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APPLE SKIN COLOUR CHANGES DURING HARVEST AS AN INDICATOR OF MATURITY

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Abstract. The CIELab colour system is used to evaluate food colours. Its advantage is that the base skin colour of bicoloured apples can be measured on the same fruit before and on the optimum harvest date. Additionally, it makes it possible to take many measurements within a short time. The changes of skin colour (yellowing) are caused by chlorophyll degradation. During fruit development and maturation chlorophyll breakdown is observed, which results in decreasing intensity of green coloration. The aim of the five-year study was to evaluate a fast and non-destructive method of determining the optimum harvest date of apples intended for long storage based on changes observed in the base skin colour. Apples of 'Ligol' and 'Jonagored' cultivars were collected every 4–5 days starting some weeks before the estimated OHD. On the last four or five sampling dates in all years of the study, apples were collected for cold storage. The storability of apples was evaluated after the same number of days of storage respectively to their harvest date. Storage efficiency was evaluated based on judgment that involved sensoric tests and checking of the incidence of diseases and disorders in apples, as well as on measurement of fruit mass loss and internal qualities (firmness, TSS, TA). From among the evaluated colour indicators L*, a*, b*, Hue_{ab} angle and chroma, changes in the base colour were best illustrated by the a* coordinate value and the Hue_{ab} angle value. Based on the evaluation of the quality of apples after storage, it can be stated that the apples had the best quality when the a* coordinate during harvest ranged between -13.5 and -15.5 for 'Ligol' and between -4.9 and -5.7 for 'Jonagored'. The Hue_{ab} angle assumed a value between 107 and 109 for 'Ligol' and between 98 and 99 for 'Jonagored' during the optimum harvest date. Therefore, the a* coordinate and the Hue_{ab} angle can be used as indicators of harvest maturity.

Key words: apple, CIELab, storability, optimum harvest date, physiological disorders, storage diseases

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ABBREVIATIONS

CIELab – L*, a*, b* colour space
OHD – optimum harvest date
TA – titratable acidity TSS – total soluble solids

INTRODUCTION

Maturity at harvest is the most important factor that determines postharvest life and final quality (appearance, texture, flavour, nutritive value) of fruits and vegetables [Kader 1999]. Apple cultivars intended for long storage have to be harvested during a 3–5 day window of the optimum harvest date [Łysiak 2011, Łysiak 2012]. From winter cultivars only apples picked on the optimum maturity date are suitable for storage for over five months because of better storage potential and organoleptic quality. Apples harvested when still unripe are more prone to shrivelling [Łysiak and Kurlus 2000], internal breakdown [Łysiak 2013] and are of inferior quality when ripe. Overly mature fruits are likely to become soft and mealy and have insipid flavour after a short storage time [Kays 1991].

Base colour is correlated with maturity in most fruits [Kays 1991, Kader 1999]. There are already colour standards for determining the optimum harvest date (OHD) of some fruits. In the United States, a colour pattern for evaluating the maturity of peaches [Delwiche and Baumgartner 1983, Meredith et al. 1989], nectarines [Luchsinger and Walsh 1998], apricots, persimmons and plums [Kader 1999] was developed. In Spain, standards for evaluating the colour of peaches [Ferrer et al. 2005] and table grapes [Carreño et al. 1995] were introduced, and in Portugal, standards for evaluating the colour of sweet cherries were proposed [Gonçalves et al. 2007]. Similarly to apples, mango has a climacteric pattern of ripening, and a study on colour changes in mango was conducted in Australia [Kang et al. 2008]. All those colour standards are based on the CIE L* a* b* (Commision Internationale de l'Eclairge) colour system, which just as other colour systems (RGB, CMYK, CIECAM02) was developed based on the mathematical model quantifying colours based on human perception that was created by Albert H. Munsell in the first decade of the 20th century [Nickerson 1976, Landa and Fairchild 2005] and is nowadays extensively used to evaluate food colours.

In many fruits, changes in colour involve the loss of chlorophyll, the synthesis of new pigments such as carotenoids and/or anthocyanins, and the unmasking of other pigments that were previously formed during the development of the fruit [Ferrer et al. 2005]. In fruits with a climacteric pattern of ripening these processes are strictly connected with increased respiration, oxygen production and starch disintegration [Valero and Serrano 2010, Łysiak 2011]. Due to their enzymatic background, the above processes are simultaneous and therefore, besides the recognised auxiliary methods, such as the measurement of firmness, starch disintegration or endogenous oxygen production, the determination of changes in fruit colour seems to be a promising method for determining the OHD. In contrast to the traditional, chemical analysis of pigment concentration, the measurement of fruit skin colour is fast and non-destructive. Another advantage of colour measurement is that it can be taken on the same fruit several times during a given period.

Additionally, the subjective judgement might lead to economic advantages. The consumers in fact make their decisions on whether or not to buy fruit mainly based on their own subjective impression of the fruit skin colour [Zude-Sasse et al. 2000]. Therefore, the observation of colour changes represents an accepted tool to estimate the market quality [Drahorad 1998, Zude-Sasse et al. 2000].

The objective of this study was to measure the apple base colour as a function of maturity and to examine its relationship with other maturity indices. Colours were measured along coordinates sufficient for later specification of colour reference shades.

MATERIAL AND METHODS

The experiment was set up in western Poland at Poznan University of Life Sciences Research Station (52°31' north latitude and 16°38' east longitude) on a grey-brown podsolic soil overlaying light boulder clay. Apples were picked from trees planted in 1992 on M.9 rootstock in single 4 × 2 m rows, the trees having a wide spindle shape. The orchard was protected and maintained (pest, disease, fertilsation, irrigation and weed control) in line with the recommendations for commercial orchards. The study was conducted in the cold storage facility and laboratory of the Department of Pomology of the Poznań University of Life Sciences between 2002 and 2006 and was designed to determine and evaluate the colour changes of 'Ligol' and 'Jonagored' cultivars.

Sampling. Apples were collected every 4–5 days starting some weeks before the estimated OHD. The schedule of all measurements is shown in table 1. The sample size was 20 apples picked from a minimum of 10 trees, from 140 to 160 cm high, from the same south-eastern side. To avoid a thinning effect on samples, apples were randomly harvested from 72 trees in the same row. Apples over or under size, infected by pests or diseases were rejected. The apples had to represent the stage of maturity (in size and colour) of those apples that were to be harvested during the main harvest. On the last four or five sampling dates in all years, apples were collected both for OHD evaluation and cold storage. The harvest was conducted according to the rules applicable to the picking samples, but the size of a single sample intended for cold storage was considerably larger and amounted to 4 boxes per 10–12 kg each box. The approximate OHD was determined mainly on the basis of starch index measurements and Streif index calculations [Łysiak 2011], whereas the exact OHD was determined after storage based on the results of the quality and quantity research described in the methods part below.

Measurement. The fruit maturity at harvest was evaluated according to the well known standard methods:

– firmness: penetrometer (probe – 8 mm depth, 11 mm in diameter), two opposite sides of the fruit, in kgf (model Effegi FT327, manufactured by Facchini srl. Alfonsine, Italy);

– refractometer value (TSS) in % (model Fefractometer RR3H, manufactured by PZO, Warsaw, Poland);

– starch disintegration according to a 10-point scale, where 1 means "no conversion" and 10 means "totally converted";

– titrable acidity (TA): titration with 0.1 n NaOH to 8.1 pH, mval/100 ml.

Table 1. Schedule of experiments

Dates and No of meas-urement	Years and dates									
	'Jonagored'					'Ligol'				
	2002	2003	2004	2005	2006	2002	2003	2004	2005	2006
Date of full bloom	27.04	5.05	1.05	4.05	6.05	27.04	4.05	30.05	3.05	8.05
1	20.08	22.08	27.08	05.09	07.09	22.08	23.08	28.08	31.08	27.08
2	24.08	27.08	02.09	10.09	12.09	26.08	28.08	2.09	5.09	1.09
3	29.08	01.09	06.09	15.09	16.09	31.08	2.09	6.09	10.09	6.09
4	2.09	06.09	10.09	19.09	20.09	4.09	**6.09**	**11.09**	16.09	11.09
5	**6.09** *	**11.09**	15.09	24.09	25.09	*9.09*	**11.09**	**16.09**	**21.09**	**21.09**
6	**11.09**	15.09	**20.09**	**01.10**	**30.09**	**15.09**	*15.09*	*20.09*	**26.09**	**26.09**
7	*16.09* **	**20.09**	*24.09*	**06.10**	**05.10**	**19.09**	**20.09**	**25.09**	*01.10*	**2.10**
8	**20.09**	**25.09**	**29.09**	*10.10*	**09.10**	**24.09**	24.09	29.09	**5.10**	*6.10*
9			**04.10**	**14.10**	*13.10*					
Date of storage end	20.03.2003	7.03.2004	2.03.2005	18.03.2006	9.03.2007	2.02.2003	3.02.2004	6.02.2005	10.02.2006	12.02.2007
Length of storage in days	166	178	164	172	161	145	149	147	141	143

* bold marked dates present dates of harvesting sample for storage
** italic marked dates present OHD based on judgement and Streif Index

Storage condition and evaluation of storability. Apples were stored in a cold storage room at 1–2°C and RH of around 90% for 3–4 months ('Ligol') and for 5–6 months ('Jonagored'). The storability of apples was evaluated after the same number of days of storage respectively to their harvest date (tab. 1). Storage efficiency was evaluated based on judgment and measurement. The judgment involved sensoric tests and checking of the incidence of diseases and disorders in apples, whereas the measurement comprised fruit mass loss and internal qualities (firmness, TSS, TA).

Each criterion was scored separately for each date of harvest. The scores were given according to the following rules:

1. Loss of fruit mass was measured in each stored box. Ten apples were numbered and weighed with the accuracy of 0.1 g before and after storage. Scores were given

according to an analysis of variance between the harvest dates. If there were no significant differences, each sample received 1 point. If the analysis showed a significant difference, a sample could receive 1, 2 or 3 points, with samples with the greatest loss receiving the lowest score.

2. Incidence of disorders and diseases was scored separately according to the analysis of variance. As in the previous case, a sample could receive 1, 2 or 3 points. If the percentage of non-healthy fruits was higher than 10% for respectively disorders or diseases, the group sample received 1 point independently of the analysis of variance results. If the value was lower than 10 and the statistical analysis showed differences, the highest score (3 points) was given to the sample with the significantly lowest number of rotten apples or apples with disorders.

3. Firmness of 'Ligol' and 'Jonagored' apples was scored according to the following point scale:

0 – below 4.0 kgf
0.5 – 4.01–4.5
1.0 – 4.51–5.0
2.0 – 5.01–5.50
3.0 – over 5.5 kgf

The point scale was developed independently based on the study by Konopacka et al. [2003] which examined the relation between texture attributes and consumers' perception and found that the minimum hardiness preferences for three examined cultivars are between 4.0 and 5.0 kgf.

4. TSS and TA were scored separately according to the same rules as the mass loss (scores 1–3) and based on the analysis of variance. If TSS for 'Jonagored' was below 11.5% and for 'Ligol' below 10.5%, and if TA for 'Jonagored' was below 0.3 and for 'Ligol' below 0.2, all samples received 1 respectively for each criterion, independently of the analysis of variance test.

5. Sensoric tests were made by 5 professional judges according to the overall acceptance on the market along the following scale: 0 – no acceptance on market, 1 – poor acceptance, 2 – good, 3 – excellent. The mean judgment score was rounded to 0.5 point.

Base colour evaluation. The apple surface colour was measured on non-coloured part of skin. Measurement was taken with a hand-held tristimulus reflectance colorimeter (Minolta CR-100, Minolta Corp., Ramsey, NJ, USA). Four replicates with two readings of 20 apples were used for each harvest date (160 readings of each sample). Colour was recorded using a CIE L* a* b* uniform colour space (-Lab), where L* indicates lightness, a* indicates chromaticity on a green (-) to red (+) axis, and b* chromaticity on a blue (-) to yellow (+) axis [HunterLab 1986]. Numerical values of a* and b* were converted into Hue_{ab} angle (H° = tan -1b*/a*) and chroma [Chroma = (a*2 + b*2)1/2] [Francis 1980]. The L* value is a useful indicator of darkening during ripening on the tree and during storage, resulting from either oxidative browning reactions or increasing pigment concentrations. The a* value is a measure of greenness, and is highly correlated with colour changes of apple flesh [Goupy et al. 1995]. The H° (Hue_{ab}) is an angle in a colour wheel of 360°, with 0°, 90°, 180° and 270° representing the Hue_{ab} red-purple, yellow, respectively, while chroma is the intensity or purity of the Hue_{ab}.

The Hue_{ab} angle value was calculated taking into account the recommendations given by McLellan et al. [1995].

The results were processed statistically using the analysis of variance. Differences between mean values were evaluated using the Duncan test with the assumed significance level of 5%.

RESULTS AND DISCUSSION

Previous studies have already shown [Streif 1983, Rutkowski et al. 1996, Łysiak 1998, Łysiak 2012] that too early or too late harvest negatively affects the storability of fruit due to higher incidence of physiological disorders and in some years the occurrence of infections with pathogens causing fungus diseases (fig. 1). The analysis of the quality and quantity loss in apples after storage is a good method for harvest date evaluation [Łysiak 2012, 2013]. A number of methods for predicting the optimum harvest date for apples were listed by Blanpied [1960] and by Kader [1999]. There are several mathematical formulas which are based on data obtained in meteorological [Łysiak 2012] or destructive measurements which are used for this purpose [Streif 1996]. Very precise methods are based on determination of ethylene production and measurement of ethylene concentration in the apple seed core [Blanpied 1989]. These methods require a gas chromatograph to measure gas concentration in a core. Because the gas chromatograph is highly sophisticated and expensive equipment, these methods will never be popular in apple production. Additionally most of precise methods are destructive and measurements cannot be conducted on the same fruit.

The changes of skin colour are caused by chlorophyll degradation. During fruit development and maturation both chlorophyll breakdown and synthesis are observed, but following maturation and ripening processes the decrease of the chlorophyll content is noticed, which results in decreasing intensity of green coloration [Kingston 1992, Rutkowski at al. 2008]. Measurement of chlorophyll content is commonly made using destructive methods, after sample homogenisation and extraction. This destructive method is very time consuming and requires a new batch of fruit for each analysis. Therefore, a quick, non-destructive method corelated with outside fruit features is desired as a techniques for predicting the harvest date and for online sorting and certifying high-quality fruit intended for storage.

The measurement of changes in the L* a* b* coordinates and the calculation of the Hue_{ab} angle and the chroma values, which were conducted every five days (± 1 day), showed a considerable regularity of changes in both cultivars (tabs 2 and 3). However, it was also possible to observe distinct differences between the changes in both cultivars. The speed and direction of changes are specific for each individual cultivar and result from differences in response of individual cultivars to the same external stimuli. This was already shown by Delfia and Clot [2001], who stated that different phenophases and plant species react differently to various environmental influences. Changes in 'Ligol' apples are slower both with respect to a* and b* coordinates, which was evidenced not only by the values of the both coordinates themselves, but also by the Hue_{ab} angle. The mean difference between the Hue_{ab} angles obtained for 'Ligol' on consecutive dates in all years of the study amounted to 1.42 whereas the mean difference between the Hue_{ab} angles obtained for 'Jonagored' in the same way amounted to 2.22. Smaller differences between the measurement results may result in a longer OHD window.

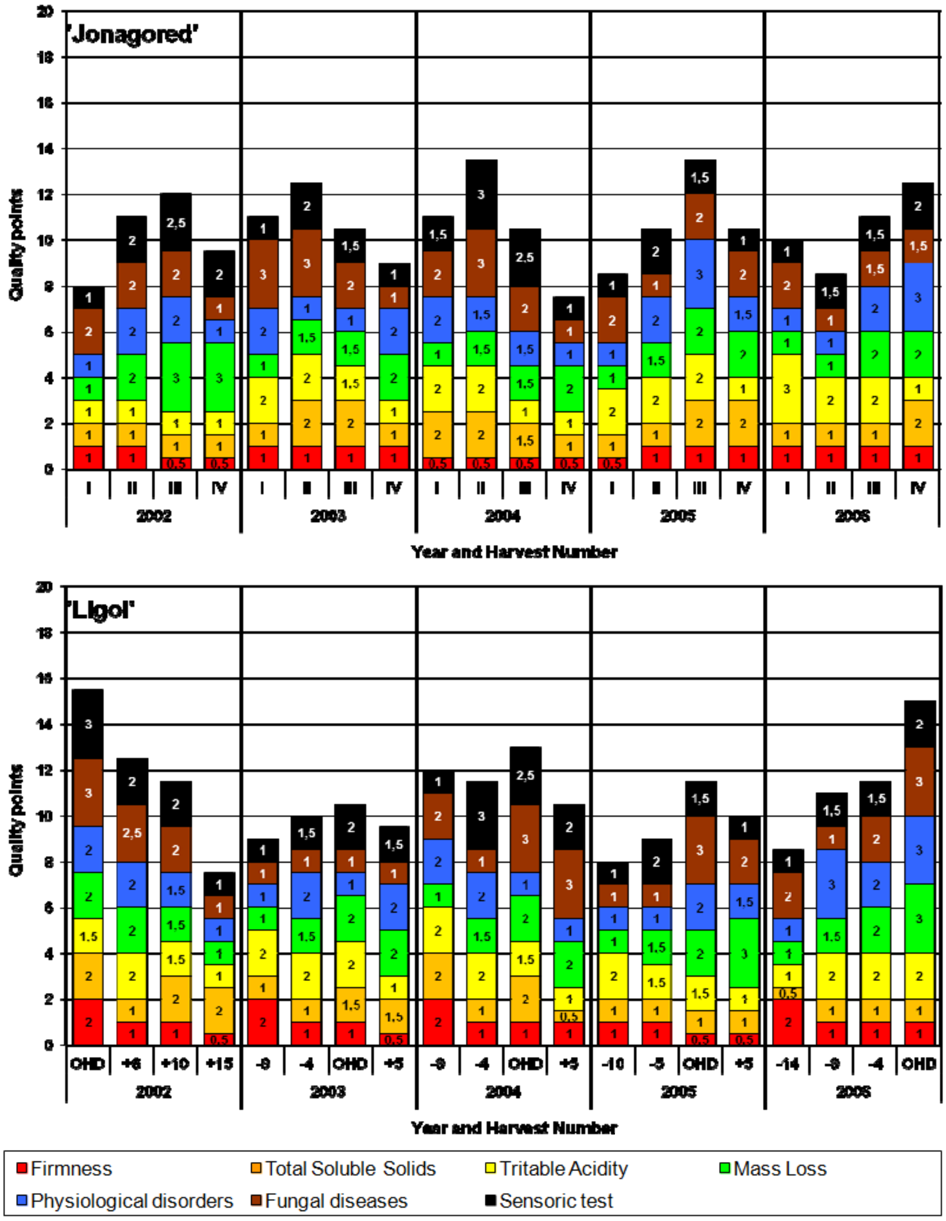

Fig. 1. Quality scores of 'Jonagored' and 'Ligol' fruits after six and four months storage, respectively

Table 2. CIE 1976 (L* a* b*) colour space of skin of 'Jonagored' cultivar at different ripeness stage

Year	No of measure-ment	'Jonagored'				
		L*	a*	b*	hue	chroma
2002	1	59.6 ±1.7a	-17.8 ±2.7e	43.9 ±2.4c	112.1 ±2.4d	47.1 ±2.1d
	2	61.7 ±0.8a	-16.9 ±1.3e	43.1 ±2.1c	111.5 ±1.6cd	46.2 ±2.1cd
	3	62.6 ±1.5a	-16.0 ±1.3de	41.8 ±2.4b	111.0 ±1.3cd	44.7 ±2.5c
	4	60.1 ±3.2a	-14.6 ±2.5d	39.7 ±2.7b	110.2 ±3.1cd	42.2 ±2.8bc
	5	60.9 ±2.9a	-10.7 ±3.2c	39.2 ±2.6b	105.3 ±4.9bc	40.7 ±2.2bc
	6	65.2 ±2.6b	-7.9 ± 2.7bc	37.2 ±3.5ab	102.2 ±4.5b	38.3 ±3.3b
	7(OHD)	63.7 ±2.9ab	-4.9 ±2.2b	35.6 ±3.4a	97.9 ±3.4ab	36.1 ±3.2ab
	8	65.7 ±4.1ab	-2.0 ±1.0a	33.4 ±3.5a	93.8 ±3.8a	33.5 ±3.3a
2003	1	60.0 ±2.3a	-17.7 ±1.6d	45.5 ±2.5c	111.3 ±2.1d	49.0 ±2.4c
	2	62.2 ±1.2a	-16.4 ±1.8d	44.0 ±2.0bc	110.4 ±2.1cd	47.0 ±2.0c
	3	61.8 ±3.2a	-14.3 ±1.6cd	42.8 ±1.9b	108.5 ±2.1cd	45.1 ±1.8bc
	4	59.5 ±2.7a	-13.3 ±3.1cd	41.3 ±1.7b	107.9 ±2.1c	43.4 ±1.8b
	5	60.8 ±2.0a	-9.9 ±3.2c	39.8 ±1.4ab	104.0 ±4.5c	41.1 ±1.2ab
	6(OHD)	62.6 ±2.9a	-5.6 ±2.7b	38.6 ±2.0ab	98.4 ±4.2b	39.0 ±1.8ab
	7	64.7 ±2.0b	-3.6 ±2.5ab	38.1 ±3.5a	95.5 ±3.9ab	38.3 ±3.4a
	8	64.9 ±2.5b	-1.4 ±2.4a	36.2 ±2.9a	92.4 ±3.9a	36.3 ±2.8a
2004	1	59.6 ±2.1a	-18.7 ±2.0e	45.2 ±3.3b	112.7 ±3.7d	49.0 ±2.4c
	2	61.9 ±3.6a	-17.3 ±2.7de	44.3 ±1,6b	111.3 ±3.0cd	47.7 ±1.9bc
	3	61.9 ±2.4a	-15.8 ±2.0d	43.2 ±1,3ab	110.1 ±2.1cd	45.9 ±1.5b
	4	60.8 ±3.9a	-14.6 ±1.0cd	42.1 ±2,2ab	109.2 ±4.0cd	44.6 ±2.0b
	5	63.5 ±2.6ab	-11.1 ±2.2c	42.3 ±0,8ab	104.7 ±2.5c	43.8 ±1.1ab
	6	65.3 ±2.4b	-10.2 ±2.6c	41.2 ±1,0a	104.0 ±2.0c	42.5 ±1.0ab
	7 (OHD)	64.8 ±3.8ab	-6.2 ±2.7b	41.0 ±1,8a	98.5 ±1.0b	41.6 ±1.9a
	8	65.4 ±4.1b	-4.2 ±3.1a	39.7 ±3,2a	96.2 ±1.0a	40.1 ±3.2a
	9	64.7 ±2.4ab	-3.4 ±2.4a	38.8 ±2,9a	95.0 ±1.0a	39.1 ±2.9a
2005	1	60.6 ±1.9a	-16.0 ±1.5c	46.4 ±2.5b	109.2 ±2.3b	49.2 ±2.2c
	2	61.4 ±1.9a	-15.5 ±1.9c	42.6 ±1.6a	110.0 ±2.1b	45.3 ±1.9b
	3	61.0 ±4.2a	-14.3 ±1.4bc	42.6 ±2.8a	108.7 ±2.5b	45.0 ±2.5b
	4	63.8 ±2.2a	-10.9 ±2.0b	42.5 ±0.7a	104.5 ±2.5ab	44.1 ±0.7b
	5	64.5 ±3.2a	-10.3 ±2.2b	41.1 ±1.6a	104.1 ±2.8ab	42.4 ±1.6a
	6	63.9 ±2.6a	-8.6 ±3.0ab	41.3 ±1.5a	101.9 ±4.2a	42.3 ±1.2a
	7	63.6 ±1.5a	-8.0 ±1.4ab	41.3 ±2.2a	101.1±2.0a	42.1 ±2.1a
	8(OHD)	65.0 ±0.6a	-6.2 ±1.6a	41.0 ±3.1a	98.7 ±2.1a	41.5 ±3.1a
	9	64.5 ±1.1a	-5.2 ±2.1a	38.7 ±4.6a	97.7 ±2.8a	39.1 ±4.6a
2006	1	59.9 ±2.5a	-17.9 ±1.8d	42.8 ±2.5b	112.7 ±2.3c	46.5 ±2.4c
	2	60.5 ±2.5a	-16.2 ±2.0cd	42.6 ±2.5b	110.8 ±2.3c	45.6 ±2.6bc
	3	59.6 ±4.3a	-15.9 ±2.0cd	41.1 ±1.4ab	110.8 ±2.8c	44.1 ±1.1bc
	4	61.2 ±3.3a	-13.1 ±2.7bcd	40.5 ±2.0ab	108.0 ±3.7c	42.6 ±2.0bc
	5	63.1 ±3.2a	-11.0 ±3.1bc	39.0 ±2.2ab	105.9 ±4.5b	40.7 ±2.1b
	6	63.4 ±3.7a	-10.3 ±3.3bc	38.6 ±2.6ab	104.8 ±4.6b	40.1 ±2.8b
	7	64.1 ±3.8a	-8.1 ±3.0b	38.7 ±2.9ab	101.7 ±3.9a	39.7 ±3.2ab
	8	64.2 ±2.4a	-6.8 ±2.3a	37.4 ±1.9a	100.3 ±3.3a	38.1 ±2.0ab
	9(OHD)	64.1 ±2.2a	-5.6 ±2.2a	35.8 ±2.3a	98.8 ±3.1a	36.2 ±2.4a

Values are means ± DS (n 60),
OHD shortcut present dates of optimum harvest dates based on evaluation after storage

Table 3. CIE 1976 (L* a* b*) colour space of 'Ligol' cultivar at different ripeness stage

Year	No of meas-urement	'Ligol'				
		L*	a*	b*	Hue	Chroma
2002	1	63.3 ±2.1a	-18.5 ±2.2a	41.1 ±3.5a	114.4 ± 2.7d	45.1 ± 3.1a
	2	62.0 ±3.0a	-18.7 ±2.4a	42.0 ±2.6a	114.2 ± 2.4cd	46.0 ± 2.3a
	3	64.1 ±1.9a	-17.1 ±3.0b	42.1 ±1.7a	112.2 ± 1.0c	45.5 ± 1.6a
	4	64.1 ±4.0a	-16.2 ±3.6b	42.4 ±1.5a	110.9 ± 5.3c	45.4 ± 1.6a
	5(OHD)	64.4 ±5.3a	-14.1 ±3.7cd	43.7 ±1.6a	107.9 ± 3.3bc	46.0 ± 1.3a
	6	64.4 ±2.4a	-13.8 ±2.4d	43.8 ±1.5a	107.6 ± 2.9bc	46.0 ± 1.1a
	7	65.6 ±5.7ab	-12.1 ±2.4de	44.7 ±0.9ab	105.2 ± 2.8b	46.3 ± 1.1a
	8	66.6 ±4.6b	-9.1 ±1.7e	45.3 ±1.2 b	101.4 ± 2.3a	46.2 ± 1.2a
2003	1	59.9 ±3.9a	-18.1 ±1.9a	41.7 ±3.1a	113.6 ±3.2c	45.5 ±2.6a
	2	62.1 ±2.9b	-17.7 ±2.2a	43.1 ±1.7b	112.4 ±3.1c	46.7 ±1.2a
	3	64.3 ±3.5b	-17.1 ±2.0ab	43.7 ±1.8b	111.4 ±2.7bc	46.9 ±1.4a
	4	63.4 ±2.8b	-16.1 ±2.2b	43.0 ±2.9b	110.6 ±2.2bc	46.0 ±3.3a
	5	64.6 ±1.5b	-15.5 ±1.8bc	44.3 ±1.5b	109.4 ±2.3b	47.0 ±1.4a
	6(OHD)	64.2 ±2.0b	-14.8 ±2.5c	43.1 ±0.9b	108.9 ±2.9b	45.6 ±1.3a
	7	65.6 ±3.1bc	-12.1 ±2.9c	44.3 ±1.3b	105.3 ±3.7ab	46.0 ±1.2a
	8	66.8 ±3.6c	-9.7 ±2.5d	44.8 ±1.8b	102.3 ±3.3a	45.9 ±1.7a
2004	1	62.3 ±2.6a	-18.5 ± 0.5a	43.2 ±2.6a	113.3 ±1.5c	47.0 ±2.3a
	2	63.3 ±1.6a	-18.3 ± 0.9a	41.9 ±3.9a	113.7 ±2.4c	45.7 ±3.5a
	3	63.5 ±2.7a	-16.6 ± 2.2b	41.9 ±2.4a	111.6 ±2.6bc	45.1 ±2.5a
	4	63.3 ±2.9a	-16.3 ± 1.4b	42.7 ±2.5a	110.9 ±1.9b	45.8 ±2.5a
	5	63.4 ±2.8a	-15.7 ± 1.9bc	42.8 ±1.7a	110.2 ±2.1b	45.7 ±1.9a
	6(OHD)	64.8 ±1.7a	-15.4 ± 2.1c	44.5 ±1.2ab	109.1 ±2.8b	47.1 ±0.8a
	7	65.3 ±1.1b	-14.2 ± 1.4c	44.6 ±1.1ab	107.7 ±1.8ab	46.9 ±1.1a
	8	65.5 ±1.2b	-12.6 ± 1.9d	45.0 ±0.6a	105.7 ±2.2a	46.7 ±0.9a
2005	1	60.7 ±1.5a	-19.2 ±0.8a	38.9 ±2.9a	116.4 ±1.7d	43.4 ±2.8a
	2	61.4 ±1.6a	-18.4 ±0.9ab	40.1 ±2.7b	114.8 ±2.4cd	44.2 ±2.2a
	3	63.2 ±2.4b	-17.3 ±2.5b	42.9 ±1.5c	112.0 ±2.9c	46.3 ±1.9b
	4	63.5 ±2.6b	-15.6 ±1.9c	42.6 ±2.5c	110.2 ±2.0b	45.4 ±2.7b
	5	64.8 ±1.8b	-15.7 ±1.2c	43.6 ±1.4c	109.8 ±1.4b	46.4 ±1.5b
	6	65.3 ±1.3bc	-14.5 ±1.6cd	43.8 ±1.0cd	108.4 ±1.6ab	46.1 ±1.4b
	7(OHD)	65.9 ±0.9c	-13.7 ±2.2d	44.4 ±1.5d	107.2 ±2.9a	46.6 ±1.2b
	8	66.7 ±1.2c	-13.2 ±1.7d	44.7 ±2.0d	106.6 ±1.2a	46.6 ±1.9b
2006	1	61.7 ±1.5a	-19.8 ±0.8a	38.3 ±2.7a	117.4± 3.2d	43.2 ± 2.2a
	2	63.4 ±2.3b	-18.5 ±0.9ab	39.9 ±2.7ab	115.1± 2.1c	44.0 ± 2.4a
	3	63.7 ±2.1b	-17.7 ±2.5bc	41.6±1.5b	113.1± 1.6bc	45.2 ± 1.5a
	4	63.6 ±2.7b	-17.4 ±1.9bc	42.2 ±2.1b	112.4 ±1.0b	45.6 ±2.1a
	5	62.7 ±1.4ab	-16.4 ±1.2c	42.6 ±2.2b	111.1 ±1.7b	45.6 ±2.1a
	6	63.9 ±1.3bc	-15.4 ±1.6d	42.3 ±2.2b	110.1 ±3.1ab	45.1 ±1.7a
	7	64.5 ±0.9cd	-14.4 ±2.2d	43.0 ±1.7bc	108.5 ±1.6a	45.4 ±1.8a
	8(OHD)	65.6 ± 0.9d	-13.5 ±1.7d	43.5 ±2.1c	107.3 ±3.1a	45.6 ±1.8a

See table 2.

Very big differences between the calendar harvest dates and OHD were observed in the five seasons under study. The difference between the earliest and the latest OHD of 'Ligol', as determined on the basis of the storage results, was 28 days because it varied between 9 September (2002) and 6 October (2006). A similar variability of OHD was also observed for 'Jonagored' (between 16 September and 13 October) (tab. 1). Such a big spread of OHD confirms the well-known view [Sass 1993] that the calendar harvest date often does not allow for determining even an approximate OHD.

Changes in the base skin colour were usually triggered by the ripening process quite early (about 4 week before OHD) and the course of changes was similar for each year, so the optimum harvest date could be predicted very early for both cultivars. Iglesias et al. [2008] showed data that apple colour progressively increased during maturation; even in early stages and also after commercial harvest.

There were changes in the values of all coordinates, but they were by far most apparent in the a* coordinate (tabs 2 and 3). The increase in the value of the a* coordinate could be clearly observed from the very first measurement. In most cases, however, the first changes (2–3 measurements) were not statistically significant. On later measurement dates the changes were more distinct. The a* coordinate reflects the change from green to yellow as a consequence of the disintegration of chlorophyll and the unmasking of xanthophyll. This is why Delwiche and Baumgartner [1983] recognised changes in the a* coordinate to be a very good indicator of harvest maturity in peaches. Later study [Delwiche and Baumgartner 1985, Corey and Schlimme 1988, Ferrer et al. 2005] allowed for establishing OHD determination standards for many peach cultivars.

There are distinct differences between values of the a* coordinate obtained for both cultivars on the same dates, which is obvious in view of differences between the base skin colour in those cultivars and the date on which each of them reaches harvest maturity. The values of the a* coordinate measured in each of both cultivars at every 5 days considerably varied (from 0 to 3.0), which was surely attributable to the weather conditions prevailing during that time. However, during the OHD window determined after fruit storage, the value of the a* coordinate varied very little and ranged between -15.4 and -13.5 (mean -14.3 ±0.79) for 'Ligol' and -6.2 and -4.9 (mean -5.7 ±0.55) for 'Jonagored'.

The value of the b* coordinate varied more, which allows for the conclusion that it is less suited for indicating maturity than the a* coordinate.

However, during the five-year study, the smallest range of variation was observed for the Hue_{ab} angle. During the OHD window its value ranged between 107.2 and 109.1 (mean 108.1 ±0.88) for 'Ligol' and between 97.9–98.8 (mean 98.5 ±0.35) for 'Jonagored'.

'Ligol' shows greater variability of CIELab values. It is also more difficult to determine its optimum harvest date based on the evaluation after storage, because differences in evaluation are smaller. This is probably caused by a longer optimum harvest period for this cultivar, and a naturally high variance of measured samples which is observed for some cultivars [Lin and Walsh 2008]. 'Jonagored' apples have a very repeatable curve of colour changes every year. Both the measurement of the a* coordinate and the Hue_{ab} angle can provide a basis for determining the harvest date. The L* and b* values are worse indicators and only the trend of b* can provide some clue as to the harvest date.

However, as was shown in the study concerned, the method of determining the OHD window based on the measurement of the base skin colour can be used for 'Ligol' and 'Jonagored'. The extension of the experiment to more than five years would have probably changed the mean values or yielded more consistent results. Still, the result obtained during the five years very different in terms of weather conditions and start of the growing season are conclusive enough to allow for a reliable determination of the OHD for 'Ligol' and 'Jonagored' apples.

CONCLUSIONS

1. The OHD for the 'Ligol' and 'Jonagored' apples intended for long storage can vary by over three weeks in Wielkopolska Region.
2. The measurement of a* coordinate and the calculation of Hue_{ab} can be a good ripening indicator.

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ZMIANA BARWY ZASADNICZEJ SKÓRKI W OKRESIE ZBIORU JAKO WSKAŹNIK DOJRZAŁOŚCI ZBIORCZEJ JABŁEK

Streszczenie. System barw CIELab jest stosowany do oceny żywności. Jego zaletą przy pomiarze barwy skórki jabłek dwubarwnych jest możliwość pomiaru barwy tego samego owocu przed okresem dojrzałości zbiorczej i w czasie tego okresu. Celem pięcioletnich badań była ocena szybkiej i niedestrukcyjnej metody wyznaczania dojrzałości zbiorczej jabłek przeznaczonych do długotrwałego przechowywania na podstawie obserwacji zmian barwy zasadniczej skórki. Owoce odmian jabłoni 'Ligol' i 'Jonagored' zbierano co 4–5 dni, zaczynając kilka tygodni przed orientacyjna datą zbioru. W okresie ostatnich czterech z pięciu pomiarów zbierano także owoce przeznaczone do przechowywania w chłodni. Ocenę zdolności przechowalniczej przeprowadzono po tym samym czasie przechowywana, w zależności od daty zbioru. Oceniano smak owoców, występowanie chorób fizjologicznych i grzybowych, a także mierzono parametry jakości wewnętrznej (jędrność, zawartość ekstraktów, kwasowość) oraz straty spowodowane transpiracją. Spośród analizowanych parametrów barwy (L*, a*, b*, Hue_{ab} i chroma) zmiany barwy zasadniczej najlepiej odzwierciedlała wartość koordynaty a* oraz wartość kąta Hue_{ab}. Na podstawie oceny jakości owoców po przechowywaniu stwierdzono, że jabłka mają największą zdolność przechowalniczą, jeśli koordynata a* w czasie zbioru zawarta jest w zakresie pomiędzy -13,5 a -15,5 dla odmiany 'Ligol' oraz pomiędzy -4,9 a -5,7 dla odmiany 'Jonagored'. Wartość kąta Hue_{ab} powinna wynieść pomiędzy 107 a 109 dla odmiany 'Ligol' oraz pomiędzy 98 a 99 dla odmiany 'Jonagored'. Uznano, że koordynata a* i wartość kąta Hue_{ab} mogą być stosowane jako wskaźniki wyznaczania dojrzałości zbiorczej.

Słowa kluczowe: jabłko, CIELab, zdolność przechowalnicza, optymalny termin zbioru, zaburzenia fizjologiczne, choroby przechowalnicze

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