ACTA Acta Sci. Pol., Hortorum Cultus 11(3) 2012, 155-178

THE ROLE OF SUNSHINE DURATION AND AIR TEMPERATURE IN SHAPING VARIABILITY IN DEVELOPMENTAL STAGES OF THE CUCUMBER (*Cucumis sativus* L.) IN POLAND, 1966–2005

Robert Kalbarczyk, Eliza Kalbarczyk[1]

[1]Adam Mickiewicz University in Poznan

Abstract. Cucumber cultivation in Poland is connected with a certain climatic risk, producing small yields of the plant. Selection of areas suitable for cucumber cultivation should be based not only on soil conditions and agrotechnical recommendations, but also on knowledge of the rate of growth and development of the plant. The aim of this work was to determine the effect of solar conditions and the thermal conditions of air on the variability of cucumber developmental stages in Poland from 1966–2005. To achieve the goals, data was collected from 28 experimental stations of the Research Centre for Cultivar Testing (RCCT) and 50 meteorological stations of the Institute of Meteorology and Water Management (IMWM) concerning respectively: the duration of cucumber development stages and sunshine duration and air temperature from 1966–2005. The relationship between the duration of developmental stages and the examined meteorological elements was determined by analysis of linear and second degree polynomial regression and thermal requirements of the cucumber in the period from sowing to the beginning of fruit setting, determined by means of the effective temperature sum method. Results obtained in this work may be used, for example, in the process of adjusting field production of cucumbers to changing climatic conditions in Poland.

Key words: analysis of regression, field production, phenology, solar and thermal conditions, vegetable

INTRODUCTION

The cucumber, as a thermophilous plant, for proper growth and development during its average 4 month vegetation season, requires proper solar and especially thermal conditions [Krug and Liebig 1991, Marcelis 1993, Sysoeva et al. 1999, Piróg et al. 2010]. Cucumber cultivation in Poland is connected with a certain risk, even in areas

Corresponding author – Adres do korespondencji: Eliza Kalbarczyk, Department of Spatial Econometrics, Adam Mickiewicz University in Poznan, ul. Dzięgielowa 27, 61-680 Poznań, Poland, e-mail: elizakalbarczyk@wp.pl

which are climatically favourable, producing small yields of the plant. Selection of areas suitable for cucumber cultivation should be based not only on soil conditions and agrotechnical recommendations, but also on knowledge of the rate of growth and development of the plant as well as temporal and spatial distribution of meteorological elements, particularly air temperature [Perry and Wehner 1996, Akinci and Abak 1999]. Climatic risk to cultivation can be minimised, through taking proper decisions before the start of production, especially in periods of recorded and predicted climatic changes [Lorenc 2000, Żmudzka 2004, Várallyay 2007, Tao et al. 2008, Kalbarczyk 2009].

The aim of the work was hence to study the variability and temporal structure of sunshine duration and air temperature in the vegetation season of the cucumber and developmental stages of this plant over the 1966–2005 period to determine the relationship between the duration of development stages and the analyzed meteorological elements, and also to determine thermal requirements of the growing plant in the period from sowing to the beginning of fruit setting and the probability of this stage falling outside the 20th and 31st July calculated stage endpoints.

MATERIAL AND METHODS

This work sourced both daily and decade data on which average values of sunshine duration and air temperature in cucumber developmental stages were determined for successive years from 1966–2005. Initial meteorological data had been collected from 28 Research Centre for Cultivar Testing stations (RCCT), and in the event of a lack of RCCT data, from Institute of Meteorology and Water Management stations (IMWM) situated in the closest vicinity and at the same time, reflecting the meteorological conditions over the period of the conducted experiments (fig. 1.) [Biuletyny Agrometeorologiczne 1965–2002, Biuletyny Państwowej Słuzby... 2003–2005]. Additionally, to determine spatial distribution of the probability of reaching the beginning of fruit setting, data from 50 IMWM stations were used, representing all climatic regions of Poland. Solar conditions and thermal conditions of the air were characterized by means of the following statistical indexes: average, minimum, maximum and standard deviation. Also, changes in the course of sunshine duration and air temperature over the 1966–2005 period were determined on the basis of a linear trend from a linear regression equation. This work also includes deviations from the average in relation to the accepted "basic" period, 1966–1985.

Identification of solar and thermal conditions in selected cucumber development stages was carried out on the basis of two statistical parameters: arithmetic mean and standard deviation, determined for the basic period 1966–1985. Criteria and classes are listed in Table 1. For example, solar and thermal conditions in particular development stages of the cucumber were considered normal when the value of sunshine duration and air temperature in a given year fulfilled the following condition: $\Pi - 1.0\delta \leq \xi \leq \Pi + 1.0\delta$, where Π denoted the mean value, δ the value of the standard deviation, with both parameters calculated for the basic period of 1966–1985, while ξ denoted the value recorded in a given year. Similar classifications concerning air temperature, soil temperature and atmospheric precipitation were conducted by, among others, Lorenc [2000], Żmudzka [2004], Węgrzyn [2007] and Pokladníková et al. [2008].

Fig. 1. Distribution of experimental stations of RCCT (■) and meteorological stations of IMWM (●)
Rys. 1. Rozmieszczenie stacji doświadczalnych COBORU (■) i stacji meteorologicznych IMGW (●)

This work, apart from the data pertaining to solar and thermal conditions, also used the duration of cucumber development stages: sowing – the end of emergence S-Ee (16.05–3.06), the end of emergence – the beginning of flowering Ee-Bf (3.06–7.07), the beginning of flowering – the beginning of fruit setting Bf-Bfs (7.07–12.07), the beginning of fruit setting – the beginning of harvesting Bfs-Bh (12.07–22.07), the beginning of harvesting – the end of harvesting Bh-Eh (22.07–3.09) and the period from sowing to the beginning of fruit setting S-Bfs (16.05–12.07). In brackets, following Kalbarczyk [2009a], there are average dates of the beginning and the end of all the considered development stages for Poland. The data had been collected from 28 RCCT experimental stations over the 1966–2005 period, except for 2003 and 2004 when experiments were not conducted (fig. 1). The duration of development stages was collected for all the most common pickling cultivars of cucumber examined in a given year, which after averaging were collated as a collective standard for the described plant to be considered at a further stage of the research. Experiments in 1966–2005 were carried out on typical soils for the cultivation of field cucumber: wheat complexes, a very good and good one and on a very good rye complex. In field experiments usually full organic manuring was used, at a dose from 30 to 40 $t \cdot ha^{-1}$, which was later ploughed in autumn, and in spring mineral fertilization was used at a dose 400 kg per 1 hectare of the crop, including N and P_2O_5 respectively 115 and 90 kg, and K_2O – 195 kg. Chance variations and temporal structures were characterized and the identification of the duration of development stages of the cucumber was carried out in the same manner as in the case of sunshine duration and air temperature.

The relationship between the duration of development stages of the cucumber and average sunshine duration and average air temperature was determined by means of linear regression and second degree polynomial regression, both single and multiple. Regression function parameters were determined by least squares method. The significance of the whole regression equation was examined with an F-Snedecor test, and the significance of parameters with a t-Student test. The Pearson's correlation coefficient served as a measure of fitting of the regression function to empirical data [Sobczyk 1998].

Table 1. Scale and classification criterion of sunshine duration and air temperature and the duration of all the considered cucumber development stages, 1966–2005
Tabela 1. Skala i kryterium klasyfikacji usłonecznienia rzeczywistego i temperatury powietrza oraz długości wszystkich rozpatrywanych okresów rozwoju ogórka, 1966–2005

Criterion Kryterium	Sunshine duration Usłonecznienie	Air temperature Temperatura powietrza	Duration of development stage Długość okresu rozwoju
$\xi > \Pi + 2.0\delta$	anomalously sunny anomalnie słonecznie	anomalously warm anomalnie gorąco	anomalously long anomalnie długi
$\Pi + 1.5\delta < \xi \leq \Pi + 2.0\delta$	very sunny bardzo słonecznie	very warm gorąco	very long bardzo długi
$\Pi + 1.0\delta < \xi \leq \Pi + 1.5\delta$	sunny słonecznie	warm ciepło	long długi
$\Pi - 1.0\delta \leq \xi \leq \Pi + 1.0\delta$	normal przeciętnie	normal przeciętnie	normal przeciętny
$\Pi - 1.5\delta \leq \xi < \Pi - 1.0\delta$	little sunlight mało słonecznie	cold zimno	short krótki
$\Pi - 2.0\delta \leq \xi \leq \Pi - 1.5\delta$	very little sunlight bardzo mało słonecznie	very cold bardzo zimno	very short bardzo krótki
$\xi < \Pi - 2.0\delta$	anomalously little sunlight anomalnie mało słonecznie	anomalously cold anomalnie zimno	anomalously short anomalnie krótki

Π – average value from the basic period of 1966–1985 – wartość średnia z okresu podstawowego 1966–1985,
δ – standard deviation from the basic period of 1966–1985 – odchylenie standardowe z okresu podstawowego 1966–1985,
ξ – average value from a given year – wartość średnia z danego roku.

Thermal requirements of the cucumber in the period from sowing to the beginning of fruit setting were determined by the sum of effective temperature, as employed for example by Yang et al. [1995], Deputat and Marcinkowska [1999], Baker and Reddy [2001], Juszczak et al. [2008]. The concept of temperature sum stability supposes that the product of the duration of a development stage expressed in days (L) and average air temperature in this period ($\overline{Ta}$) above a particular threshold is constant, i.e. $L \cdot \overline{Ta}$ = constant [Deputat and Marcinkowska 1999]. For these reasons, the relationship between the rate of plant development and average air temperature was not described with a hyperbolic function but rather a simple linear function, substituting a dependent variable with its reverse, i.e., with the rate of development. The following formula was employed in calculating this relationship [Deputat and Marcinkowska 1999]:

$$Ta = \overline{Ta} + \frac{\delta Ta}{\delta c}\left(c - \bar{c}\right)$$

where: Ta – air temperature corresponding to a certain rate of development (in °C),
$\overline{Ta}$ – average air temperature of a given period (in °C),
δTa – standard deviation of air temperature of a given period (in °C),
δc – standard deviation of the rate of development (in 1/day),
c – rate of development (in 1/day),
$\bar{c}$ – average rate of development (in 1/day).

After substituting data in the above formula, parameters of the equation were obtained in which the absolute term constituted the value of a thermal threshold, and the gradient argument was the sum of the effective temperature. After calculating the average value and standard deviation for the 1966–2005 period, and the sum of effective temperature for 50 meteorological stations (IMWM) and 28 experimental stations (RCCT), in the period from 16th May to 12th July the probability of the occurrence of the beginning of fruit setting in the assumed period in whole Poland was determined. The dates of 16th May for sowing and 12th July for the beginning of fruit setting were accepted as average in Poland, following an earlier work by Kalbarczyk [2009a]. The assumed dates: 20th and 31st July, for which probability of the beginning of cucumber fruit setting was determined, were between the absolute earliest (29th June) and the absolute latest (2nd August) date of the occurrence of this development stage.

RESULTS

Multiannual variability of solar and thermal conditions

Sunshine duration. In Poland in 1966–2005, the average sunshine duration in the cucumber vegetation season ran from 6.9 h in the period from the beginning of harvesting – the end of harvesting (Bh-Eh), up to 8.0 h in the period of sowing – the end of emergence (S-Ee) (tab. 2). Minimum values of sunshine duration oscillated between 4.4 h in the period of the beginning of flowering – the beginning of fruit setting (Bf-Bfs) up to 5.2 h in the period Bh-Eh, and maximum from 9.3 h in the period of fruiting (Bh-Eh) to 11.7 h in the first period of cucumber vegetation (S-Ee). Minimum values of sunshine duration were recorded in the following years: 1968 (S-Ee), 1978 (Bh-Eh), 1980 (Ee-Bf, Bfs-Bh) and 2000 (Bf-Bfs), and maximums in: 1979 (S-Ee), 1992 (Ee-Bf, Bh-Eh), 1994 (Bfs-Bh) and 1995 (Bf-Bfs). The standard deviation for the described meteorological element oscillated between 1.1 and 1.7 h, while the highest was recorded in the period Bf-Bfs, and the lowest in the final development stage of cucumber (Bh-Eh).

Sunshine duration in the period from sowing to the beginning of fruit setting (S-Bfs), starting in Poland on average on 16th May and ending on 12th July, amounted to, on average, 7.6 h, with a standard deviation equal to 1.0 h, oscillating between 5.7 h in 1980 to 9.7 h in 1992.

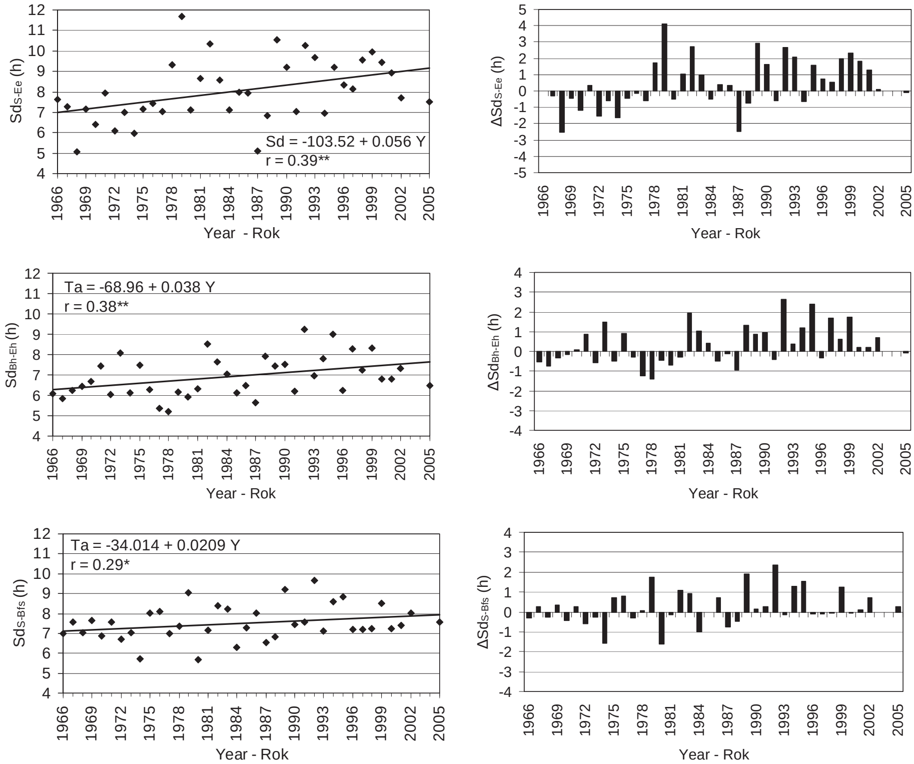


Fig. 2. Course of average sunshine duration according to cucumber development stages (S-Ee, Bh-Eh, S-Bfs) in Poland, 1966–2005 and left: periodical average values (Sd), right: anomalies (ΔSd) compared to the 1966–1985 basic period. Trends are significant with $*P < 0.1$, $**P < 0.05$. Other explanations see Table 2.

Rys. 2. Przebieg średniego usłonecznienia rzeczywistego wg okresów rozwoju ogórka (S-Ee, Bh-Eh, S-Bfs) w Polsce, 1966–2005, po lewo: wartości średnie okresowe (Sd), po prawej: odchylenia (ΔSd) w porównaniu do okresu podstawowego 1966–1985. Trendy istotne przy $*P < 0.1$, $**P < 0.05$. Pozostałe objaśnienia: patrz tabela 2.

Out of five considered stages of cucumber development and, additionally, in the period S-Bfs, for which the description of variability and temporal structure of sunshine duration was conducted, only in three periods was a statistically significant increase in the number of hours with sunlight proven (tab. 2, fig. 2). In the 1966–2005 period the highest increase was shown in the period S-Ee by +0.56 h/10 years ($r = 0.39$, $P \leq 0.05$), next in the period Bh-Eh by +0.38 h/10 years ($r = 0.38$, $P \leq 0.05$) and in the period S-Bfs by +0.21 h/10 years ($r = 0.29$, $P \leq 0.1$).

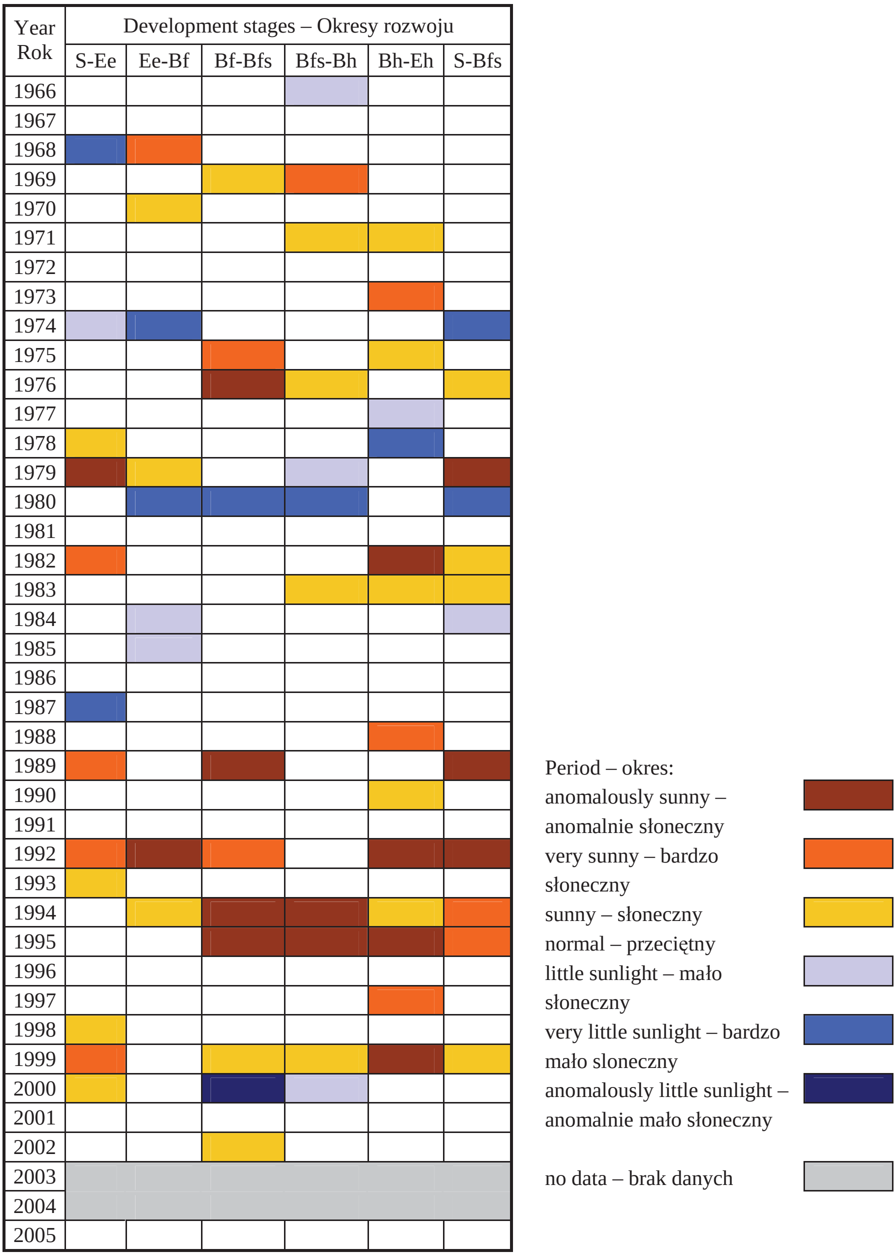
Table 2. Statistical parameters and linear trend of average sunshine duration (in h) in Poland, 1966–2005
Tabela 2. Charakterystyki statystyczne i trend liniowy średniego usłonecznienia (w h) w Polsce, lata 1966–2002

Development stage Okres rozwoju	Mean – Średnia		Standard deviation Odchylenie standardowe	Minimum/ Year Minimum/ Rok	Maximum/ Year Maksimum/ Rok	Trend (h/decade) Trend (h/10 lat)
	1966–1985[a]	1966–2005				
S-Ee	7.5	8.0	1.6	5.1/1968	11.7/1979	0.56**
Ee-Bf	7.3	7.3	1.2	4.9/1980	9.5/1992	Ns
Bf-Bfs	7.2	7.4	1.7	4.4/2000	10.5/1995	Ns
Bfs-Bh	7.3	7.3	1.5	4.8/1980	10.6/1994	Ns
Bh-Eh	6.5	6.9	1.1	5.2/1978	9.3/1992	0.38**
S-Bfs	7.3	7.6	1.0	5.7/1980	9.7/1992	0.21*

[a] basic period – okres podstawowy.
S – sowing – siew, Ee – end of emergence – koniec wschodów, Bf – beginning of flowering – początek kwitnienia, Bfs – beginning of fruit setting – początek zawiązywania owoców, Bh – beginning of harvesting – początek zbiorów, Eh – end of harvesting – koniec zbiorów.
Trends are significant with – trendy istotne przy $*P < 0.1$, $**P < 0.05$. Ns – non-significant – nieistotne.

As illustrated in Figure 2, deviations of sunshine duration in the period S-Ee, compared to the basic period of 1966–1985, in particular the years' 1966–2005 multiannual period oscillated between -2.5 h in 1968 and +4.1 h in 1979, while the longest, uninterrupted sequence of positive deviations was recorded in 8 years from 1995 to 2002, and negative deviations – in 6 years from 1972 to 1977. In the subsequent development stage of cucumber (Bh-Eh), in which a significant increase in the number of hours with sunshine duration, the highest negative deviations amounted to: -1.4 h in 1978, -1.2 h in 1977 and -1.0 h in 1987, whereas the highest positive deviations: +2.7 h in 1992, +2.4 h in 1995 and +1.9 h in 1982; since 1992, positive deviations which definitely led to a significant increase of the number of hours with sunlight in this period, were recorded as many as 10 times (without the considered years: 2003 and 2004). The lowest number of positive deviations of the analyzed meteorological element, from the average of the basic period, was recorded in the period S-Bfs. In the 1966–2005 multiannual period, positive deviations were recorded only 17 times (of which only 3 times were in the last decade, in the following years: 1999, 2002 and 2005), that is, 4 and 3 times less than in the respective periods of S-Ee and Bh-Eh.

It results from the classification of 6 development stages of cucumber conducted on the basis of the course of sunshine duration in successive years 1966–2005 that for 228 analyzed periods (6 stages × 38 years) 23 were identified as sunny, 13 as very sunny and 15 as anomalously sunny (fig. 3). Solar conditions identified as sunny occurred most often in the period Bh-Eh, and very sunny in the period S-Ee and as anomalously sunny in two periods: Bf-Bfs and Bh-Eh. In three years: 1992, 1994 and 1999 at as many as 5 development stages of cucumber sunshine duration were characterized by above-average values; in 1992, 3 stages (Ee-Bf, Bh-Eh and S-Bfs) were anomalously



Explanations see Table 2 – Objaśnienia patrz tabela 2.

Fig. 3. Identification of solar conditions in Poland according to cucumber development stages on the basis of average sunshine duration, 1966–2005

Rys. 3. Identyfikacja warunków solarnych w Polsce wg okresów rozwoju ogórka na podstawie średniego usłonecznienia rzeczywistego, 1966–2005 sunny, and 2 (S-Ee and Bf-Bfs) – very sunny, in 1994, 2 stages (Bf-Bfs and Bfs-Bh) were anomalously sunny, 1 (S-Bfs) – very sunny and 2 (Ee-Bf and Bh-Eh) – sunny, whereas in 1999, 1 stage (Bh-Eh) was anomalously sunny, 1 (S-Ee) – very sunny and 3 (Bf-Bfs, Bfs-Bh and S-Bfs) – sunny. Since 1988 only 2 stages, in 2000, were identified as having anomalously little sunlight (Bf-Bfs) and having little sunlight (Bfs-Bh).

Air temperature. In 1966–2005, the temporal distribution of average air temperature in the vegetation season of cucumber was different than that of sunshine duration (tab. 2–3). The highest mean air temperature, amounting to 18.2°C, occurred in the period Bfs-Bh and the lowest, amounting to 14.6°C, in the initial development stage of

Table 3. Statistical parameters and linear trend of average air temperature (in °C) in Poland, 1966–2005
Tabela 3. Charakterystyki statystyczne i trend liniowy średniej temperatury powietrza (in °C) w Polsce, 1966–2005

Development stage Okres rozwoju	Mean – Średnia		Standard deviation Odchylenie standardowe	Minimum/ Year Minimum/ Rok	Maximum/ Year Maksimum/ Rok	Trend (°C/decade) Trend (°C /10 lat)
	1966–1985[a]	1966–2005				
S-Ee	14.6	14.6	1.5	12.0/1991	18.4/1979	Ns
Ee-Bf	16.5	16.6	1.0	14.3/1984	18.7/1979	Ns
Bf-Bfs	17.5	17.8	1.6	14.9/1978	20.4/1999	Ns
Bfs-Bh	18.1	18.2	1.5	15.4/1979	20.8/1994	Ns
Bh-Eh	16.7	17.4	1.3	14.9/1978	20.7/1992	0.64***
S-Bfs	16.2	16.3	0.9	14.5/1984	18.5/1979	Ns

[a] basic period – okres podstawowy.
Trend is significant with – trend istotny przy ***$P < 0.01$.
Other explanations see Table 2 – pozostałe objaśnienia patrz tabela 2.

cucumber, that is from sowing to emergence. The minimum average air temperature in the cucumber vegetation season oscillated between 12.0 and 15.4°C, and the maximum between 18.4 and 20.8°C, whereas the lowest values of both temperatures were recorded in the period S-Ee and the highest values in the period Bfs-Bh; as in the case of the course of mean air temperature. The minimum air temperature, like in the case of sunshine duration, in the period Bh-Eh was recorded in 1978, and the maximum in the following periods: S-Ee, Bfs-Bh and Bh-Eh respectively in: 1979, 1994 and 1992. The standard deviation oscillated between 1.0 and 1.6°C, the highest in the period Bf-Bfs. A linear trend was proved only for the temperature measured at the end of the vegetation season of cucumber (Bh-Eh), which rose by 0.64°C/10 years (tab. 3, fig. 4). On the other hand, average air temperature in the period S-Bfs amounted to 16.3°C and oscillated between 14.5 in 1984 and 18.5 in 1979.

From the analysis of average air temperature deviations in successive years 1966–2005, in the period of cucumber fruiting (Bh-Eh), compared to the average from the basic period, they oscillated between -1.3°C in 1978 and +4.5°C in 1992. Standard deviations were recorded in as many as 31 years, since 1980 they have occurred continually (fig. 4).

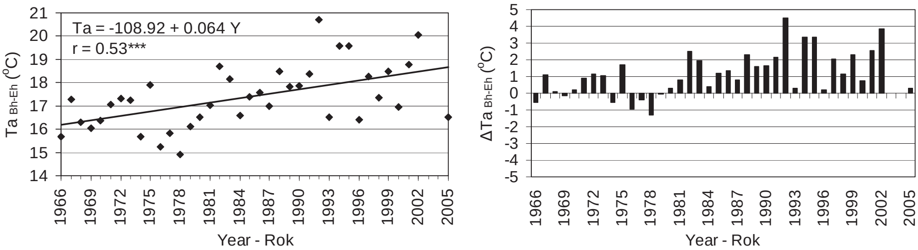
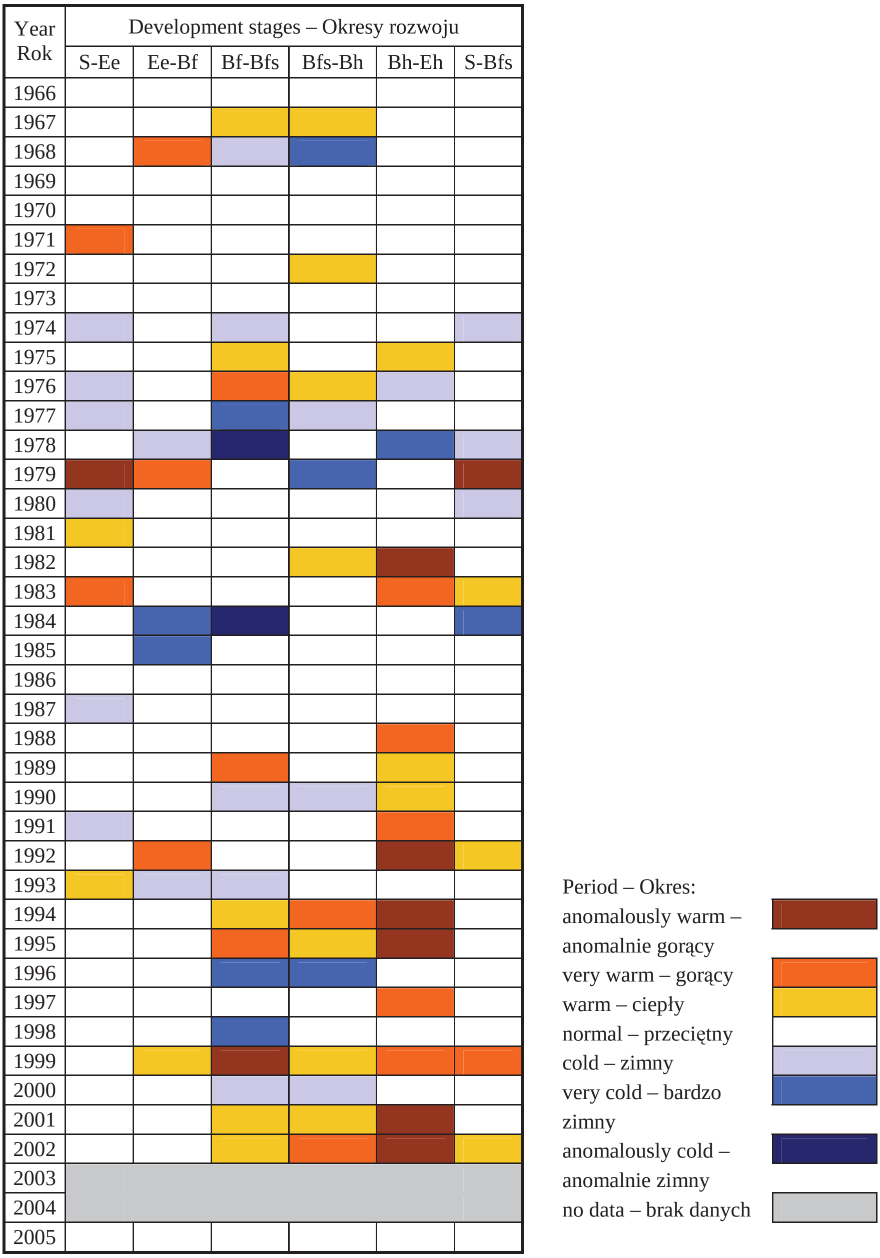


Fig. 4. Course of average air temperature in the period of the beginning of harvesting – the end of harvesting of cucumber (Bh-Eh) in Poland, 1966–2005 and left: periodical average values, right: anomalies (ΔTa) compared to the 1966–1985 basic period. Trend is significant with ***P < 0.01

Rys. 4. Przebieg średniej temperatury powietrza w okresie początek zbioru – koniec zbioru ogórka (Bh-Eh) w Polsce, 1966–2005. Po lewo: wartości średnie okresowe, po prawej: odchylenia (ΔTa) w porównaniu do okresu podstawowego 1966–1985. Trend istotny przy ***P < 0.01 ***P < 0.01

Out of 228 analyzed development stages of cucumber (6 stages × 38 years), 46 were identified as anomalously warm, very warm or warm, most of which, namely 21, were warm periods, and the fewest, namely 9, were anomalously warm periods (fig. 5). In 1999 all development stages of the described plant were characterized by above-average air temperatures, except for the period S-Ee, which was identified as normal. Periods identified as anomalously warm and very warm most numerously occurred during cucumber fruiting (Bh-Eh) respectively 6 and 5 times, and as warm 7 times – in the period Bf-Bfs. The period S-Bfs (in 1983, 1992 and 2002) was classified 3 times as warm and only once as very warm (in 1999) or anomalously warm (in 1979).

Temporal structure of cucumber development stages. From the analysis of five development stages of cucumber in 1966–2005, constituting the whole vegetation season of the characterized plant, on average the longest development stage, lasting about 43 days, was the period Bh-Eh, and next, the period Ee-Bf, which lasted about 33 days. On average, the shortest development period, several times shorter than the longest one, was the period Bf-Bfs, which lasted only about 6 days (tab. 4). The biggest difference in the duration of development stages, between the basic period of 1966–1985, and the 1966–2005 multiannual period, concerned the period Bh-Eh (longer than the basic period by 4.3 days), and next, the period Bfs-Bh (longer than the basic period by 2.2 days). Minimum durations of development stages in the whole analyzed period 1966–2005 were shorter than the average by about 2 days in Bf-Bfs, up to 16 days in the case of the period Bh-Eh. Minimum durations of five development stages of cucumber were recorded in: 1979 (S-Ee, Ee-Bf), 1989 (Bf-Bfs), 1992 (Bh-Eh) and 2002 (Bfs-Bh). Maximum durations of development stages of cucumber were from about 1.3 up to 2.6 times longer than the average in 1966–2005, and from 2 up to 6.3 times longer than the



Explanations see Table 2 – Objaśnienia patrz tabela 2.

Fig. 5. Identification of thermal conditions in Poland according to cucumber development stages on the basis of average air temperature, 1966–2005

Rys. 5. Identyfikacja warunków termicznych w Polsce wg okresów rozwoju ogórka na podstawie średniej temperatury powietrza, 1966–2005

Table 4. Characteristics of cucumber development stages (in day) in Poland, 1966–2005
Tabela 4. Charakterystyka okresów rozwoju ogórka (w dniach) w Polsce, 1966–2005

Development stage Okres rozwoju	Mean – Średnia		Standard deviation Odchylenie standardowe	Minimum/Year Minimum/ Rok	Maximum/ Year Maksimum/ Rok	Trend (day/decade) Trend (dzień/ 10 lat)
	1966–1985[a]	1966–2005				
S-Ee	19.4	18.5	4.3	13/ 1979	27/ 1991	-1.8**
Ee-Bf	34.0	33.2	4.1	21/ 1979	42/ 1984	Ns
Bf-Bfs	5.8	5.5	1.5	4/ 1989	12/ 1984	Ns
Bfs-Bh	11.8	9.8	3.8	4/ 2002	25/ 1979	Ns
Bh-Eh	47.5	43.2	8.2	27/ 1992	58/ 1978	-3.7***
S-Bfs	59.2	57.1	6.2	42/ 1979	76/ 1974	-2.0***

[a] basic period – okres podstawowy.
Trend is significant with – trend istotny przy ***$P < 0.01$.
Other explanations see Table 2. Pozostałe objaśnienia patrz tabela 2.

minimum, the biggest differences concerned the period Bfs-Bh. Maximum durations of development stages occurred in different years than the minimums, except for 1979, when the longest period Bfs-Bh was observed, the remaining maximum durations of stages were recorded in: 1984 (Ee-Bf, Bf-Bfs), 1978 (Bh-Eh) and 1991 (S-Ee). Chance variation, described by a standard deviation determined for cucumber development stages, oscillated between 1.5 days in the case of the shortest considered period (Bf-Bfs) and 8.2 days in the case of the longest period (Bh-Eh).

On the other hand, the period S-Bfs in 1966–2005, lasted on average about 57 days and was shorter by 2.1 days than the basic period of 1966–1985 (tab. 4). The minimum duration of the period, amounting to 42 days, was observed in 1979, that is, when the minimum duration of two initial cucumber development stages was noted (S-Ee, Ee-Bf); the maximum duration, on the other hand, lasting 76 days in 1974. The standard deviation of the period S-Bfs amounted to 6.2 days and was only lower than the standard deviation determined for the period Bh-Eh.

Out of all the analyzed cucumber development stages only three were characterized by a statistically significant negative trend: S-Ee, Bh-Eh and S-Bfs (tab. 4, fig. 6). The period Bh-Eh was shortened most: by -3.7 days/10 years ($r = 0.59$, $P \leq 0.01$), next, the period S-Bfs by –2.0 days/10 years ($r = 0.52$, $P \leq 0.01$), and the period S-Ee by -1.8 days/10 years ($r = 0.42$, $P \leq 0.05$).

As illustrated in Figure 6, the highest positive deviations of the period duration of S-Ee from the average in the basic period of 1966–1985 were recorded in: 1991 (+7.6 days) and 1977 (+7.5 days), and negatives in 1979 (-6.4 days), 1971 and 1996 (-6.3 days each). In the whole analyzed 1966–2005 multiannual period (apart from 2003 and 2004) as many as 23 out of the 38 considered years recorded a negative deviation of the period duration of S-Ee, and uninterruptedly since 1992, which was undoubtedly caused by the occurrence of, among other things, above-average solar conditions (fig. 2). Deviations from the average, concerning the duration of the period Bh-Eh, oscillated between -20.5 and +10.5 days, whereas the highest negative deviations were recorded in 1992 (-20.5 days) and 1994 (-20.4 days), and positives in 1978 (+10.5 days) and in 1971 (+7.2 days). In the analyzed multiannual period times there were as many as 26 negative deviations, occurring uninterruptedly since 1980. On the other hand, deviations from the average in 1966–2005 of the period S-Bfs were lower than for the period Bh-Eh and oscillated between -17.5 days in 1979 and +16.4 in 1974, while negative deviations were recorded 25 times in the 38 considered years, uninterruptedly since 1992, that is, the same as in the case of the period S-Ee.

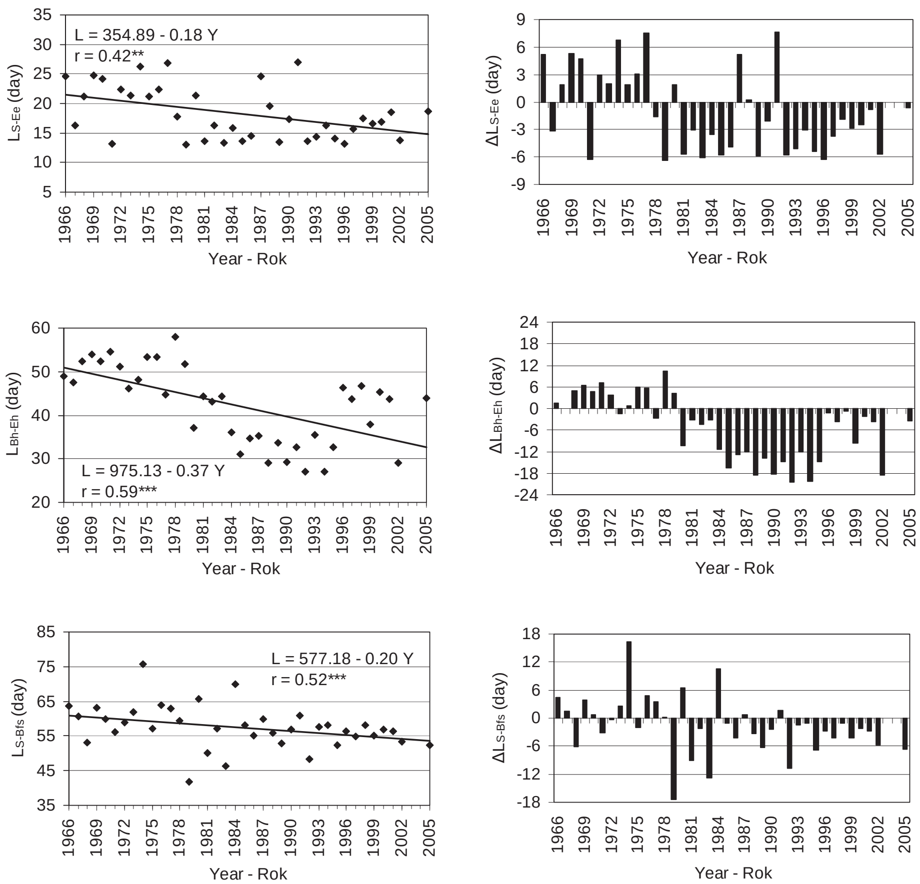
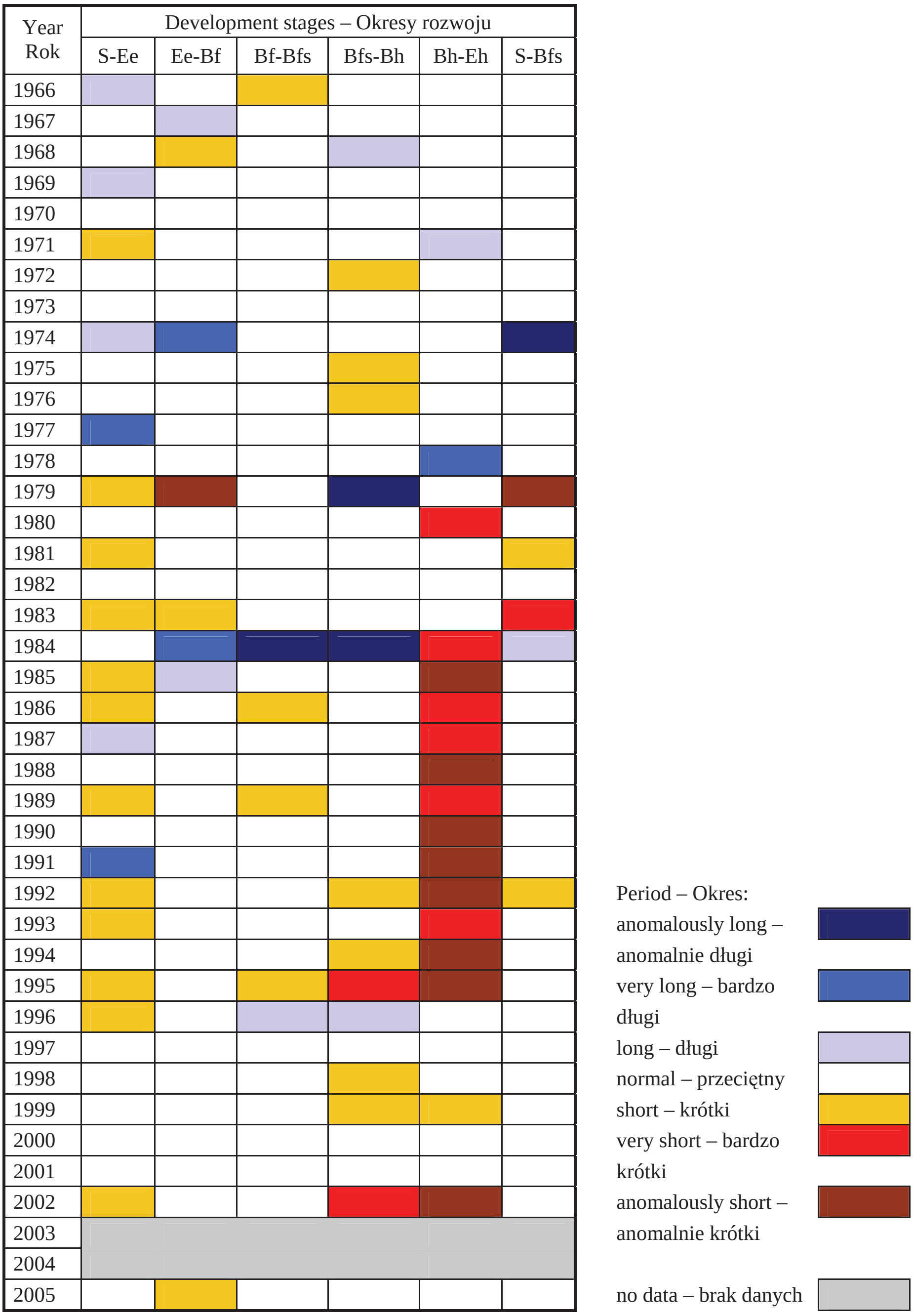


Fig. 6. Course of the duration of cucumber development stages ($L_{S\text{-}Ee}$, $L_{Bh\text{-}Eh}$, $L_{S\text{-}Bfs}$) in Poland, 1966–2005 and left: periodical average values, right: anomalies ($\Delta L_{S\text{-}Ee}$, $\Delta L_{Bh\text{-}Eh}$, $\Delta L_{S\text{-}Bfs}$) compared to the 1966–1985 basic period. Trends are significant with ***$P < 0.01$

Rys. 6. Przebieg długości okresów rozwoju ogórka ($L_{S\text{-}Ee}$, $L_{Bh\text{-}Eh}$, $L_{S\text{-}Bfs}$) w Polsce, 1966–2005. Po lewo: wartości średnie okresowe, po prawej: odchylenia ($\Delta L_{S\text{-}Ee}$, $\Delta L_{Bh\text{-}Eh}$, $\Delta L_{S\text{-}Bfs}$) w porównaniu do okresu podstawowego 1966–1985. Trendy istotne przy ***$P < 0.01$



Explanations see Table 2 – Objaśnienia patrz tabela 2.

Fig. 7. Identification of the duration of cucumber development stages in Poland, 1966–2005
Rys. 7. Identyfikacja długości okresów rozwoju ogórka w Polsce, 1966–2005

From the conducted classification of the duration of six cucumber development stages, 48 periods out of 228 examined (38 years × 6 periods) development stages were identified as short (anomalously short, very short and short) in comparison with those identified as long (anomalously long, very long and long), only 20 periods during the analyzed time of 1966–2005 (fig. 7). Among all the periods identified as short, 29 were classified as short periods, 9 as very short and 10 as anomalously short ones. In the first development stage of the cucumber (S-Ee), short periods occurred in as many as 12 years, which definitely led to the significance of the negative trend of the period, while in the second stage (Ee-Bf) they occurred in 3 years, in the third stage (Bf-Bfs) in 4 years, in the fourth (Bfs-Bh) in 7 years, in the fifth stage (Bh-Eh) in one year, and in the period S-Bfs in 2 years. Very short durations and anomalously short ones were recorded in four development stages of the cucumber, with both classes of duration in the periods Bh-Eh and S-Bfs. A very short stage was recorded in the period Bf-Bfs and an anomalously short one – in the period Ee-Bf. The anomalously short development stage was most frequent, as many as 8 times in 38 years, recorded in the fifth stage (Bh-Eh) in the following years: 1985, 1988, 1990–1992, 1994, 1995 and 2002, i.e. in years when average sunshine duration or average air temperature were characterized by higher values than average in the basic period. In two years, 1992 and 1995, when anomalously short durations of the period Bh-Eh occurred, during this period anomalously warm and sunny weather conditions were recorded simultaneously.

Relationship between the duration of cucumber development stages and sunshine duration and air temperature

All the analyzed durations of cucumber development stages were strongly statistically significantly correlated with average sunshine duration and average air temperature (tab. 5). Values of correlation coefficients for these relationships differed very little, as determined both by means of a linear function and a second degree polynomial. Slightly higher or the same values of correlation coefficients were determined for as many as 4 out of 5 analyzed periods (S-Ee, Ee-Bf, Bf-Bfs and Bh-Eh) with the use of linear regression in comparison with a second degree polynomial. Sunshine duration most strongly determined the duration of the period S-Ee (r = -0.65, $P \leq 0.01$), and next, the period Ee-Bf (r = -0.61, $P \leq 0.01$). On the other hand, the period S-Bfs was even more strongly dependent on average sunshine duration (r = -0.68, $P \leq 0.01$) when compared to 5 shorter development stages composing the period of the cucumber vegetation season. Air temperature to a much larger extent explained the variability of the duration of cucumber development stages than sunshine duration, as the correlation coefficient for these relationships oscillated between -0.66 and -0.79 when linear regression was used, and between -0.68 and -0.77 with second degree polynomial regression. The biggest difference in the description of the duration variability of development stages, resulting from the type of regression equation used, concerned the period Bfs-Bh. When linear regression was used the correlation coefficient for this relationship amounted to -0.66, and with second degree polynomial regression -0.71; both coefficients were significant $P \leq 0.01$.

Table 5. Correlation coefficients for linear (L) and second degree polynomial (Pw) relationships between the duration of cucumber development stages and average sunshine duration (Sd, in h) and average air temperature (Ta, in °C), 1966–2005

Tabela 5. Współczynniki korelacji dla zależności liniowych (L) i wielomianowych 2^{o} (Pw) między długością okresów rozwoju ogórka a średnim usłonecznieniem rzeczywistym (Sd, in h) i średnią temperaturą powietrza (Ta, in °C), 1966–2005

Development stage Okres rozwoju	Sd		Ta	
	L	Pw	L	Pw
S-Ee	-0.65***	-0.65***	-0.79***	-0.77***
Ee-Bf	-0.61***	-0.61***	-0.78***	-0.76***
Bf-Bfs	-0.46***	-0.45***	-0.76***	-0.72***
Bfs-Bh	-0.47***	-0.49***	-0.66***	-0.71***
Bh-Eh	-0.42***	-0.41***	-0.68***	-0.68***
S-Bfs	-0.68***	-0.68***	-0.75***	0.74***

*** significant at – istotne przy $P \leq 0.01$.
Other explanations see Table 2. Pozostałe objaśnienia patrz tabela 2.

Table 6. Shortening of the duration of cucumber development stages (calculated from a linear regression equation) as a result of an increase in average sunshine duration (Sd) by 1 h and by 1°C of average air temperature (Ta), 1966–2005

Tabela 6. Skrócenie długości okresów rozwoju ogórka (obliczone z równania regresji liniowej) w wyniku wzrostu o 1 h średniego usłonecznienia rzeczywistego (Sd) i o 1°C średniej temperatury powietrza (Ta), 1966–2005

Development stages Okres rozwoju	Sd	Ta
	(day/decade) (dzień/10 lat)	
S-Ee	-1.8***	-2.3***
Ee-Bf	-1.8***	-3.0***
Bf-Bfs	-0.3***	-0.6***
Bfs-Bh	-1.2***	-1.8***
Bh-Eh	-3.1***	-4.5***
S-Bfs	-3.5***	-4.4***

*** significant at – istotne przy $P \leq 0.01$.
Other explanations see Table 2. – Pozostałe objaśnienia patrz tabela 2.

Shortening of the duration of a cucumber development stage caused by an increase in sunshine duration by 1h depended on the development stage of the described plant, and oscillated between -0.3 days/10 years in the case of the period Bf-Bfs, and -3.1 days/10 years in the last cucumber development stage (Bh-Eh) (tab. 6). An increase in average air temperature by 1°C caused much greater shortening of particular development stage durations than the increase in average sunshine duration by 1h; it oscillated between -0.6 and -4.5 days/10 years. The period from sowing to the beginning of fruit setting became shortened even by -4.4 days/10 years as a result of a rise in temperature and by -3.5 days/10 years caused by stronger insolation.

The effect of solar and thermal conditions on the duration of cucumber development stages in 1966–2005 was also examined jointly, namely, in the regression equation both sunshine duration and air temperature were considered as independent variables. However, average sunshine duration, with the consideration of average air temperature, was not statistically significant in any of the formed regression equations and did not significantly result in increasing the variability description of the duration of cucumber stages.

Assessment of thermal conditions in the period from sowing to the beginning of fruit setting (S-Bfs)

Thermal requirements of the cucumber for the period S-Bfs were determined through calculating the sum of effective air temperature necessary to reach the beginning of fruit setting. The calculations of thermal requirements for cucumber were carried out for the S-Bfs phase due to its greatest coefficient of correlation between the duration of the period and its mean air temperature, in comparison with other periods (tab. 5). Next, its course in Poland was characterized, and the probability of the occurrence of this stage before 20^{th} and 31^{st} July was determined (tab. 7, fig. 8–9). Based on the formula describing the dependence between the rate of the plant growth and the mean air temperature [Deputat and Marcinkowska 1999], we established the parameters of the equation in which the thermal threshold (12.2°C) was the intercept, and the sum of effective temperature (236.1°C) was the directional coefficient. Cucumber reaches the stage of the beginning of fruit setting when the sum of effective temperature, calculated above 12.2°C from sowing, totalled 236.1°C. The temporal distribution of the sum of effective temperature (ΣTa > 12.2°C) in Poland oscillated most frequently between 160 and 220°C. The smallest sum, below 160°C, occurred in the northern part of Poland (in the Koszalin region) and in the south-west and south-east, i.e. in mountainous parts of Poland. In the central latitudinal strip of Poland and in the Rzeszów region the sum of effective temperature (ΣTa > 12.2°C) amounted to above 200°C, and in Warsaw and Wrocław regions even above 220°C.

Table 7. Thermal requirements of cucumber in the period from sowing to the beginning of fruit setting
Tabela 7. Wymagania termiczne ogórka w okresie od siewu do początku zawiązywania owoców

Development stage Okres rozwoju	$\overline{Ta}$ (°C)	δTa (°C)	c (1/dzień)	δc (1/dzień)	A (°C)	ΣTa (°C)
S-Bfs	16.35	0.85	0.018	0.0036	12.2	236.1

$\overline{Ta}$ – average air temperature of a given period – średnia temperatura powietrza w danym okresie, δTa – standard deviation of air temperature of a given period – odchylenie standardowe temperatury powietrza w danym okresie, c – rate of development – prędkość rozwoju, δc – standard deviation of the rate of development – odchylenie standardowe prędkości rozwoju, A – temperature threshold – próg termiczny, ΣTa – cumulative degree-days values – suma temperatur efektywnych

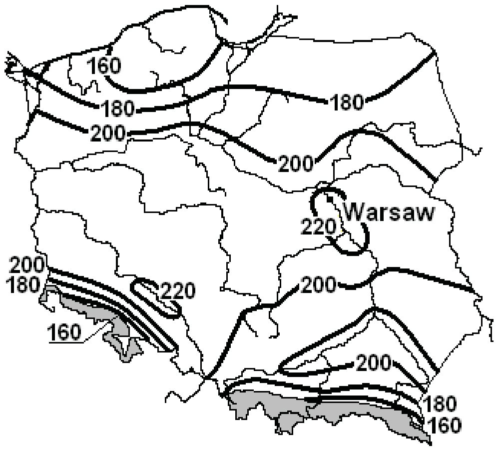


Fig. 8. Spatial distribution of the cumulative degree-days values (ΣTa > 12.2°C) in the period from sowing to the beginning of fruit setting of cucumber in Poland

Rys. 8. Rozkład przestrzenny sumy temperatur efektywnych (ΣTa > 12.2°C) w okresie od siewu do początku zawiązywania owoców ogórka na terenie Polski

a b

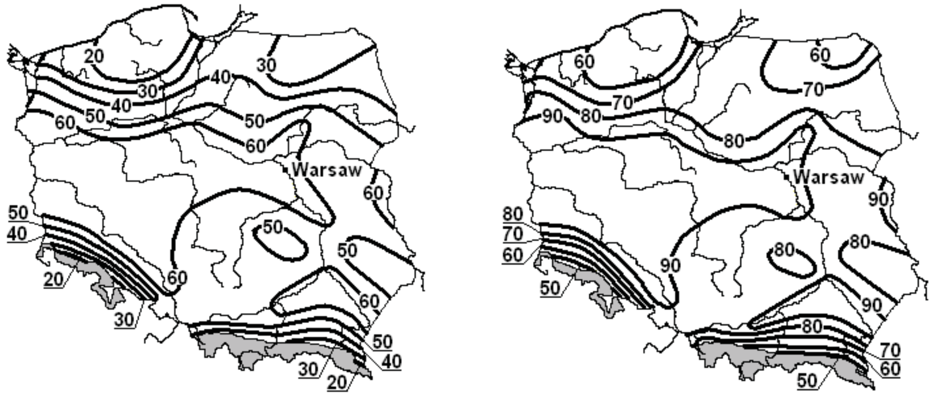


Fig. 9. Probability of reaching the beginning of cucumber fruit setting before 20th July (a) and before 31st July (b) in Poland

Rys. 9. Prawdopodobieństwo osiągnięcia początku zawiązywania owoców ogórka przed 20 lipca (a) i przed 31 lipca (b) na terenie Polski

The probability that cucumber plants would reach the beginning of fruit setting before 20th July, was from below 20% in the northern part of Poland and in the mountainous regions, to over 60% in the central-west and central-east of Poland and in Warsaw and Rzeszów regions. A delay of 10 days, in relation to the 20th July, caused the occurrence probability of the beginning of fruit setting to be at least 60%, and in the area covering about one third of Poland even exceeding 90%. The lowest probability of the occurrence of the stage before 31st July, amounting to no more than 60%, occurred in the north-west and north-east and in the Sudety mountains and the Carpathians. On the other hand, the probability of reaching the beginning of fruit setting exceeding even 90% occurred mostly in the central strip of Poland and in the Sandomierz Basin (in the Rzeszów region).

DISCUSSION

Many scientists claim that the climate undergoes changes, yet both the causes and direction are still an open question and have been assessed differently [Semenov and Barrow 1997, Várallyay 2007, Parey 2008]. Therefore studies concerning meteorological conditions are important, especially those conducted on various different agricultural crops which acquire special significance in the optimization of possibilities of their cultivation in the future. Each change in the climate causes serious problems in agriculture, forcing seeking new solutions and production technologies [Iglesias and Minguez 1997, van Minnen et al. 2002, Svenning and Skov 2006, Dragańska et al. 2008, Kalbarczyk 2009].

Variability and temporal structures of sunshine duration and air temperature in cucumber development stages have not been the subject of studies so far. Therefore, it is difficult to compare the obtained results with other scientific works because these elements are characterized most often by monthly periods or seasons of the year and not in development periods, that is, periods which are consistent with a calendar of the described plant [Koźmiński and Michalska 2004, Żmudzka 2004, Bryś and Bryś 2007, Węgrzyn 2007]. Definitely more works in literature on the subject, both Polish and international, can be found on the analysis of air temperature variability and its effect on the rate of growth and development of plants, rather than on sunshine duration [Chmielewski et al. 2004, Dragańska et al. 2008, Tao et al. 2008, Kalbarczyk 2009].

From the research by Koźmiński and Michalska [2004], in Poland in the 1952–2001 period, a significant increase in sunshine duration occurs most of all in May and August, in the time partly overlapping development stages of the cucumber (S-Ee, Bh-Eh, S-Bfs) in which a significant increase in this meteorological element was proved. According to these researchers, insolation variability in Poland is diverse; the highest occurs in the south-west. Also Kożuchowski and Degirmendžić [2005], on the basis of the 1971–2000 period, determined the highest increase in the sums of sunlight hours in May (from 12.1 h/10 years in SW Poland up to 26.5 h/10 years in NE), next in July (from 4.1 h/10 years in central Poland up to 17.8 h/10 years in NE) and in August (from 1.5 h/10 years in SW Poland up to 18.8 h/10 years in NE). In the case of average air temperature, the highest increase in the May–September period (determined on the basis of comparing average regional values in Poland in 1961–1990 and 1991–2000), the vegetation season of the cucumber, occurs in August and next in July, respectively by 1.1 and 0.9°C [Zawora 2005]. From research by Kalbarczyk [2009ab] as well, based on the 1964–2004 multiannual period, the highest increase of average air temperature in Poland is recorded in August (+0.53°C/10 years, $P < 0.01$). An increase in this meteorological element in the successive months of the cucumber vegetation season was also noticeable in other countries of central Europe: Germany [Chmielewski et al. 2004], the Czech Republic and Slovakia [Brázdil et al. 1995]. For example, in Germany (1961–2000) the highest increase in average air temperature was recorded in August (+0.64°C/10 years), so in a similar way to Poland, and in the Czech Republic (1961–1992) – in spring and summer 0.24°C/10 years for each season, and in Slovakia 0.16°C/10 years for each season.

There are no research studies concerning the effect of solar and thermal conditions on the duration of cucumber development stages and concerning the assessment of thermal requirements for the needs of reaching the beginning of fruit setting. Nevertheless, these can be compared to research on other plants [Iglesias and Minguez 1997, Chmielewski et al. 2004, Kałużewicz et al. 2010, Kalbarczyk et al. 2011]. Like in the case of the cucumber, as a result of an increase in sunshine duration and air temperature, the duration of particular development stages of different plants in different parts of Europe become shortened. For example, in Poland, the length of the period of emergence-tillering, and tillering-shooting of spring triticale, becomes shortened respectively by –1.0 and -1.5 days/10 years, and the period of heading-wax maturity, on average 3.5 times longer than the previous ones, by -5.9 days/10 years [Kalbarczyk 2009]. In Germany it has also been observed that the period of sowing- emergence becomes shortened in the case of rye (by -0.3 days/10 years, $P < 0.05$) and maize (by -1.6 days/10 years, $P < 0.01$) [Chmielewski et al. 2004]. On the basis of different scenarios of climate change, forecasts in Spain predict the vegetation season of maize will become shortened by 6 days in the Lerida region up to even 26 days in the Zamora region [Iglesias and Minguez 1997]. From research by Dragańska et al. [2008], conducted on the basis of simulations of climate change for 2050 in relation to the current climatic conditions in Poland, there will be a considerable shortening of the whole vegetation season of maize from 149 to 126 days, also all development stages will become shortened, except for the period of silking – full maturity, which will be lengthened, on average, by 20 days.

From specialist literature, solar and thermal air conditions are used not only to determine the rate of growth and development of plants but also, for example, to forecast: crop yields and the date of the beginning and the duration of cucumber harvesting [Górka 1987, Scheunemann et al. 1990, Kalbarczyk 2009a]. Krug and Liebig [1991] created a model with consideration of two meteorological elements, solar radiation and air temperature to forecast cucumber weekly crop yields. Scheunemann et al. [1990] forecast the date and length of cucumber harvesting depending on the date of sowing and on the basis of sunshine duration and air temperature. According to them, the beginning of cucumber harvesting occurs when the sum of sunshine in the vegetation season amounts to 350 h, and the sum of air temperature – 950–1000°C. Higher sums of air temperature in the cucumber vegetation season were determined by Górka [1987], according to whom in Poland they oscillate between 1055°C and 1217°C. In the opinion of Marcelis [1993], at the initial stage of the development of cucumber fruits, the effect of solar radiation on the rate of growth depends on the presence of earlier developed fruits because of the domination of internal fruits. But at the end of fruiting, a lessened intensity of solar radiation reduces the rate of growth of all fruits irrespective of their age and the presence of other cucumber fruits. Perry et al. [1986] forecast the date of cucumber harvesting on the basis of the sum of effective temperature calculated above 10, 13, 18 and 23.5°C. Akinci and Abak [1999] determined the sums of effective temperature in successive stages of cucumber vegetation: sowing-emergence, emergence-pollen production, pollen production-maturity and sowing-beginning of harvesting, using different methods and threshold values and obtained best results at the 12°C threshold, which is close to that determined in this work for the period from sowing to the beginning of fruit setting. Lederle and Krug [1985] quantitatively determined the relationship between the rate of germination and the index of emergence and air temperature by means of linear regression and of third, fourth and fifth degree polynomial regression, and determined the minimum and maximum temperature of cucumber germination. According to them, in good weather conditions, cucumber seeds germinate even after 5–10 days. According to Górka [1987], cucumbers in Poland emerge, depending on average air temperatures, quickest after 5 days at a temperature of 19°C, at the latest after 20 days – at the temperature of 11°C.

CONCLUSIONS

In the 1966–2005 period, an increase in average sunshine duration in Poland, significant in the development stages of cucumber: sowing-the end of emergence (+0.56 h/10 years, $P < 0.05$), the beginning of harvesting-the end of harvesting (+0.38 h/10 years, $P < 0.05$) and sowing-the beginning of fruit setting (+0.21 h/10 years, $P < 0.1$) for sunshine duration, and the beginning of harvesting-the end of harvesting (+0.64°C/10 years, $P < 0.01$) for air temperature, caused significant shortening of the periods: sowing-the end of emergence (-1.8 days/10 years, $P < 0.05$), the beginning of harvesting-the end of harvesting (-3.7 days/10 years, $P < 0.01$) and sowing-the beginning of fruit setting (-2.0 days/10 years, $P < 0.01$). The duration of cucumber development stages were closely dependent on both the considered meteorological elements, of an increase by 1h of average sunshine duration which shortened the stages of the plant from -0.3 to -3.5 days/10 years, and an increase by 1°C of average air temperature – from -0.6 to -4.5 days/10 years; the smallest shortening concerned the shortest of the analyzed periods: the beginning of flowering-the beginning of fruit setting. Cucumber (pickling cultivars) in Poland reached the beginning of fruit setting when the sum of air temperature, calculated above 12.2°C from the date of sowing, amounted to 236.1°C. The probability of reaching the beginning of cucumber fruit setting was between below 20% and above 60% in the case of the accepted date before 20th July, and between below 60% and above 90% for before 31st July; the lowest probability occurred in the north-western, south-western and south eastern parts of Poland, and the highest probability in the central strip of Poland and in the Sandomierz Basin (in the Rzeszów region).

REFERENCES

Akinci S., Abak K., 1999. Determination of a suitable formula for the calculation of sum growing degree days in cucumber. Acta Hort. (ISHS) 492, 273–280.

Baker J.T., Reddy V.R., 2001. Temperature effects on phenological development and yield of muskmelon. Ann. Bot. 87, 605–613.

Biuletyny Agrometeorologiczne 1965–2002. Instytut Meteorologii i Gospodarki Wodnej, Warszawa.

Biuletyny Państwowej Służby Hydrologiczno-Meteorologicznej 2003–2005. Instytut Meteorologii i Gospodarki Wodnej, Warszawa.

Brázdil R., Budìková M., Faško P., Lapin M., 1995. Fluctuation of maximum and minimum air temperatures in the Czech and the Slovak Republics. Atmospheric Res. 37, 53–65.

Bryś K., Bryś T. 2007. Zmienność warunków solarnych klimatu Wrocławia w latach 1875–2004. Pam. Puł. 144, 13–33.

Chmielewski F.M., Müller A., Bruns E., 2004. Climate changes and trends in phenology of fruit trees and field crops in Germany, 1961–2000. Agric. Forest Meteorol. 121, 69–78.

Deputat T., Marcinkowska I., 1999. Wymagania termiczne pszenicy ozimej. Pam. Puł. 118, 87–98.

Dragańska E., Szwejkowski Z., Panfil M., Orzech K., 2008. Influence of expected climate changes on phenology of corn cultivated for grain in Wielkopolska region. Acta Agrophysica 12(2), 327–336.

Górka W., 1987. Valuation of agroclimatic conditions in Poland for selected vegetables. Agric. Univ. in Szczecin. (in Polish)

Iglesias A., Minguez M.I., 1997. Modelling crop-climate interactions in Spain: vulnerability and adaptation of different agriculural systems to climate change. Mitigation and Adaptation Strategies for Global Change 1, 273–288.

Juszczak R., Leśny J., Olejnik J., 2008. Sumy temperatur efektywnych jako element prognozy agrometeorologicznej Wielkopolskiego Internetowego Serwisu Informacji Agrometeorologicznej (WISIA). Acta Agrophysica 12(2), 409–426.

Kalbarczyk E., 2009. Trends in phenology of spring triticale in response to air temperature changes in Poland. Acta Agrophysica 13(1), 141–153.

Kalbarczyk R., 2009a. Air temperature changes and phenological phases of field cucumber (*Cucumis sativus* L.) in Poland, 1966–2005. Hort. Sci. (Prague) 36(2), 75–83.

Kalbarczyk R. 2009b. Use of cluster analysis in the determination of the influence of agrotechnical dates and phenological phases on field cucumber (*Cucumis sativus* L.) yields in Poland. Acta Sci. Pol., Hortorum Cultus 8(1), 63–75.

Kalbarczyk R., Raszka B., Kalbarczyk E., 2011. Variability of the course of tomato growth and development in Poland as an effect of climate change. [In:] Climate Change – Socioeconomic Effects, Eds. J. Blanco, H. Kheradmand, InTech, 279–306.

Kałużewicz A., Krzesiński W., Knaflewski M., Lisiecka J., Spiżewski T., Frąszczak B., 2010. The effect of temperature on the broccoli yield and length of the period from head initiation to harvest. Acta Sci. Pol., Hortorum Cultus 9(3) 2010, 167–174.

Kożuchowski K., Degirmendžić J., 2005. Contemporary changes of climate in Poland: trends and variation in thermal and solar conditions related to plant vegetation. Pol. J Ecol. 53, 283–297.

Koźmiński C., Michalska B., 2004. Zmienność usłonecznienia rzeczywistego w Polsce. Acta Agrophysica 3(2), 291–305.

Krug H., Liebig H.P., 1991. Response of cucumber to climate (B). Acta Hort. (ISHS) 287, 47–50.

Lederle E., Krug H., 1985. Model experiments for energy saving temperature control for germinating cucumbers. Acta Hort. (ISHS) 156, 105–116.

Lorenc H., 2000. Analysis of the 220 year long Warsaw temperature series and the assessment of its long-term tendencies. Institute of Meteorology and Water Management. Research Material, Series: Meteorology 31. (In Polish)
Marcelis L.F.M., 1993. Effect of assimilate supply on the growth of individual cucumber fruits. Physiologia Plantarum 87(3), 313–320.
Parey S., 2008. Extremely high temperatures in France at the end of the century. Clim. Dyn. 30, 99–112.
Perry K.B., Wehner T.C., Johnson G.L., 1986. Comparison of 14 methods to determine heat unit requirements for cucumber harvest. HortScience 21(3), 419–423.
Perry K.B., Wehner T.C., 1996. A heat unit accumulation method for predicting cucumber harvest date. HortTechnology 6(1), 27–30.
Piróg J., Bykowski G., Krzesiński W., 2010. Effect of substrate type and method of fertigation control on yield size and fruit quality of greenhouse cucumber. Acta Sci. Pol., Hortorum Cultus 9(4) 2010, 99–109.
Pokladníková H., Rožnovský J., Středa T., 2008. Evaluation of soil temperatures at agroclimatological station Pohořelice. Soil & Water Res. 3(4), 223–230.
Scheunemann C., Schonhof I., Vogel G., Fröhlich H., 1990. Influence of elected factors for the timing of fruit vegetables. Acta Hort. (ISHS) 267, 339–347.
Semenov M.A., Barrow E.M., 1997. Use of a stochastic weather generator in the development of climate change scenarios. Climatic Change 35, 397–414.
Sobczyk M., 1998. Statystyka. Aspekty praktyczne i teoretyczne. Wyd. UMCS, Lublin.
Svenning J.-C., Skov F., 2006. Potential impact of climate change on the northern nemoral forest herb flora of Europe. Biodiversity and Conservation 15, 3341–3356.
Sysoeva M.I., Markovskaya E.F., Kharkina T.G., Sherudilo E.G., 1999. Temperature drop, dry matter accumulation and cold resistance of young cucumber plants. Plant Growth Regulation 28, 89–94.
Tao F., Yokozawa M., Liu J., Zhang Z., 2008. Climate-crop yield relationships at provincial scalesin China and the impacts of recent climate trends. Climate Res. 38, 83–94.
Węgrzyn A., 2007. Klasyfikacja okresów wegetacyjnych pod względem termicznym na Lubelszczyźnie w latach 1951–1990. Acta Agrophysica 9(2), 505–516.
van Minnen J.G., Onigkeit J., Alcamo J. 2002. Critical climate change as an approach to assess climate change impacts in Europe: development and application. Environ. Sci. Policy 5, 335–347.
Várallyay G., 2007. Potential impacts of climate change on agro-ecosystems. Agriculturae Conspectus Scientificus 72(1), 1–8.
Yang S., Logan J., Coffey D.L., 1995. Mathematical formulae for calculating the base temperature for growing degree days. Agric. Forest Meteorol. 74, 61–74.
Zawora T., 2005. Temperatura powietrza w Polsce w latach 1991–2000 na tle okresu normalnego 1961–1990. Acta Agrophysica 6(1), 281–287.
Żmudzka E., 2004. The climatic background of agricultural production in Poland (1951–2000). Miscellanea Geographica 11, 127–137.

ROLA USŁONECZNIENIA RZECZYWISTEGO ORAZ TEMPERATURY POWIETRZA W KSZTAŁTOWANIU ZMIENNOŚCI OKRESÓW ROZWOJU OGÓRKA (*Cucumis sativus* L.) W POLSCE, 1965–2005

Streszczenie. W Polsce uprawa ogórka polowego związana jest z określonym ryzykiem klimatycznym, polegającym na zebraniu małego plonu owoców tej rośliny. Wybór odpowiednich rejonów uprawy ogórka powinien być oparty nie tylko na warunkach glebowych i zaleceniach agrotechnicznych, ale również na znajomości tempa wzrostu i rozwoju rośliny. Celem pracy było poznanie zmienności i struktury czasowej usłonecznienia rzeczywistego i temperatury powietrza w okresie wegetacji ogórka oraz okresów rozwojowych tej rośliny w latach 1966–2005, określenie zależności między długościami okresów rozwojowych a analizowanymi elementami meteorologicznymi, a także wyznaczenie wymagań termicznych opisywanej rośliny w okresie od siewu do początku zawiązywania owoców i prawdopodobieństwa osiągnięcia tej fazy przed 20 i 31 lipca. Do realizacji tych celów wykorzystano dane pochodzące z 28 stacji doświadczalnych COBORU i 50 stacji meteorologicznych IMGW, dotyczące odpowiednio długości okresów rozwojowych ogórka oraz usłonecznienia rzeczywistego i temperatury powietrza w latach 1966–2005. Zależność między długością okresów rozwojowych a rozpatrywanymi elementami meteorologicznymi określono za pomocą analizy regresji liniowej i wielomianowej 2^{o}, natomiast wymagania termiczne ogórka w okresie od siewu do początku zawiązywania owoców ustalono metodą sumy temperatury efektywnej. Uzyskane wyniki będą mogły być wykorzystane m.in. w procesie dostosowywania produkcji polowej ogórka do zmieniających się warunków klimatycznych na terenie Polski.

Słowa kluczowe: analiza regresji, fenologia, produkcja polowa, warunki solarne i termiczne, warzywo

Accepted for print – Zaakceptowano do druku: 8.03.2012