7±0.9	72±11	1.1±0.2
25.08.	080.5±18	11.7	091	186.4±13	12.6±0.6	70±14	1.2±0.4
01.09.	095.3±17	13.3	119	198.9±12	11.3±0.9		1.5±0.6
08.09.	086.4±13	13.6	097	191.2±10	12.5±0.6		2.5±0.6
15.09.	093.5±16	13.8	128	195.7±12	12.6±0.9	85±06	4.1±1.2
22.09.	104.3±17	12.7	116	204.0±12	12.6±0.9	74±04	7.7±1.9
29.09.	111.4±25	10.7	111	210.9±15	12.6±0.9	68±06	9.1±1.0
06.10.	116.1±25	18.9	164	211.4±14	12.7±0.9	67±09	9.6±0.8
13.10.	105.2±20	14.2	137	204.0±13	11.9±1.0	70±05	10±0.0
20.10.	116.2±26	22.2	160	210.6±15	12.9±0.7	68±03	10±0.0
27.10.	103.5±14	14.8	132	204.3±09	12.4±0.9	67±06	10±0.0
03.11.	116.7±18	17.2	154	214.2±10	13.2±0.9	55±07	10±0.0
11.11.	114.9±26	16.8	147	212.4±15	13.5±0.9	58±06	10±0.0

b

Date 1999	Fresh weight [g/fruit]	Dry weight [g/fruit]	Volume [ml/fruit]	Circumference [mm/fruit]	TSS [Brix]	Firmness [N/cm²]	Starch-index [1-10]
21.07.	070.8±10.5	08.9	077	171.9±08.9	08.4±0.7	163±14	1.9±0.4
04.08.	088.8±11.8	12.3	116	189.9±07.8	09.0±0.9	111±15	2.0±0.5
11.08.	102.0±13.4	12.2	117	196.9±09.5	09.6±0.6	111±07	2.0±0.6
18.08.	112.8±16.3	13.3	129	202.2±10.2	09.9±0.5	105±16	2.3±0.4
25.08.	124.3±14.0	15.9	147	210.7±09.1	10.8±0.7	104±08	2.5±0.5
01.09.	132.1±19.1	16.3	166	214.5±10.7		110±13	3.5±0.6
08.09.	142.1±21.3	18.7	177	219.6±11.5		110±11	4.3±1.0
15.09.	134.7±23.8	16.8	165	212.5±13.4	11.3±0.9	103±07	6.5±0.9
22.09.	157.7±28.1	18.3	171	224.9±12.6	11.7±1.4	088±08	8.7±0.4
29.09.	166.9±26.1	16.3	180	228.9±12.1	11.9±1.6	085±08	9.7±0.5
06.10.	164.7±26.8	16.8	178	226.9±13.2	12.3±1.5	081±09	9.9±0.2
13.10.	157.2±30.9	18.6	146	224.0±15.7	11.2±1.2	082±11	10±0.0
20.10.	171.4±35.4	20.7	190	230.7±15.4	10.8±1.7	074±07	9.8±0.6
27.10.	170.2±34.5	18.8	192	231.9±14.2	11.5±1.7	071±09	10±0.0
03.11.	178.5±39.8	20.9	218	234.3±15.8	11.5±1.8	060±11	10±0.0
11.11.	176.5±34.6	18.3	190	232.5±15.4	12.1±0.9	051±12	10±0.0

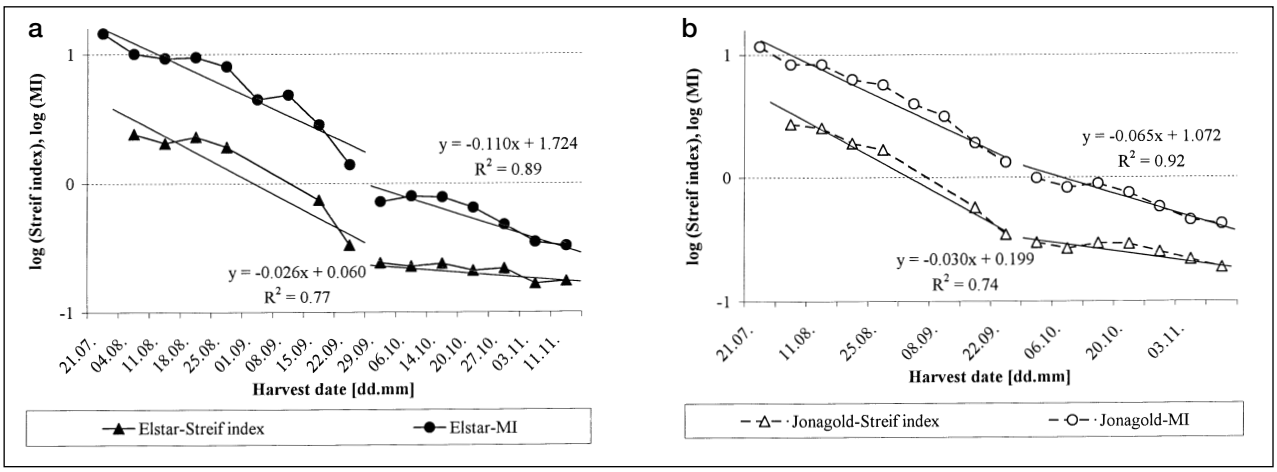


Fig. 3. Influence of fruit development stage on logarithmic Streif index and maturity index (MI) of 'Elstar' (Figure 3a) and 'Jonagold' (Figure 3b). R^2 is given of late harvest dates linear regression in ripe apples.

Einfluß des Stadiums der Fruchtentwicklung auf den Logarithmus des Streifindexes und des maturity index *bei 'Elstar' (Abbildung 3a) und 'Jonagold' (Abbildung 3b). Die R^2-Werte sind angegeben für die lineare Regression der späten Erntetermine von reifen Äpfeln.*

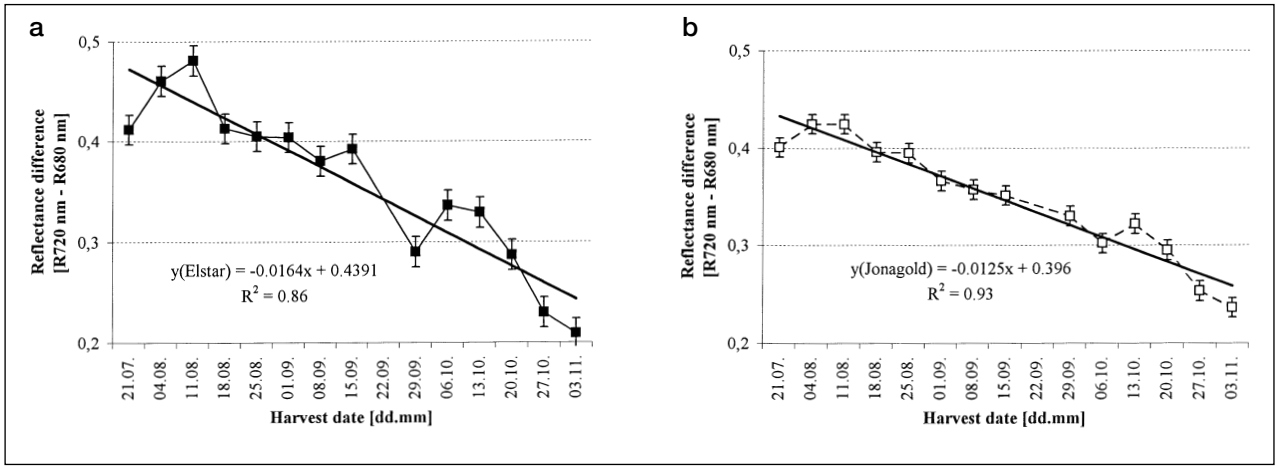


Fig. 4. Influence of fruit development stage on the reflectance, given as difference (720 nm – 680 nm) in 'Elstar' (Figure 4a) and 'Jonagold' (Figure 4b).

Einfluß des Stadiums der Fruchtentwicklung auf die Lichtreflexion, aufgetragen als die Differenz der Meßwerte bei 720 nm und 680 nm bei 'Elstar' (Abbildung 4a) und 'Jonagold' (Abbildung 4b).

Table 2. Principle component analysis (PCA) on 10 variables during fruit development.
Beschreibende statistische Analyse (PCA) bezogen auf zehn variable Fruchtparameter im Verlauf der Fruchtentwicklung.

	Total period 21.07.1999 – 11.11.1999		Period 1 21.07.1999 – 22.09.1999		Period 2 22.09.1999 – 11.11.1999	
PC No.	% variance captured	total	% variance captured	total	% variance captured	total
1	73.00		63.91		58.05	
2	9.94		13.43		22.13	
3	5.67		11.20		12.37	
4	4.80		5.29		4.03	
5	3.02		2.72		2.16	
6	1.54		2.68		1.18	
7	0.98		0.76	100	0.09	100
8	0.59		0.00		0.00	
9	0.08	100	0.00		0.00	
10	0.00		0.00		0.00	

shape of the curves appears mainly influenced by the starch degradation in unripe apples (period 1). The starch index remains constant in ripe fruits (period 2) due to completely starch degradation, while the spectral reflectance data varies due to the chlorophyll content decrease in ripe fruits further (Figure 4). The reflectance values decreased linearly during fruit development. Resulting, the accuracy of stage of fruit development prediction in ripe and overripe fruits was improved by inserting the ground colour into a maturity-index.

Descriptive analysis

Data were processed by principle component analysis (PCA) on mean valued and centred variables to eliminate scaling effects (Figure 5). PCA is a multivariate technique which generates correlated variables into uncorrelated new variables (components). This allows to identify the substantial amount of information (Table 2) as well as to describe comparable parameter development (Figure 5). PCA was done for the periods 1 and 2 in one step as well as discriminated for the two periods. To predict the stage of fruit development in one step over the period from 21.07.1999 to 11.11.1999 it was necessary to include 9 principle components based on 10 analysed fruit parameters to capture 100 % variance. Discriminated data processing for the periods 1 and 2 only 7 principle components were necessary to capture 100 % variance (Table 2).

The first two principle components (PC) explain at minimum 77 % variance, which prove a sufficient data representation in the plots (Figure 5).

For unripe and ripe fruits the loadings for the principle components 1 and 2 appear in 3 groups (Figure 5a). The respiration rate and chlorophyll decrease form one group, while starch index, dry weight and Brix as well as fresh weight and circumference appear as a second and third group, respectively. Firmness, ground colour and respiration rate develop opposite behaviour compared to the second and third group due to the negative correlated values.

Discriminated PCA for unripe 'Jonagold' apples (period 1) leads to opposite loadings for one group including firmness, respiration rate, reflectance and a second group with remaining variables (Figure 5b). The loadings for measured parameters of unripe apples indicate an obviously parallel evolution of dry weight and circumference increase as well as to a minor extend volume and Brix. A close relation between respiration rate and the decline in chlorophyll content was indicated at the same time.

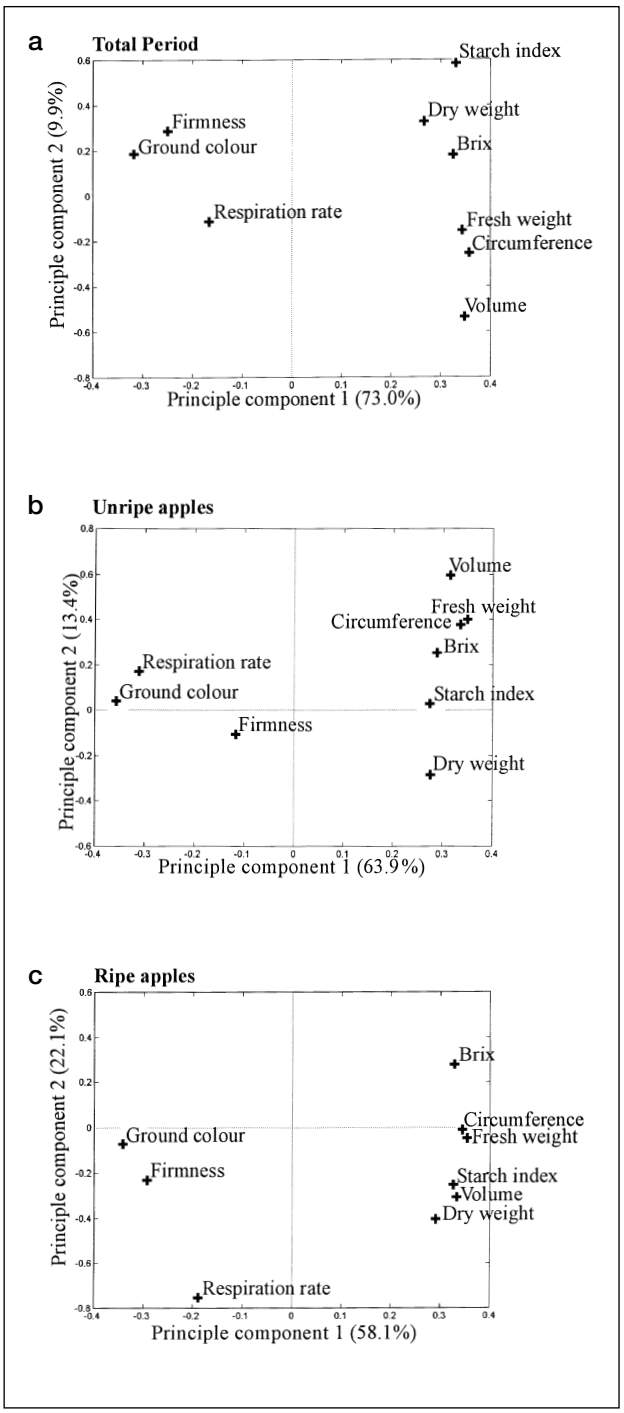


Fig. 5. Loading plots for the first two dimensions of PCA on mean centred linear regression of various 'Jonagold' properties during the fruit development described by the time evolution (21.07.1999 to 11.11.1999) in unripe and ripe apples (Figure 5a) as well as separated PCA on the period of 21.07.1999 to 22.09.1999 in unripe apples (Figure 5b) and on the period of 22.09.1999 to 11.11.1999 in ripe apples (Figure 5c).
Mit Hilfe der Hauptkomponentenanalyse ermittelte Wichtung der zentrierten, linearen Regressionen verschiedener Fruchtparameter von 'Jonagold' bezogen auf die ersten zwei Dimensionen. Die Analyse erfolgte für den Verlauf der Fruchtentwicklung beschrieben mit Hilfe des Zeitverlaufs (21.07.1999 bis 11.11.1999) in unreifen und reifen Äpfeln (Abbildung 5a) sowie separat für das Intervall vom 21.07.1999 bis 22.09.1999 in unreifen Äpfeln (Abbildung 5b) und vom 22.09.1999 bis 11.11.1999 in reifen Äpfeln (Abbildung 5c).

In ripe apples (period 2) the respiration rate exhibited outstanding loading on PC 1 (Figure 5c). Loadings of ground colour and firmness and, as a second group, Brix, circumference, fresh weight, dry weight, volume and starch index were related to each other. A close correlation between ground colour and firmness occurs, while Brix value appears negatively correlated. Although the other measured parameters form one group, the meaning to predict fruit development stage is marginal due to the relatively stable values.

Discussion

The determination of respiration rate provides the most sensitive means to determine the stage of fruit development (BURTON, 1988). In the present investigation the description of fruit development stage was achieved from the fruit respiration rate.

Two maturity indices were evaluated to determine the optimum harvest date in unripe apples as well as to estimate the fruit quality in ripe apples. Both, the traditional applied Streif index and the modified maturity index (MI) were highly sensitive to determine the optimum harvest date. Particularly the MI provides sufficient data to predict the stage of fruit development in unripe as well as in ripe fruits. The Streif index is mainly influenced by changes of starch index. Therefore, the accuracy is limited in ripe fruits due to the finally constant starch index value. The improved sensitivity of MI to estimate the stage of fruit senescence was achieved by inserting light reflectance parameters. Reflectance spectra in the range of visible light represent the pigments concentration in the fruit skin (BLANKE, 1998; BUSCHMANN & LICHTENTHALER, 1998). The reflectance difference between 720 nm and 670 nm was detected taking into account the chlorophyll absorption. The ground colour determined by the chlorophyll content is a parameter to describe the stage of fruit development with high correlation to other parameters usually approached in fruit science (SMOCK, 1964; SMITH, 1985; AGERSKOV *et al.*, 1996; OBAID *et al.*, 1996; MERZLYAK *et al.*, 1999). The spectral analysis provides valuable information on chlorophyll content, while colour changes recorded by L*a*b* values might be disturbed by the blush colour of the fruits.

Chlorophyll determination has the advantage to obtain sensitive alteration data around harvest date, which are relatively independent of seasonal influences. Colour measurements on fruit surface are accepted as a method to determine the stage of fruit maturity (DE JAGER, 1994; DE JAGER *et al.*, 1996; ZERBINI *et al.*, 1994). Furthermore, chlorophyll content decreases continuously in ripe fruits, either on the tree or stored under conditions enabling further fruit development.

Discrimination analysis of unripe and ripe apples may further improve fruit maturity prediction. This seems reasonable due to the non-proportional development of the investigated fruit properties (FRIEDRICH *et al.*, 1986). A principle component analysis (PCA) allows to identify the substantial amount of information on varying parameters to predict the stage of fruit development. The analysed parameters correlation of unripe and ripe fruits seems insufficient to represent the fruit development taking into account the expert knowledge (Figure 5a). To avoid the mixture of non-

parallel development of various parameters a discriminated PCA was done on unripe (period 1) and ripe (period 2) fruits (Figure 5b,c). Noticeable is the close relation of respiration rate and reflectance data in unripe fruits. In ripe apples the respiration rate exhibited outstanding loadings due to non-linear climacteric fruit behaviour, while firmness and reflectance data exhibited parallel development. Summarising, the accuracy to predict the optimum harvest date and to monitor the fruit quality during shelf life might be increased by using different fruit parameters.

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