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THE USE OF IMAGE ANALYSIS TO ESTIMATE HARVEST RIPENESS OF APPLES

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Abstract. Determination of harvest time of seed fruits through observation of starch decomposition (determination of starch index – SI) is accepted as an approved and effective method of estimation of harvest ripeness. The advantages of the method are simplicity and low cost of analyses. In the determination of the index, errors of estimation are made, caused by the subjective nature of the used visual assessment (VA). The paper presents a methodology of calculation of starch index (SI) of apples through analysis of images recorded in the course of starch decomposition in fruits. In view of the increasingly stringent requirements concerning fruit quality it is necessary, apart from an improvement of fruit storage methods, to develop an accurate and widely accessible method for an estimation of the stage of physiological ripeness of fruits. Fruit ripeness at the time of harvest frequently has a decisive effect on changes in fruit material during its storage, and thus also on its final quality. The currently employed precise and costly methods for an estimation of the physiological status of fruits are beyond the reach of orchard farmers due to the high cost of apparatus and complicated procedure of determinations. In this study the authors propose the use of three commonly available video-computer devices for recording starch images, and a method for the determination of the degree of starch decomposition.

Keywords: Starch Index, apples, image analysis, storage of fruits.

INTRODUCTION

The time of harvest can be determined with methods based on measurement of ethylene concentration in seed pockets. Such methods are costly and require specialized equipment. Prediction of harvest time through ethylene induction by means of the Streif and De Jeger indexes requires simultaneous measurement of a number of parameters such as firmness, extract, and degree of starch decomposition. Under orchard farming practice such methods are difficult or downright impossible to use [Łysiak 1998]. In recent years attempts have been made at using ultrasonic waves for an estimation of fruit ripeness as well as fruit colouring changes in the course of ripening [Mizrach et al. 2000]. Such methods are not accepted yet as approved and reliable methods for determinations of this type. The simplest and sure method of estimation of the harvest ripeness of apples and pears is observation of starch distribution – the starch test. In consists in activating the colour reaction of iodine with starch and determination of the so-called Starch Index (SI). The accessible, inexpensive and easy to use methods include the starch test. The test is based on observation of decomposition of starch, taking place in the course of ripening of apples. Observing this phenomenon, a close relation was noted between the content of starch and the stage of ripeness of the fruits. Special model tables were developed that are used for conventional determination of the so-called starch index which is a function of the content of starch in the fruit on a cross-section perpendicular to its axis [Tomala 1995, Werner 2005].

Determination of the index consists in comparing the area coloured by iodine with standard tables. The rate of starch decomposition and its course differ between various fruit cultivars. It happens frequently that the "starch pattern" is asymmetric and non-specific in character. The value of SI is a function of the area free of starch, and therefore its precise determination through visual assessment is often very difficult. Determination of the area occupied by starch (the value of the SI index is related to it) is difficult due to the complex form of the starch patterns observed in various fruit cultivars. The precision of the determination is also dependent on the quality of specimen illumination at the place of measurement, and on the subjective perception of the person making the assessment [Peirs et al. 2002]. Application of such a simplified procedure causes that determinations are burdened with a notable error. There is a need, therefore, to improve the accuracy of measurement and reliability through the application of modern methods of starch index reading and calculation.

The availability of computer techniques with suitable software permits more precise determination of that important index. Contemporary fruit-storage facilities with controlled atmosphere (CA and ULO) ensure high quality of fruits after long-term storage, provided that the fruits are harvested at a precisely determined time so that they are at the phase of harvest ripeness [Tomala 1995, Tomala 2004]. Storage of fruits with the CA and ULO methods requires high accuracy in estimation of their ripeness stage due to the fact that only fruits in the phase of harvest ripeness are capable of adapting to the modified atmosphere in storage chambers of that type [Rutkowski 2001]..

Fruits harvested too late can only be used for short-term storage. Application of CA or ULO storage chambers does not cause retardation of fruit ripening. The fruits are susceptible to storage diseases and to internal decomposition [Andrich i in, 1998]. The values of respiration heat are extremely high in fruits harvested late [Song, Bangerth 1996]. This affects the growth of energy consumption which has to be calculated in storage power balance [Ircha 2005]. Fruits harvested too early are prone to surface burn that occurs due to an increased level of CO_2 concentration in storage chambers of the type [Skrzyński 2000, Rutkowski 2001].

OBJECTIVE OF THE STUDY

The objective of the study was calculation of the starch index with the use of commonly available methods of digital analysis of images. Also, differences were determined in the values of SI obtained with the BW (black and white), DC (digital camera), SC (scanner) and VA (visual assessment) methods.

MATERIALS AND METHODS

The study was conducted in the period of 10th September – 6th November, 2007. The material used in the study originated from the experimental orchard of the Lublin University of Life Sciences at Felin. The choice of apple cultivars was made based on their starch content and distribution and starch decomposition in the fruits was observed until its total disappearance (Fig. 1). The starch test was made on fresh fruits and on storage fruits. The test was performed for 15 fruits of a given cultivar and time of harvest.

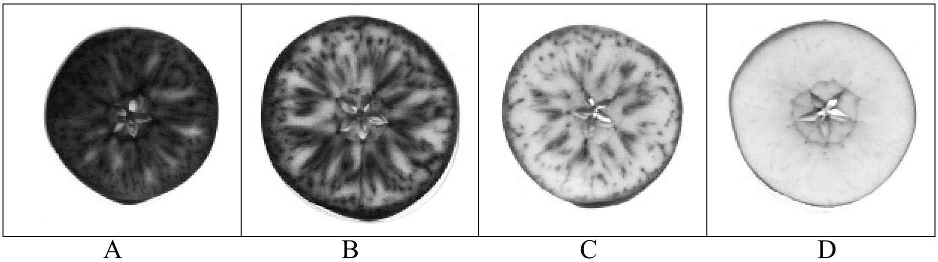

Fig. 1. Decomposition of starch in fruits of cv. Ligol: A – initial stadium of decomposition (first time of harvest), B – after 16 days, C – after 30 days, D – after 40 days of experiment

Fruits of the Gloster cultivar (high-starch) and of the Ligol cultivar (low-starch) were harvested at 4-day intervals in late-morning hours. Average-size apples (7-8 cm) were picked at a height of about 1.5 m above the ground level. The experiment was begun three weeks prior to the calendar harvest time for the fruits.

After performing the standard starch test in a solution of 5g J_2 + 20g KJ/1000 ml of water and allowing the specimens to dry, slices with the "starch pattern" were cut and then their images were acquired by means of a monochromatic CCD camera connected with PC system in the SVISTMET system. Next, under the same lighting conditions, colour images of the specimens were taken with a digital camera. The last stage of specimen image acquisition was scanning of the surface of sheared and coloured slices of the apples. Also, visual assessment of the material was performed (5 jurors), consisting in comparison of the specimens with standard tables (Plantpress, Kraków 2003) and estimation of the value of the starch index in the scale from 1 to 10. Digital images of dyed slices were saved and used for further analyses with the help of the SUPERVIST software (Fig. 2).

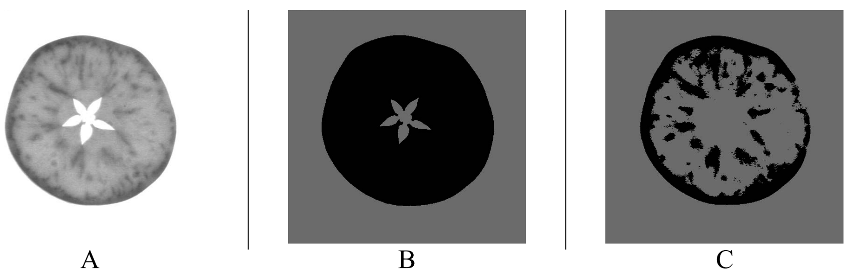

Fig.2. Determination of IS values using the SUPERVIST system: A – specimen image, B – binary image of whole slice, C – binary image of starch pattern

Recorded images were subjected to computer image analysis. In the slice images the whole cross section area of the fruit was isolated with the method of filtration, and then the part of the area that was occupied by dark-blue iodine complexes containing starch. Computer analysis of the images was preceded with generation of histograms of distribution of luminance of pixels forming the analysed images . This served as a basis for determination of limit values of image filtration thresholds.

Separate analyses were performed for images acquired with the digital camera. In this case the analysis consisted in a precise determination of brightness levels of the starch pattern and of the brightness of areas free of starch, using the Photoshop software. Next, an analysis of the histograms of image pixel luminance distribution was performed taking into account those brightness levels

(Fig.3). Images of the specimens were taken at the same resolution (300 dpi), with special care to maintain uniform white background image that facilitated identification of objects. Colour images acquired with the help of the digital camera and the scanner were analysed using graphic software, following the same procedure of determinations. After an analysis of histograms of image luminance distribution determinations were made of the area occupied by starch and of the surface area of the whole slice. The values of the starch index as the share of surface area occupied by starch were calculated from the formula:

$$IS = 10(1 - \frac{p_w}{p_c}), \qquad (1)$$

where:
SI – value of starch index,
P_w – area occupied by starch,
P_c – surface area of slice.

Determination of the starch index (SI) consisted in the calculation of the surface area of the whole slice p_c and of the area of the starch pattern p_w. The starch index value was calculated in the same way from the data obtained by all the methods (except visual assessment).

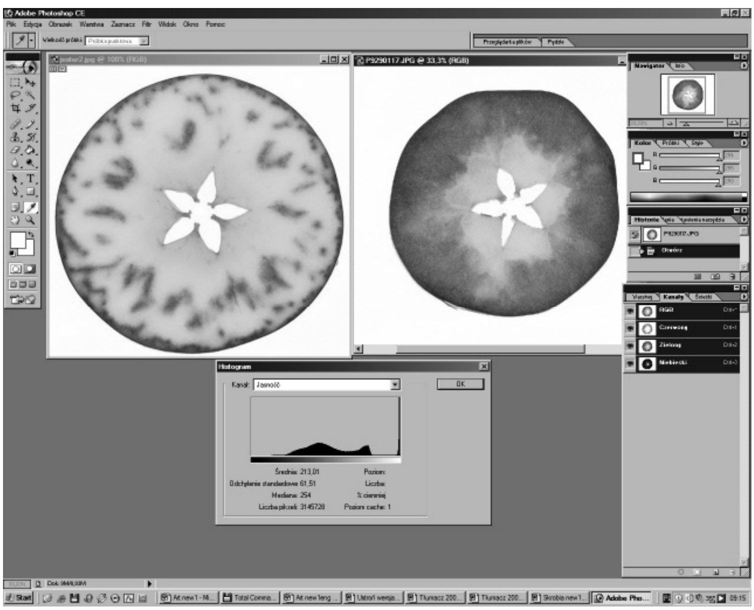

Fig. 3. Methods of analysis of colour images (DC and SC methods)

Determinations with the method of computer image analysis and the method of visual assessment were made for 15 fruits of each cultivar and each time of harvest. The obtained results were subjected to statistical analysis to evaluate the significance of differences in starch index estimation between computer analysis of COL and B-W images and the mean values submitted by the jurors (VA). The calculations of significance of differences were made using two-factor analysis of variance.

RESULTS

Symbols used:
SI – starch index,
BW – analysis of images acquired with a monochromatic camera (SUPERVIST),
DC – analysis of images acquired with a digital camera,
SC – analysis of images acquired with a scanner,
VA – conventional method of assessment (visual).

At the begining a comparison was made between SI values obtained for various methods of starch pattern image acquisition with reference to the zero sample (VA), and for results obtained with the particular methods of image analysis – BW, DC and SC (Tab. 1). Values of SI, calculated in accordance with formula (1), were compared so that calculations were made of differences between values obtained with the particular methods and referenced to specimen “0”, i.e. that estimated with the method of visual assessment. In the comparison mean values were used, obtained from the jurors (5 persons). Likewise, differences in SI interpretation with the image analysis methods were compared. The obtained differences were used to determine mean values for all the harvest times. Differences in SI estimations referenced to the VA specimen for the Gloster cultivar were 0.63, 0.64 and 0.46, and were higher than those for the Ligol cultivar (-0.39, 0.01 and 0.24).

Tab. 1. Mean values of differences in SI estimation with methods used in the experiment

method→ cultivar↓	BW-VA	DC-VA	SC-VA	DC-BW	SC BW	VA-BW	SC-DC
Gloster	**0,63**	**0,64**	**0,46**	**-0,18**	**-0,17**	**-0,63**	**0,18**
Ligol	**-0,39**	**0,01**	**0,24**	**0,57**	**0,63**	**0,39**	**0,06**

The accuracy of measurement of this parameter with relation to the value obtained with the VA method is hard to evaluate, as SI determined conventionally is burdened with a large error [Peirs 2002]. Analysing the obtained results one can note that the Ligol cultivar displays smaller differences in the comparison of SI values obtained with the methods used in the experiment.

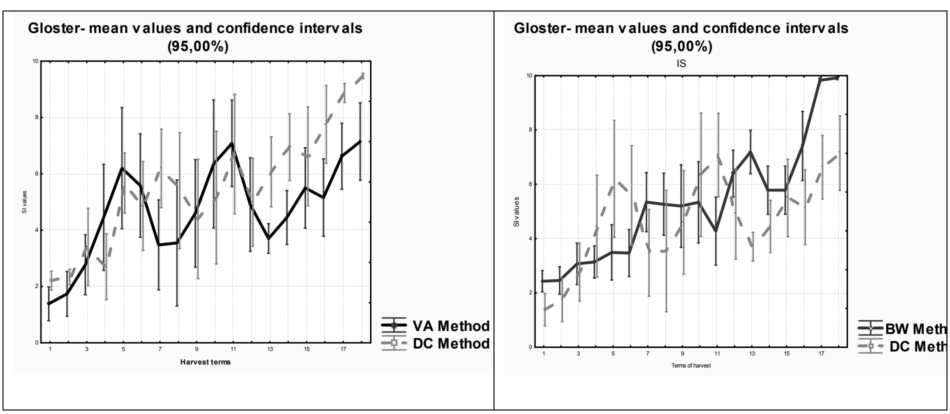

Fig. 3. Comparison of changes in SI values for Gloster cultivar

Differences in the estimation of SI with the methods of image analysis were lower than those obtained in the comparison with the VA method. For the Gloster cultivar they were, on average, 0.17 – 0.18 of SI unit. It should be assumed that they can be used for SI estimation in that group of apple cultivars (high-starch). For the Ligol cultivar the differences were 0.23-0.63 of SI unit. The mean values were determined on the basis of approximately 270 measurements (Gloster) and about 170 measurements (Ligol). Low content of starch in Ligol fruits permitted determinations to be made for only 11 harvest times. Due to the fairly big differentiation in starch content in fruits harvested on the same date, broad intervals of confidence were obtained for SI values in most of the harvest times. The course of changes in the SI values is presented in Figs. 3 and 4.

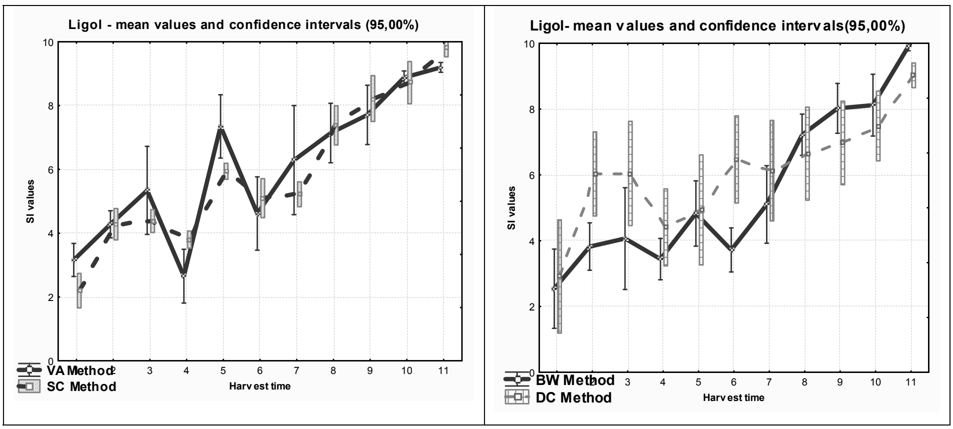

Fig. 4. Comparison of changes in SI values for Ligol cultivar

After the calculation of starch content notable scatter of SI values was obtained due to the differentiation in its content in the fruit samples. The result of this is the extension of the intervals of confidence. The method of data acquisition (BW or DC) had no statistically significant effect on the result of the measurement. Significant differences were obtained most frequently for the latest harvest times (Fig. 3B). Similar relations were obtained in the comparison of results obtained with the two methods of colour image analysis.

Tab. 2. Results of analysis of variance

	Gloster					Ligol				
Variation source	n	Sum.of squares	sq. mean	F_{Kr}	$F_{obl.}$	n	Sum.of squares	sq. mean	F_{Kr}	$F_{obl.}$
Harvest time	17	32,037	1,885	0,26	1,66	10	15,946	1,565	0,25	1,85
Method	3	50,077	16,692	2,31	2,62	3	15,523	5,174	0,80	2,62
Time*Method	51	170,53	3,344	0,46	1,38	30	49,346	1,645	0,25	1,49
Residuals	648	4679,422	7,221			396	2565,198	6,478		
Total	719	4932,066				439	2646,013			

The performed analysis of variance showed that there were no significant differences (α=0,05) in the estimations of SI values considering the harvest dates and the methods of estimation. The calculated values of function F were always greater than the critical values (Tab.2)

CONCLUSIONS

1. Smaller differences between mean values of SI determined with methods of image analysis were obtained for the Ligol cultivar.

2. In the comparison with the VA sample greater convergence of values obtained with that method with those obtained with methods of image analysis was observed for the Ligol cultivar (0.01-0.39). For the fruits of the Gloster cultivar the corresponding values were 0,46-0.64.

3. SI values calculated with the particular methods showed insignificant differences that could have resulted only from different methods of specimen illumination. The lack of significant differences in estimation with the methods used in the experiment may also result from the notable heterogeneity of the material (starch content differentiation) within the sample taken for the tests.

4. The obtained results cannot be taken as grounds for the rejection of any of the proposed methods of image analysis from application in SI estimation.

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OCENA DOJRZAŁOŚCI ZBIORCZEJ JABŁEK PRZY UŻYCIU METOD ANALIZY OBRAZU

Streszczenie. Określenie terminu zbioru owoców ziarnkowych poprzez obserwację rozpadu skrobi (wyznaczanie indeksu skrobiowego – IS) jest uznawane za pełnoprawną i skuteczną metodę oceny dojrzałości zbiorczej. Wyznaczanie tego wskaźnika oceną wzrokową (OW).powoduje błędy w jego szacowaniu spowodowane czynnikami subiektywnego postrzegania przez oceniających. Zaletą jej jest prostota wykonania oraz niski koszt analiz. W pracy przedstawiono metodykę oraz wyniki obliczania indeksu skrobiowego (IS) jabłek przez analizę obrazów rejestrowanych przez urządzenia cyfrowe. Wobec rosnących wymagań jakości owoców potrzebne jest obok doskonalenia metod ich przechowywania opracowanie precyzyjnej i powszechnie dostępnej metody oceny stanu dojrzałości fizjologicznej. Dojrzałość owoców w czasie zbioru ma często decydujący wpływ na przebieg zmian w surowcu podczas przechowywania a tym samym na końcową jego jakość. Obecnie stosowane, pewne, lecz kosztowne metody oceny stanu fizjologicznego nie są dostępne dla sadowników ze względu na wysoki koszt aparatury jak i skomplikowaną procedurę oznaczeń. W pracy zaproponowano użycie trzech powszechnie dostępnych urządzeń wideo-komputerowych rejestrujących obrazy skrobi oraz metodykę oceny jej rozpadu.

Słowa kluczowe: indeks skrobiowy, jabłka, analiza obrazu, przechowywanie.