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THE SUM OF ACTIVE TEMPERATURES AS A METHOD OF DETERMINING THE OPTIMUM HARVEST DATE OF 'ŠAMPION' AND 'LIGOL' APPLE CULTIVARS

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Abbreviations in text
OHD – optimum harvest date
TSS – total soluble solids
TA – titrable acidity
SAT – sum of accumulative temperatures
FB – full bloom

Abstract. The harvest date is crucial for the storability of autumn apple cultivars like 'Šampion' and winter apples cultivars like 'Ligol' intended for long storage. Only apples picked at the optimum maturity stage are suitable for storage over 3 months because of better storage potential and organoleptic quality. The research was conducted in the cold storage facility and laboratory of the Department of Pomology of the Poznan University of Life Sciences between 1999 and 2006 and was designed to evaluate and determine the sum of accumulative temperatures for both cultivars. Fruits were collected every 4–5 days starting some weeks before the estimated OHD. Maturity at harvest was evaluated in terms of firmness, TSS, starch disintegration, ground colour and titrable acidity. There were 3–4 main harvests from which fruits were stored in a cold storage facility for 3 months. The storability of apples was evaluated after an equal number of days of storage respectively to their harvest date. The evaluation was based on subjective quality judgments and measurements made after storage. The air temperatures in the orchard were measured every 2 hours. The results obtained from the four loggers provided the basis for the calculation of (a) the average day temperature and (b) the cumulative temperature, for which the values of 0.0°C, 4.0°C, 5.0°C, 10.0°C, and 15.0°C were taken respectively as reference. After eight years of study the optimal value of the SAT for 'Šampion' was determined at 2550 degrees and for 'Ligol' at 2600 degrees with 0°C as the base temperature. The OHD was determined most accurately for both cultivars taking 0°C as the base

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temperature. The SAT method was recognized as the basis for determining the harvest date of the apple cultivar 'Šampion' and 'Ligol'.

Key words: fruit storage, storability, fruit quality, decision support, fruit development, harvest date prediction, active temperatures

INTRODUCTION

'Šampion' and 'Ligol' have belonged to the most important cultivars in our country for many years [Bruille and Barritt 2004]. They owe their status to high productivity, easy cultivation and popularity among consumers. However, as late-autumn cultivars they are not especially suitable for long storage and therefore particular attention must be paid to measures allowing to optimise their storability.

The correct determination of the harvest date is crucial for storability [Łysiak 2011]. Only apples picked at the optimum maturity stage are suitable for storage over 6 months because of better storage potential and organoleptic quality [Streif 1996]. In Poland fruit growers determine the harvest date based on the fruit appearance, firmness or sometimes the starch content. However, methods which rely on separate parameters are not sufficient since they do not allow to correctly predict the harvest date each year [Streif 1996, Łysiak 1998].

Observations regarding yield phenophases and the influence of temperatures on their beginning and unfolding were found to be very important in choosing the right pollinators and determining the average number of days from flowering until harvest [Căpraru and Zlati 2009]. The degree-day accumulation method or the sum of active temperatures method are successfully used to identify infection periods [MacHardy and Gadoury 1985, Howell and Neven 2000] and to predict the symptom appearance for distinct phases [Reissig et al. 1973, Steiner 1990] or accumulation of desired substances like anthocyanins or sugars [Spayd et al. 2002]. Researchers have found that air temperature is a dominant factor controlling crop development [Yang et al. 1995]. To predict crop development with air temperature, growing degree days or similar linear unit system is widely used [Gilmore and Rogers 1958, Hortik and Arnold 1965, Yang et al. 2000].

However the selection of appropriate beginning of temperature calculation is disputable. Whereas in spring the phenological phases in mid-latitude highlands are considered to depend strongly on temperature conditions during winter and spring, the most important factors causing phase changes in autumn are not as clear [Menzel et al. 2001, Gian-Reto 2003].

Organ growth depends on the temperature accumulation from the flowering period and fruit maturity is reached after a fixed number of degree-days. This finding allows to simulate and compare different years and locations [Mimoun and DeJong 1999]. The choice of the full bloom period as the starting point for the measurements – thus eliminating any possible influence of the location and the weather in winter and early spring – allows for higher repeatability of results. The temperatures and weather fluctuations directly after the flowering period have a strong impact on the fruit size and a smaller

impact on the harvest maturity date due to the process of cell differentiation. High fruit growth rates in apples were associated with increased rates of cell division in the cortical region [Bergh 1990].

Another factor influencing the accuracy of measurement is the selection of an appropriate base temperature. Base temperature can vary widely among different crops and may be sometimes assumed to be below zero, which is difficult to explain in biology [Yang et al. 1995].

This work presents the results of a nine-year research designed to:

– determine the influence of the harvest date on the quality of two apple cultivars

– determine the base temperature and

– calculate the degree day accumulation for 'Šampion' and 'Ligol' cultivars, one of the most frequently grown cultivars in Poland.

MATERIALS AND METHODS

The research was conducted in the experimental orchard, cold storage room and laboratory of the Department of Pomology of the Poznan University of Life Science between 1999 and 2006. Fruits were picked from trees of 'Šampion' cultivar planted in 1992 in 4 × 2 m, and from trees of 'Ligol' cultivar planted in 1994 in 4 × 1.75 m. Trees were grown on M.26 rootstock in a single row and were pruned into a wide spindle shape. The orchard was protected and maintained in line with the recommendations for commercial orchards.

Sampling. Fruits were collected every 4–5 days starting some weeks before the estimated OHD. The sample size was 20 fruits picked from a minimum 10 trees, from 140 to 160 cm high, outside part of the tree, from the same east-southern side. Fruits over or under size, infected by pests or diseases were rejected. The fruits should represent the stage of maturity (in size and colour) of those fruits that will be harvested during the main harvest. In most years on the last four sampling dates also the fruits intended for cold storage were collected. The harvest was conducted according to the rules applicable to the picking samples, but the size of a single sample intended for storage was considerably larger and amounted to 4 boxes per 10 kg each box.

Measurements. Evaluation of maturity and ripening at harvest were done according to well known standard methods:

– firmness: penetrometer (probe – 8 mm depth, 11 mm in diameter), two opposite sides of the fruit, in kgf,

– refractometer value (TSS) in %,

– starch disintegration 10 points scale where 1 is no conversion and 10 is totally converted ,

– titrable acidity (TA): titration with 1n NaOH to 8.1 pH, mval/100 ml.

Storage condition and evaluation of storability. Fruits were stored in a cold storage room at 1–2°C and around 90% of RH for 3 months. The schedule of all measurements is shown in table 1. The storability of apples was evaluated after the same number of days of storage respectively to their harvest date. The evaluation was based on the judgment and on measurements. The judgment was made using sensoric tests, incidence

of diseases and disorders, fruit mass loss and internal quality criteria (firmness, TSS, TA).

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

1. Loss of fruit mass was measured in each stored box. Ten fruits 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.

2. Incidence of disorders and diseases was scored separately according to the same rules as fruit mass loss. If percentage of non-healthy fruits was higher, then 10% for each (disorders or diseases) group sample received 1 point independently of the analysis of variance.

3. Firmness of 'Šampion' 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

Due to the naturally higher firmness of 'Ligol' the kgf values on the scale were increased by 0.5 when scoring its firmness.

The point scale was developed independently based on the research by Konopacka et al. [2003] which examined the relation between texture attributes and consumers' perception and found that 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 analysis of variance based on the same rules as the mass loss (scores 1–3). If TSS for 'Šampion' was below 11.5% and below 10.5% for 'Ligol' and TA for 'Šampion' below 0.25 and below 0.2 for 'Ligol' all samples received 1 independently of the analysis result.

5. Sensoric tests were made by 3–5 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 average judgment was rounded to 0.5 point.

Temperature measurements. Four data loggers HOBO ® – Plus4 made by ONSET Computers were put on trees in the orchard, in shaded places 2 meters above the earth, and set to measure the temperature every 2 hours. The accuracy of measurement was 0.1 deg. The measurements started during the full bloom period. "Full bloom" was defined as the point of time when 80 percent of the blossoms on the north side of the tree were open. Readouts were downloaded from the loggers once a month till the last harvest date. The results obtained from the four loggers provided the basis for the calculation of (a) the average day temperature and (b) the cumulative temperature, for which the values of 0.0°C, 4.0°C, 5.0°C, 10.0°C, and 15.0°C were taken respectively as reference. The calculations were conducted in reference to the OHD obtained through applying the procedure described in section "Storage condition and evaluation of storability". For all years of experiment the mean and standard deviation were calculated.

All the measured data were subjected to the analysis of variance. The mean comparisons were performed using the Duncan test to examine differences ($P < 0.05$) among the harvest dates.

RESULTS AND DISCUSSION

Previous research has already shown [Streif 1983, de Jager and Roelofs 1996, Skrzyński 1996, Rutkowski et al., 1996, Łysiak 1998] that too early or too late harvest affect negatively the storability of fruits due to higher incidence of physiological disorders and in some years the occurrence of infections with pathogens causing fungus diseases (fig. 1). The presented firmness and TSS figures are relative as they result from the comparative analysis of significant losses between the respective harvests, but it could nevertheless be observed that fruits harvested later were either less or equally firm after storage, whereas their TSS content either remained equal or was higher.

However, although the firmness and the TSS content are very important in describing the fruit quality, they were not so crucial for the overall assessment as were the acidity, which decreased very fast with the harvest date, the mass loss and the incidence of fungal and physiological diseases.

The incidence of bitter pit and other physiological disorders is closely related to the respiratory activity at harvest [Wilkinson and Sharples 1967], and this activity is strongly depended on the development stage of fruits and the temperature in the orchard.

Other quality features including firmness and TSS also change fast during the ripening period and the fruits, if harvested too late, are too soft and show low TSS and acidity after storage. The fruit mass losses caused by transpiration and breathing and the low taste quality in most years were observed for the fruits picked too early (fig. 1).

The measurement of all those parameters after an equal storage period showed that the OHD for the respective eight years differed by even 25 calendar days for 'Šampion' since it ranged from 11 September (in 2000) to 5 October (in 2001) (tab. 2). The full bloom date for 'Šampion' fell between 25 April and 6 May with standard deviation of 4.2 days. The full bloom date is sometimes difficult to determine because in some years the flowering is prolonged due to low temperatures during this period and can last even more than ten days [Lakatos et al. 2008]. However, the range of OHD was larger as the standard deviation was 8.6 days. According to the above observations the number of days between FB and OHD varied from 137 to 150 days. Such measurement results show the length of the fruit development period and as such do not allow for the correct determination of the harvest date. However, the SAT measured for the 0°C base temperature shows small variation. The mean for the 8-year research was 2543 degrees with standard deviation of 25.7 degrees, which, given the average temperature in mid-September of about 10°C, allows for determining the harvest date with an about 2-day error margin. In view of the fact that the optimum harvest period amounts to about 5 days according De Jager and Roelofs [1996], this measurement is sufficiently accurate. Since a lot of physiological processes start between 4°C and 5°C [Monson et al. 1992], both these values were also assumed as the base temperatures in the calculation, along

Table 1. Schedule of experiments
Tabela 1. Harmonogram badań

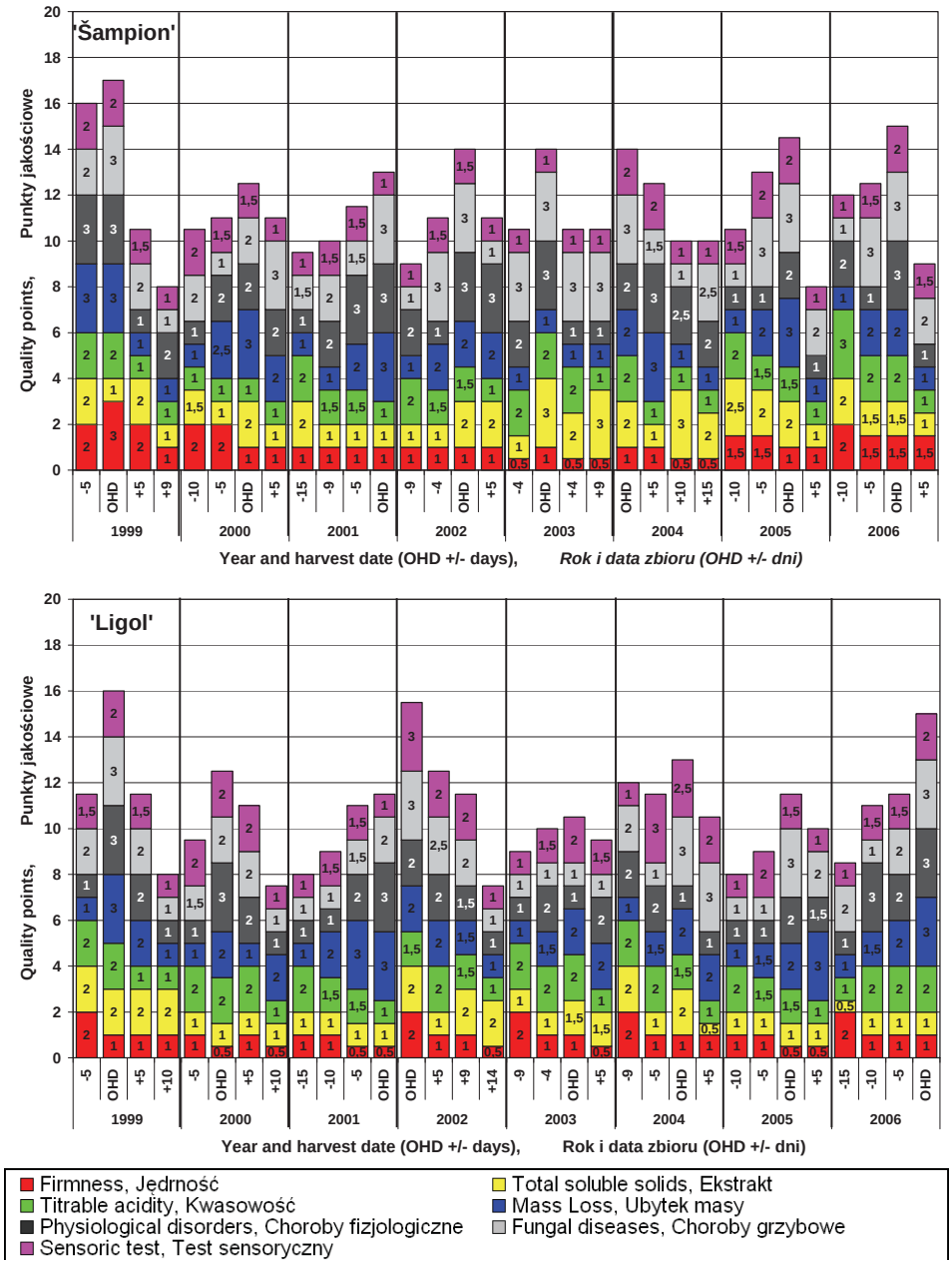
No of measurement Numer pomiaru	Years and dates – Rok i data															
	Šampion								Ligol							
	1999	2000	2001	2002	2003	2004	2005	2006	1999	2000	2001	2002	2003	2004	2005	2006
Date of full bloom Data pełni kwitnienia	28 IV	25 IV	5 V	27 IV	5 V	1 V	4 V	6 V	26 IV	25 IV	4 V	27 IV	4 V	30 IV	3 V	8 V
1	1 IX	23 VIII	5 IX	22 VIII	9 IX	8 IX	7 IX	27 VIII	1 IX	27 VIII	5 IX	28 VIII	23 VIII	28 VIII	5 IX	2 IX
2	6 IX	28 VIII	10 IX	26 VIII	13 IX	13 IX	12 IX	31 VIII	6 IX	1 IX	10 IX	31 VIII	28 VIII	2 IX	10 IX	7 IX
3	11 IX	2 IX	15 IX	31 VIII	17 IX	18 IX	16 IX	5 IX	11 IX	6 IX	14 IX	5 IX	2 IX	6 IX	16 IX	12 IX
4	16 IX	7 IX	20 IX	5 IX	21 IX	23 IX	21 IX	15 IX	16 IX	11 IX	19 IX	9 IX	6 IX	11 IX	21 IX	18 IX
5	21 IX	12 IX	25 IX	10 IX	25 IX	28 IX	26 IX	20 IX	21 IX	16 IX	24 IX	15 IX	11 IX	16 IX	26 IX	23 IX
6	27 IX	17 IX	1 X	14 IX	30 IX	3 X	30 IX	25 IX	27 IX	21 IX	29 IX	19 IX	15 IX	20 IX	30 IX	28 X
7	1 X	22 IX	5 X	19 IX	3 X	8 X	5 X	30 IX	1 X	26 IX	4 X	24 IX	20 IX	24 IX	5 X	3 X
8			10 X	24 IX				1 X		30 IX	9 X		24 IX	29 IX		
Date of end of storage Data końca przechowywania	03-Jan-2000	05-Jan-2001	14-Jan-2002	06-Jan-2003	12-Jan-2004	14-Jan-2005	16-Jan-2006	15-Jan-2007	10-Feb-2000	12-Feb-2001	28-Feb-2002	02-Feb -2003	3-Feb-2004	6-Feb-2005	10-Feb-2006	12-Feb-2007
Length of storage in days Długość przechowywania w dniach	113	124	110	122	118	114	121	121	147	149	147	145	149	147	141	143

underlined dates present dates of harvesting sample for storage – daty podkreślone przedstawiają terminy zbioru owoców przeznaczonych do przechowywania
double underlined dates present OHD based on judgement and Streif Index – daty podkreślone podwójnie przedstawiają daty optymalnego terminu zbioru na podstawie oceny jakościowej i indeksu Streifa

Table 2. Dates of full bloom, harvest and sum of active temperatures for 'Šampion' and 'Ligol' cultivars
Tabela 2. Daty kwitnienia, zbioru oraz suma temperatur aktywnych dla odmian Šampion i Ligol

Year Rok	Šampion								Ligol							
	F*	OHD*	No*	sum of active temperatures (SAT) suma aktywnych temperatur					F*	OHD*	No*	sum of active temperatures (SAT) suma aktywnych temperatur				
				0°C	4°C	5°C	10°C	15°C				0°C	4°C	5°C	10°C	15°C
1999	28 IV	11 IX	139	2526	1974	1836	1141	501	26 IV	16 IX	143,0	2617	2041	1897	1182	531
2000	25 IV	12 IX	137	2529	1965	1824	1094	465	25 IV	16 IX	144,0	2582	2002	1857	1132	466
2001	5 V	5 X	145	2589	1925	1805	1107	469	4 V	4 X	153,0	2609	1993	1839	1074	472
2002	27 IV	13 IX	142	2516	1980	1851	1312	587	27 IV	9 X	135,0	2592	2056	1879	1234	570
2003	5 V	20 IX	143	2571	2031	1896	1255	589	4 V	15 IX	134,0	2570	2030	1884	1220	570
2004	1 V	25 IX	150	2523	1931	1783	1072	449	30 IV	24 IX	147,0	2575	1967	1800	1070	449
2005	4 V	26 IX	145	2533	1949	1803	1097	491	3 V	30 IX	149,0	2617	2009	1846	1120	497
2006	6 V	27 IX	141	2554	1974	1829	1106	479	8 V	3 X	148,0	2607	2011	1862	1119	476
Mean Średnio	1 IV	16 IX	142,8	2543	1966	1828	1148	504	1 IV	22 IX	144,1	2596	2014	1858	1144	504
Standard deviation Odchylenie standardowe	4.2	8.6	4.0	25.7	33.3	34.7	87.3	54.2	5.1	9.3	6.7	18.9	28.2	30.7	62.1	47.3

F – date of full blooming, OHD – date of optimum harvest date, No – number of days from full bloom until OHD
F – daty pełni kwitnienia, OHD – daty optymalnego terminu zbioru, No – liczba dni od pełni kwitnienie do zbioru



* The highest bar indicate the best storability according harvest date

Fig. 1. Assessment according to a point scale of the quality aspects of fruit samples harvested on the respected dates examined after storage in the years 1999–2006

Rys. 1. Ocena punktowa parametrów jakościowych owoców po przechowywaniu pochodzących z poszczególnych zbiorów w latach 1999–2006

with two others, namely 10°C and 15°C. It was found out that for the OHD determined using base temperatures other than 0°C the standard deviation was higher, which means that the method was less accurate in those cases.

As for 'Ligol', the OHD range was 28 days, i.e. from 9 September (in 2002) to 6 October (in 2006). The FB dates were between 25 April and 8 May with standard deviation of 5.1 days. The standard deviation for OHD is slightly higher than for 'Šampion' (9.3 calendar days). Due to a wider range of respectively FB and OHD dates, the number of days between the FB and OHD varied more, namely from 135 to 153 days with standard deviation of 6.7 days. The SAT calculated for 0°C is 2596 with standard deviation of 18.9 degrees. For other temperatures the SAT assumes smaller values but the standard deviation increases. This calculation shows that, as in the case of 'Šampion', the base temperature for the calculation of the OHD of 'Ligol' is 0°C.

The extension of the experiment to more than eight years would have probably reduced the spread of the results. Still, the result obtained for the eight years very different in terms of vegetation onset and weather conditions allowed for obtaining a very coherent result which can provide a basis for determining the OHD for 'Šampion' and 'Ligol'.

This method permits the estimation of fruits maturation for harvesting [Căpraru and Zlati 2009]. Therefore, this method can be recommended for practical application all the more as it requires only the precise determination of the full bloom date and continuous measurement of daily average temperatures.

The limitation of the sum of active temperatures method is that it cannot be used in each location because different phenophases and plant species react differently to various environmental influences [Defila and Clot 2001].

CONCLUSIONS

1. Too early or too late harvest brought about substantial quality and quantity losses of the apple cultivar 'Šampion' during storage.

2. The metrological method can be the basic tool for determining the harvest date of the apple cultivars 'Šampion' and 'Ligol'.

3. The best basic temperature for calculation is 0°C.

The sum for active temperatures according 0°C basis for 'Šampion' is 2550 deg and 'for 'Ligol' is 2600 deg.

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SUMA AKTYWNYCH TEMPERATUR JAKO METODA WYZNACZANIA OPTYMALNEJ DATY ZBIORU DLA JABŁEK ODMIAN ‘ŠAMPION’ I ‘LIGOL’

Streszczenie. Dla owoców jesiennych odmian jabłoni, takich jak ’Šampion’ i ’Ligol’, przeznaczonych do długiego przechowywania kluczowe jest prawidłowe wyznaczenie terminu zbioru. Do przechowywania dłużej niż 3 miesiące można przeznaczać tylko owoce zebrane w stadium optymalnej dojrzałości zbiorczej, gdyż daje to gwarancję dużej zdolności przechowalniczej i wysokiej jakości po wyjęciu z chłodni. Badania mające na celu ocenę metody określania terminu zbioru oraz wyznaczenie wartości sumy temperatur aktywnych dla obu odmian przeprowadzono w latach 1999–2006 w chłodni i laboratorium Katedry Sadownictwa Uniwersytetu Przyrodniczego w Poznaniu. Próby owoców zbierano co 4–5 dni, poczynając na kilka tygodni przed przewidywanym terminem zbioru. Dojrzałość w czasie zbioru określano na podstawie jędrności, zawartości ekstraktu, stopnia rozkładu skrobi, zmiany barwy zasadniczej skórki oraz kwasowości. W okresie optymalnego zbioru przeprowadzono 3–4 zbiory owoców, które przechowywano w chłodni przez około 3 miesiące. Zdolność przechowalniczą oceniano po równej liczbie dni dla każdego zbioru. Ocenę przeprowadzono na podstawie pomiarów jakościowych oraz oceny subiektywnej prowadzone przez panel ekspercki. W sadzie co 2 godziny mierzono temperaturę przez cały okres wzrostu. Otrzymane wyniki posłużyły do obliczenia (a) średniej temperatury dobowej, (b) sumy temperatur aktywnych dla temperatur bazowych 0,0°C, 4,0°C, 5,0°C, 10,0°C i 15,0°C. Osiem lat badań pozwolił na ustalenie sumy temperatur aktywnych dla odmiany ’Šampion’ wynoszącej 2550 stopni oraz dla odmiany ‘Ligol’ wynoszącej 2600 stopni przy 0°C jako temperaturze bazowej. Dla 0°C jako temperatury bazowej wyniki były najbardziej powtarzalne. Metoda sumy temperatur aktywnych może być podstawową praktyczną metodą dla wyznaczania dojrzałości zbiorczej odmian ‘Šampion’ i ‘Ligol’.

Słowa kluczowe: przechowywanie owoców, zdolność przechowalnicza, jakość owoców, przewidywanie daty zbioru, suma temperatur aktywnych, wspomaganie decyzyjne

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