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THE IDENTIFICATION OF EARLINESS CLASSES IN SWEET CORN CULTIVARS WITH THE SUMS OF EFFECTIVE TEMPERATURES

A. WEBER*[1], H. WALIGORA[1], W. SKRZYPCZAK[1] and E. CHWASTEK[2]
[1] *Poznań University of Life Sciences, Department of Agronomy, 61-693 Poznań, Poland*
[2] *Bielska Wyższa Szkoła J. Tyszkiewicza, 43-300 Bielsko-Biała, Poland*

Abstract

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At present there is no system classifying the cultivars of the sweet corn subspecies according to their earliness. The length of the vegetation period is determined with the number of vegetation days. It ranges from 70 to 110 days and it largely depends on the course of environmental conditions. This study attempts to classify sweet corn cultivars with the Sums of Effective Temperatures. Apart from that, the aim of the study was to present the dependence between the course of temperature, total radiation, atmospheric precipitation and the length of the vegetation period. The Sums of Effective Temperatures which were calculated from sowing to the stage of lactic ripeness were found to be useful for the classification of sweet corn cultivars. The distribution into the classes of earliness was the most equal for the threshold temperature of 6°C. The length of sweet corn vegetation was found to be directly proportional to atmospheric precipitation and total radiation, but it was inversely proportional to temperature. Temperature had the most significant influence on the length of vegetation.

Key words: corn, earliness, temperature, precipitation, solar radiation

Introduction

Unlike any other species, the choice of the cultivar is a significant determinant of successful growing of maize (Michalski, 1997). A longer vegetation period increases the number of assimilation days and thus, it enables greater yield. Therefore, later cultivars usually give slightly higher yield. On the other hand, sowing the cultivars ripen earlier results in such benefits as lower risk of growing and better organisation of further work in autumn (Michalski, 2004). At present sweet corn cultivars are not classified according to the earliness of ripening. Growers determine the length of the vegetation period of this subspecies with the number of vegetation days. It ranges from 70 to 110 days (Bruździak, 2002). The Sums of Effective Temperatures is a more reliable system assessing the earliness of hybrids. It is used in most of the US states, in Canada and it is suggested for Europe. The method consists in specifying the amount of heat units which are necessary to achieve a particular stage of development (florescence, physiological maturity, total maturity) (Synder et al., 2001). At present there are a large number of different methods to calculate the Sum of Effective Temperatures. Most of those methods consist in measuring the minimum and maximum daily temperatures reduced by a specific threshold temperature below and above which physiological processes are inhibited. In the US the minimum threshold temperature for maize is 10°C, in France it is 8°C and in Germany it usually is 6°C (Siódmiak and Heimann, 1991).

This study attempts to classify sweet corn cultivars with the Sum of Effective Temperatures and to determine the threshold temperature at which the cultivars can be most reliably allocated to earliness groups. Apart from that, the aim of the study was to present the dependence between the course of temperature, total radiation, atmospheric precipitation and the length of the vegetation period.

Material and Methods

Field experiment method

The results of the study are based on 17 years of investigations made from 1994 to 2010 at Gorzyn Experimental and Educational Station, Swadzim Branch (52°26'N; 16°45'E),

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*Corresponding author: aweber@up.poznan.pl

Poznan University of Life Sciences. It was a univariate experiment in a randomised block design with four replications. The research was conducted on 94 sweet corn cultivars with different lengths of vegetation. Each cultivar was researched at least for three years. In each year of the research the cultivars were sown on the same day.

The dates when the cultivars reached the stage of milk ripeness was calculated by summing the days between the sowing and the stage of milk ripeness.

Measurement of daily temperature, atmospheric precipitation and total radiation

Every day during the vegetation period the minimum and maximum temperatures and the atmospheric precipitation were measured at the weather station of the Experimental and Educational Station in Swadzim. The temperature was measured with an accuracy of 0.1°C by means of a mercury thermometer. The thermometer was located at a height of 2 m above the ground. The precipitation was measured by means of a rain gauge with an accuracy of 0.1 mm and collecting area of 200 cm^2.

The data about total radiation (W/m^2) between 2005 and 2010 came from the Regional Inspectorate for Environmental Protection. The measurements were made at the weather station in Poznan Botanic Garden.

The method of calculation of the Sums of Effective Temperatures

The Sums of Effective Temperatures (°C) were calculated on the basis of the course of daily temperature from sowing to the stage of milk ripeness. The calculations were made according to the following formula:

$$\sum\left(\frac{Tmax + Tmin}{2} - t_0\right),$$

where: SET - Sums of Effective Temperatures (°C); $T\ max$ - maximum temperature (°C); $T\ min$ - minimum temperature (°C); t_0 - threshold temperature (°C)

Due to the differences in the SET calculation method the following three threshold temperature variants were assumed: 6, 8 and 10°C.

Statistical analysis

The coefficient of variation, correlation coefficient, standardised partial regression coefficient and coefficient of determination were all calculated to measure the dependence between the length of vegetation and temperature, atmospheric precipitation and total radiation. The absolute mean of the coefficients was calculated to present the strength of the relationship between the correlations. The STATISTICA 10 software was used for the calculations.

The Sums of Effective Temperatures calculated from the moment of sowing to the stage of milk ripeness, including the three threshold temperature variants, were used to allocate the 94 sweet corn cultivars under investigation to the following four classes of earliness: early class, medium early class, medium late class and late class. The cultivars were classified by means of the R statistical software and Ward's method (1963). As a result, three dendrograms were formed.

Weather conditions

Table 1 and Figures 1 and 2 show the weather conditions, i.e. total radiation ($W\cdot m^{-1}$), mean air temperature (°C), and atmospheric precipitation (mm) during the growth and development of the plants.

Results and Discussion

The Sums of Effective Temperatures, including the threshold temperatures of 6, 8 and 10°C, were used to allocate 94 sweet corn cultivars to the four classes of earliness: late class, medium late class, medium early class and early class (Figures 3, 4 and 5). The most equal distribution was observed at the threshold temperature of 6°C, when 24, 30, 18 and 22

Table 1
The mean total radiation ($W\cdot m^{-1}$) at the weather station in Poznan Botanic Garden (the data from the Regional Inspectorate for Environmental Protection)

Year	Month					
	May	June	July	August	September	Mean
2005	6454	6737	6601	5527	4808	6025
2006	4795	7486	8404	4272	4705	5932
2007	2669	6544	5707	5158	3736	4763
2008	3557	7919	7554	4643	3486	5432
2009	3327	5920	6650	6585	4493	5395
2010	4326	6251	6215	5874	3298	5193
Mean	4188	6809	6855	5343	4088	5457

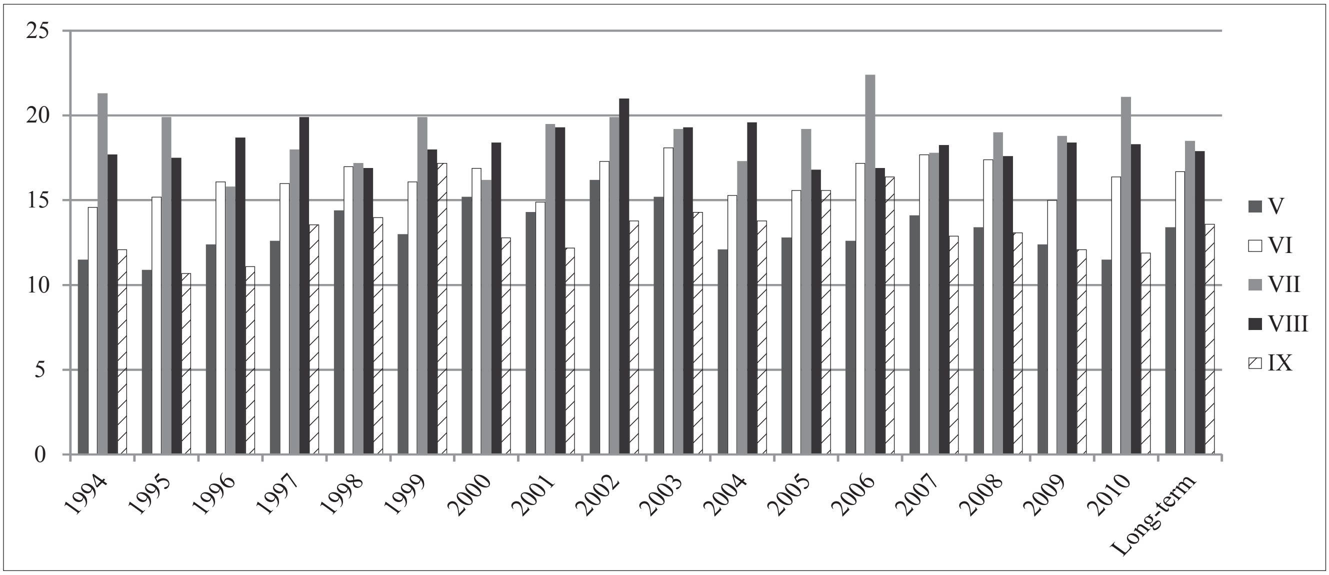

Fig. 1. The mean air temperature (°C) in the vegetation seasons 1994-2010 at Gorzyn Experimental and Educational Station, Swadzim Branch

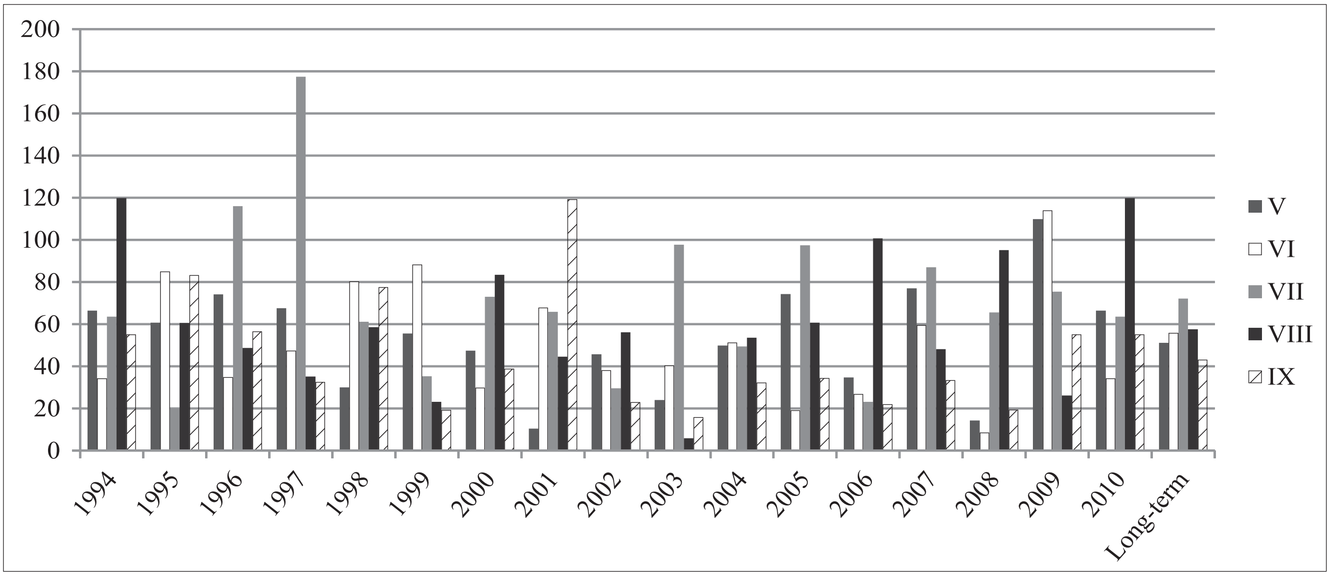

Fig. 2. The total atmospheric precipitation (mm) in the vegetation seasons 1994-2010 at Gorzyń Experimental and Educational Station, Swadzim Branch

cultivars were allocated to the respective earliness classes. A disproportional number of cultivars were allocated to the earliness classes in the other dendrograms. Apart from that, the classification at the threshold temperature of 6°C was the most precise reflection of the moments when the sweet corn cultivars achieved different stages of development in individual years of the research.

Górski and Jakubczak (1965) found that the assessment of earliness of hybrids based on their requirements concerning effective temperatures may be a supplementary and verifying method of assessment of the FAO earliness units. It would be necessary to assess a group of model hybrids and selected new hybrids which stand the greatest chance to be registered and widely cultivated. Jakacka (1986) and Siód-

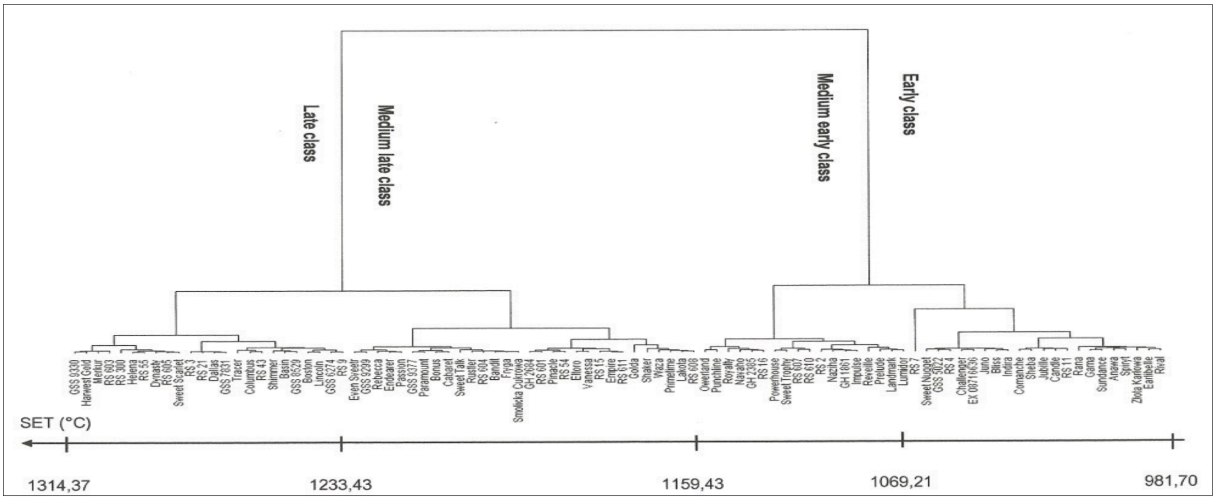

Fig. 3. The classification of sweet corn cultivars according to the SET, at the threshold temperature of 6°C

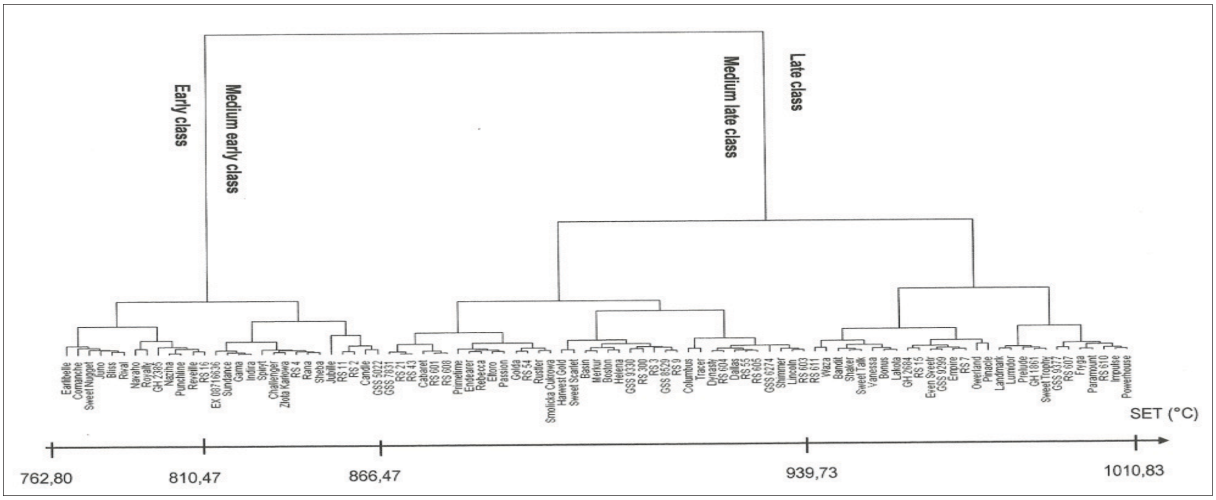

Fig. 4. The classification of sweet corn cultivars according to the SET, at the threshold temperature of 8°C

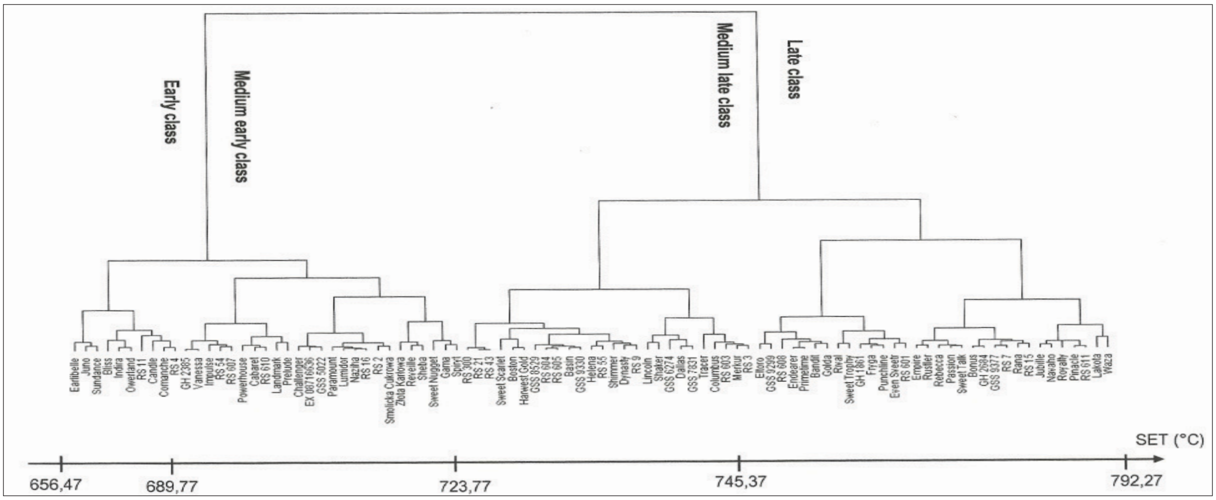

Fig. 5. The classification of sweet corn cultivars according to the SET, at the threshold temperature of 10°C

miak and Heimann (1991) made other observations. They found that hybrids were poorly diversified in terms of their thermal requirements and for this reason it was difficult to classify them.

Primault (1977) found that the knowledge of thermal requirements of hybrids and the sums of heat units in individual regions of the country enables selection of the hybrids which fully use the vegetative season and thus, it is possible to specify their harvest time in advance if there are no considerable deviations from the long-term norm. It is possible to forecast the yield and dry matter content in grain (regression equation of those parameters) on the basis of the sum of heat units as long as there are no stress factors in the environment, e.g. noticeable water deficit (Mederski et al., 1997). According to Phipps and Fulford (1977), the SET-based equations may be helpful to forecast the ripening of corn cultivars with different earliness and in different regions of the country. However, in order to make sure that the calculations of the dependence between the yield and earliness of hybrids and the amount of heat are useful for production it is necessary to make long-term calculations for different sowing density, humidity and nutritional stress.

In order to calculate the Sums of Effective Temperatures it is necessary to know the thermal threshold below which the growth and development of the plant is inhibited. One of the methods applied in the US is the GDD method (Growing Degree Days), where the minimum threshold temperature is 10°C, whereas the maximum temperature is 30°C. If the temperature is lower than 10°C, it is assumed to be 10 and if it is higher than 30°C, it is assumed to be 30 (McMaster and Wilhelm, 1997). In Germany 6°C was assumed as the minimum threshold temperature, but lower temperatures are also included in calculations (Eckert, 2006). French studies have shown that although 8°C is not a physiological threshold temperature (threshold temperatures are a few degrees higher and they are different at individual stages of development), it results in the highest correlation between the number of heat units accumulated and the content of dry matter in grain (Derieux and Bonhomme, 1981). Hunt et al. (2003) suggest that the thermal thresholds should be calculated with the equation of general linear dependence based on the equal-distance rule. This method may guarantee more accurate presentation of the dependence between the rate of plant growth and development and the Sums of Effective Temperatures.

Figures 6 and 7 and Tables 2 and 3 show how the length of vegetation (days) of sweet corn cultivars depends on temperature (°C), atmospheric precipitation (mm) and total radiation ($W \cdot m^{-1}$). The length of sweet corn vegetation was directly proportional to atmospheric precipitation and total radiation, but it was inversely proportional to temperature. The strength of the dependence between the environmental factors and the length of vegetation was determined with the mean absolute correlation coefficient and standardised partial regression coefficient. In most cases the absolute mean values of temperature were higher and they ranged from 0.45 to 0.87. The goodness of fit of the model was determined by means of the correlation coefficient. It ranged from 43.99 to 64.02. The highest coefficient of variation was noted for precipitation, which indicates that it was the most diversified element.

According to Waligóra et al. (1996), the growth, development and yield of corn are most influenced by two factors, i.e. temperature and precipitation. Cirkov (1969) found

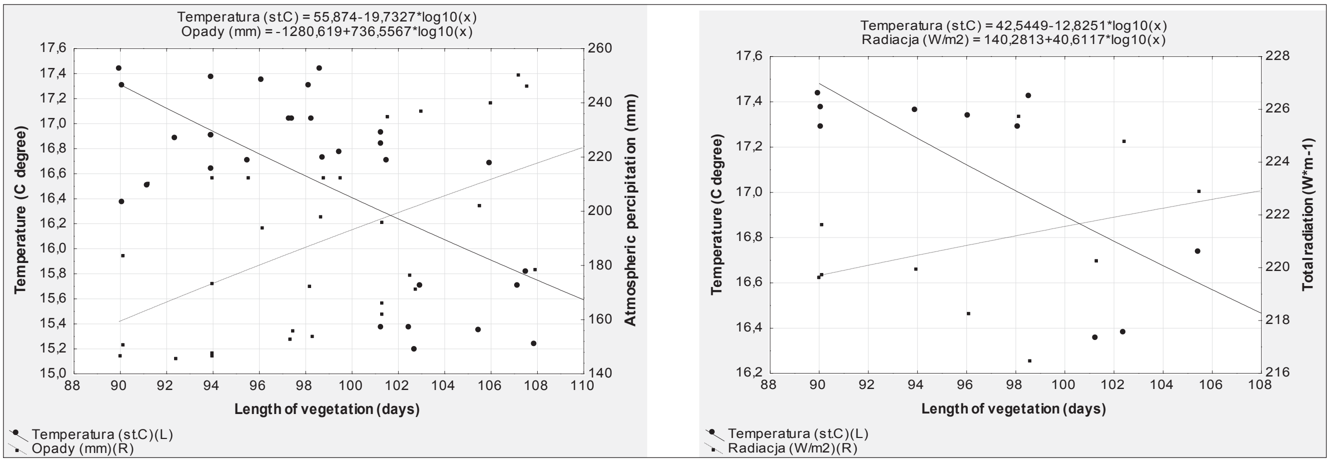

Fig. 6 and 7. The dependence between the length of vegetation (days) and the temperature (°C), atmospheric precipitation (mm) and total radiation ($W.m^{-1}$) from sowing to the stage of lactic ripeness

Table 2
The influence of temperature (°C) and atmospheric precipitation (mm) on the length of vegetation (days) of selected sweet corn cultivars (1994-1998 and 1999-2004)

Cultivar	1994 - 1998							
	Correlation coefficient		Standardised partial regression coefficient		Coefficient of determination, %	Coefficient of variation, %		
	Temp.	Precipitation	Temp.	Precipitation		Temp.	Precipitation	Length of vegetation
Candle	-0.77	0.24	-0.73	0.33	70.95	2.89	29.48	4.94
Earlibelle	-0.52	-0.47	-0.54	-0.40	60.90	3.12	29.12	0.92
Gama	-0.69	0.57	-0.62	0.44	40.62	2.60	29.41	3.36
Landmark	-0.54	0.34	-0.47	0.34	89.13	2.79	29.57	4.82
Lumidor	-0.64	0.76	-0.62	0.76	57.67	2.65	29.55	4.69
Pinacle	0.44	0.34	0.31	0.25	73.48	2.54	26.63	6.96
RS3	0.56	0.69	0.49	0.55	54.48	2.11	23.55	6.04
RS 608	-0.81	0.69	-0.75	0.67	49.50	1.97	27.20	2.68
Sweet Trophy	-0.54	0.55	-0.47	0.39	41.49	2.14	24.06	3.79
Smolicka Cukrowa	-0.58	0.56	-0.53	0.40	47.03	2.09	24.25	3.50
Absolute mean	0.61	0.52	0.55	0.45	58.53	2.49	27.28	4.17
	1999 - 2004							
Anawa	-0.52	0.33	-0.79	-0.32	30.48	3.89	8.28	7.07
Bonus	-0.50	0.49	-0.41	0.40	39.93	4.16	16.16	7.45
Candle	-0.39	-0.47	-0.81	-0.87	72.49	4.62	9.30	3.56
Comanche	-0.64	0.57	-0.49	0.21	43.25	3.41	17.90	8.02
Golda	-0.57	0.35	-0.92	-0.42	38.01	3.51	11.74	8.77
Indira	-0.61	0.58	-2.73	-2.13	41.51	3.57	8.45	8.45
Jubille	-0.47	0.44	-0.33	0.26	27.43	3.58	16.46	9.21
Primetime	-0.68	0.48	-0.60	0.16	48.28	3.53	18.37	7.91
Sheba	-0.63	0.31	-0.68	-0.09	40.59	4.46	13.78	4.15
Sweet Trophy	-0.72	0.33	-0.97	-0.35	57.92	4.23	12.73	5.38
Absolute mean	0.57	0.43	0.87	0.52	43.99	3.90	13.32	7.00

Table 3
The influence of temperature (°C), atmospheric precipitation (mm) and total radiation (W·m^{-1}) on the length of vegetation (days) of selected sweet corn cultivars (2005-2010)

2005 - 2010											
	Correlation coefficient			Standardised partial regression coefficient			Coefficient of determination, %	Coefficient of variation, %			
Cultivar	Temp.	Precipit.	Total radiation	Temp.	Precipit.	Total radiation		Temp.	Precipit.	Total radiation	Length of vegetation
Candle	-0.64	-0.22	-0.24	-0.67	-0.58	-0.33	63.57	3.11	24.67	8.45	5.40
Challenger	-0.91	0.12	-0.14	-1.12	-0.33	0.16	95.81	2.80	29.36	6.61	6.27
Comanche	-0.43	0.40	-0.54	-0.27	0.24	-0.31	37.81	3.95	23.04	8.62	3.09
Golda	-0.60	0.42	-0.94	-0.29	-0.07	-0.86	95.11	3.15	31.12	7.19	3.88
GSS 5022	-0.83	0.79	-0.78	-0.55	0.27	-0.38	96.26	3.51	45.99	8.66	6.31
Indira	0.14	-0.54	0.65	0.07	-0.47	0.52	59.99	3.74	9.92	15.03	4.44
Shaker	-0.41	-0.84	0.17	-0.24	-0.74	0.12	73.53	3.71	10.99	15.24	3.99
Sheba	-0.25	0.09	0.34	-0.12	0.55	0.76	33.82	3.35	36.73	6.97	5.50
Shimmer	-0.47	0.28	-0.14	-0.44	0.17	0.04	25.13	3.11	28.51	6.12	8.01
Sweet Trophy	-0.68	0.06	0.45	-0.68	-0.41	0.57	59.12	3.34	30.95	6.59	5.03
Absolute mean	0.54	0.38	0.44	0.45	0.38	0.40	64.02	3.38	27.13	8.95	5.19

that insufficient climatic conditions, especially precipitation, cause the yield of corn to be lower than possible. Water fulfils a number of important functions in the growth and development of plants. On the other hand, Kalbarczyk (2005) claims that the air temperature is the main element affecting the rate of plant development. This factor influences such processes in plants as the rate of cell division, diversification and growth (Starczewski et al., 1997). Temperature plays a significant role at the initial period of vegetation, i.e. during germination and sprouting (Jamieson et al., 1995). Kruse et al. (2008) observed in their research that there was a significant dependence between the time of ripeness, the quality of the corn yield and the course of temperature during the whole vegetation period. Herrmann et al. (2005) drew similar conclusions from their study on forage maize. According to Sulewska (2007), in spite of the progress in cultivation, which resulted in considerable reduction of the thermal requirements of maize, it still has high demands concerning the soil and air.

According to Błażejczyk et al. (2005), the supply of solar radiation is one of the significant factors determining the photosynthetic process and in consequence, the growth, development and yield of crops. The spectral composition and intensity of radiation reaching the plant has fundamental influence on its development. It is decisive not only to the possible course and efficiency of the photochemical processes which are part of photosynthesis, but it also provides information about the surrounding environment and the season of the year, enabling the plant to adapt to the current environment in the best possible way in the process of photomorhogenesis (Pilarski et al., 2012). The rate of photosynthesis is influenced by such factors as light intensity and air temperature. In the same species of plants the rate of photosynthesis is usually higher at higher temperatures (Odum, 1982).

Conclusions

- The Sums of Effective Temperatures which were calculated from the moment of sowing to the stage of lactic ripeness were found to be useful for the classification of sweet corn cultivars. The distribution into the classes of earliness was the most equal for the threshold temperature of 6°C. This method was the most precise reflection of the moments when the sweet corn cultivars achieved different stages of development in individual years of the research.
- The length of sweet corn vegetation was found to be directly proportional to atmospheric precipitation and total radiation, but it was inversely proportional to temperature. The length of vegetation was significantly influenced by all of the three factors. However, the effect of temperature was the most significant at most of the stages of development.

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