Air temperature changes and phenological phases of field cucumber (*Cucumis sativus* L.) in Poland, 1966–2005

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ABSTRACT: The aim of the work was to determine whether and how the frequently observed trends in air temperature changes affect the dates of phenophases of field cucumber (pickling variety) cultivated in Poland. Completion of the task included gathering of monthly and seasonal data concerning average air temperature in the vegetation season of cucumber collected from 53 stations of the Institute of Meteorology and Water Management and of phenological and agrotechnical dates collected from 28 experimental stations of the Research Centre for Cultivar Testing over 1966–2005 all over Poland. Dependence between the dates of phenological phases and average air temperature, their trend and the size of the changes for the 40-year research period of 1966–2005 were determined on the basis of a linear regression analysis. Moreover, the generalized cluster analysis was employed to group years, similar in terms of the course of cucumber phenophases: emergence, flowering and fruit setting, together with thermal conditions of air in the period preceding their occurrence. If the current tendencies hold slight acceleration of phenophases: emergence (+1.2 days/10 years), flowering (+1.9 days/10 years), fruit setting (+2.1 days/10 years) and growing acceleration of the dates of harvesting (the beginning by +3.1 days/10 years, and the end by +6.4 days/10 years), it leads to the shortening of the fructification period and it may thus deteriorate conditions for achieving good cucumber yields in Poland.

Keywords: cucumber; phenology; climate change in Poland; linear trend

At the end of the 20th century and at the beginning of the 21st century there were numerous reports on fast changes occurring in air temperature both in Europe and in the world. An increase in average monthly air temperature measured by meteorological stations was confirmed, among others by Knight and Staneva (2002) or Ventura et al. (2002), in Poland by Lorenc (2000), Kożuchowski and Żmudzka (2002) and Boryczka and Stopa-Boryczka (2004).

Air temperature is one of the most important meteorological elements determining the rate of plant growth and development (Sysoeva et al. 1997; Popov et al. 2003; Ahmed et al. 2004; Chmielewski et al. 2005). Air temperature fluctuations in subsequent years modify the course of the occurrence of phenological phase dates and, thus, affect the size and quality of the yield of crop plants. Changes in the course of phenology occurring under influence of climate changes, depending on a plant species and a world region, can be totally different – from acceleration to retardation of the occurrence of phenological phases (Chmielewski et al. 2004; Lobell et al. 2007; Wang et al. 2008; Xiao et al. 2008). In the case of the cucumber, characterized by a quite early date of fruit ripening, the course of weather during emergence, flowering and fruit setting is especially important, and later largely determines the duration of fructification and the level of crop productivity. In climatic conditions of Poland average length of cucumber fructification amounts to 44 days and oscillates, in general, between 4 and 8 weeks (Kalbarczyk 2006). Publications concerning the effect of climate changes on the course of plant phenophases are comparatively rare (Ahas et al. 2000; Menzel 2000; Dalezios et al. 2002; Mazurczyk et al. 2003; Chmielewski et al. 2004; Tao et al. 2006). There are no similar studies for field vegetables, including cucumber.

The goal of the work was to determine whether and how the highly observed trends in air temperature changes affect the dates of phenophases of field cucumber cultivated in Poland.

MATERIAL AND METHODS

The work uses data from 53 stations of the Institute of Meteorology and Water Management (IMGW),

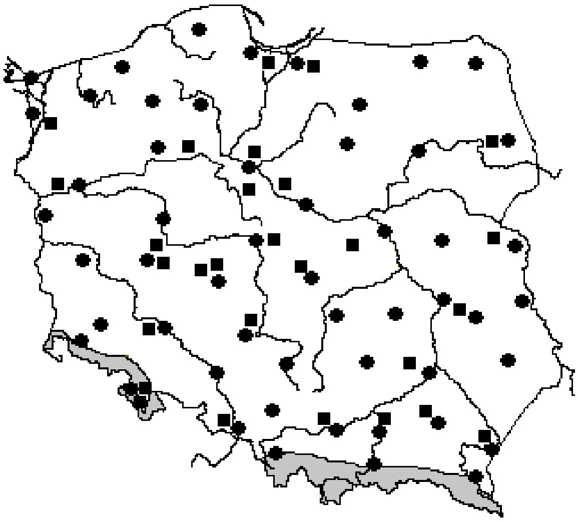

Fig. 1. Distribution of experimental stations of COBORU (■) and meteorological stations of IMGW (●)

encompassing the average monthly air temperature in Poland from the months from May to October and from the May–October season, over 1966–2005 (Fig. 1). Air temperature was collected from the Agrometeorological Bulletins (Agrometeorological Bulletins 1966–2002) and the Bulletin of State Hydrological and Meteorological Service (Bulletin of State Hydrological and Meteorological Service 2003–2005) and was partially made accessible by IMGW in Warsaw. The temporal structure of air temperature was statistically described with the use of the following: the average (X), the standard deviation (S), extreme values of the minimum (Min) and the maximum (Max), deviations from the multi-annual average over 1966–1995 (ΔTa) and the linear trend. Based on linear regression equations created for the relation of average air temperature (calculated on the basis of 53 IMGW stations) to subsequent years of the period from 1966–2005, 10-year upward temperature changes were calculated.

The work also employed the results of phenological observations of field cucumber, conducted in the whole country in 28 experimental stations of the Research Centre for Cultivar Testing (COBORU) over 1966–2005, excluding two years: 2003 and 2004, in which the tests were not conducted (Fig. 1). Phenological observations covered the following dates: the end of emergence (Ee), the beginning of flowering (Bf) and the beginning of fruit setting (Bfs). The work also used the following agrotechnical dates of cucumber: sowing (Sg), the beginning of harvesting (Bh) and the end of harvesting (Eh). In order to standardize the terms of cucumber development, each development stage determined according to COBORU was additionally described with the numerical scale of BBCH (Biologische Bundesanstalt, Bundessortenamt and Chemical Industry), binding in EU states, with the use of the principle for determining development stages of monocotyledonous and dicotyledonous plants (Meier 2001). Starting materials were collected for all, the most common in cultivation, cucumber pickling cultivars examined in a given year, which were after averaging accepted as a collective standard of the described plant. Experiments from 1966–2005 were carried out on soils for field cucumber cultivation: very good and good wheat complexes and a very good rye complex. In the cultivation mainly fully organic manuring was used, at a dose from 30 to 40 t/ha, which had been ploughed up in the autumn. Spring organic manuring, on the other hand, amounted on average to 400 kg/ha of the crops, where N and P_2O_5 were embedded at the doses of 115 and 90 kg, and K_2O at 195 kg, respectively.

In order to determine the relations between the dates, emergence, flowering and fruit setting of the cucumber, and average air temperature in May and in the period of May–June and to determine the linear trend of phenological phases over 1966 to 2005 the analysis of single regression was used. Parameters of the regression function were defined with the least squares method. The hypothesis of the significance of regression, i.e. the correlation coefficient, was examined with the *F*-Snedecor test, and the significance of regression coefficients with the *t*-Student test. The measure of matching of the regression function to empirical data was the correlation coefficient (*r*) (Sobczyk 1998).

In order to group years (1966–2003, 2005), similar as to the course of cucumber phenological phases, and accompany them with thermal conditions of air in May and the period of May–June, method of the generalized cluster analysis was used. Before the analysis the phenological dates and values of average air temperature underwent normalization based on the formula:

$$Z_j = \frac{X_j - \mathrm{Min}(X_j)}{\mathrm{Max}(X_j) - \mathrm{Min}(X_j)}$$

where:
$\mathrm{Max}(X_j)$, $\mathrm{Min}(X_j)$ – highest and the lowest j value of this variable X.

After such normalization all variables assumed values from the same interval (0; 1). The division of all the analyzed variables into clusters was carried out with the non-hierarchical method of *k*-means, in which the squared Euclidean distance was used

(Jain et al. 1999; Everitt et al. 2001). Grouping of observations with the method of *k*-means consisted in moving observations from cluster to cluster in order to maximize variance between particular clusters, at the same time minimizing variance within the analyzed clusters. For the determination of the number of clusters the test of the *v*-fold cross-validation was used. The significance of differences between isolated clusters was assessed by means of the variance analysis using the Fisher's test at the level of $P < 0.05$ (Dobosz 2001).

RESULTS AND DISCUSSION

Variability of average air temperature

In the years of 1966–2005 average air temperature in Poland in the vegetation season of field cucumber (May–October) amounted to 14.6°C. The lowest one, amounting to 12.9°C, was recorded in 1980 and the highest one, amounting to 16.3°C, in 2002 (Table 1, Fig. 2). In the May–October season a significant increase in air temperature was noted, the linear trend equalled +0.21°C per each 10 years ($r = +0.37$, $P < 0.05$), which gave an increase by 0.84°C in the whole period of 40 years. During 40 years of observations air temperature lower than average was recorded 17 times (the average for 1966–1995) and higher than average 23 times. An especially intense increase in air temperature was observed from the beginning of the 1990s, from 1992 almost all years were warmer than the average. The exception was two years: 1996, by 0.3°C colder than the average and 1993, colder by 0.2°C.

An increase in air temperature in particular months of the cucumber vegetation season in Poland was determined by three months: May, July and August (Table 1, Fig. 2). The highest significant increase in average air temperature occurred for August (+0.42°C/10 years; $r = 0.42$, $P < 0.01$), a lower one for July (+0.35°C/10 years; $r = 0.28$, $P < 0.1$) and May (+0.32°C/10 years; $r = 0.27$, $P < 0.1$). As in the case of the average air temperature from the whole season of May–October, also in the case of particular months of this period one can note a higher increase in air temperature from the beginning of the 1990s. In May from 1966–2005 air temperature higher than average was recorded 25 times, and in the last 15 years (1991–2005) – 10 times. The highest positive deviation of air temperature from the norm (the average for 1966–1995) was noted, like in the whole analyzed period, in 2002 (+3.5°C), and next in 1993 (+3.0°C). In July the highest positive deviation of air temperature from the norm was recorded in 1994 (+3.4°C) and 2002 (+2.4°C); in August, in 1992 (+3.4°C) and 2002 (+2.9°C). Analyzing deviations of air temperature in subsequent years of the period of 1966–2005 simultaneously in three months, in which its significant increase was proved, it can be said that the highest positive deviation in the whole research period occurred in 2002, and next in: 2003, 1992 and 2001.

Significant differences in the value of air temperature in Poland at the turn of the 20th and the 21st century, in subsequent years of the cucumber vegetation season (May–October), were also confirmed by Michalska and Kalbarczyk (2005), Kożuchowski and Degirmendžić (2005), and Zawora (2005). Zawora (2005), on the basis of 44 stations of IMGW, noted an increase in average air temperature in the 1990s in comparison with the normal period of 1960–1990, with the highest increase in August by 1.1°C and in July by 0.9°C, and a lower one in May and June –0.3°C each. Michal-

Table 1. Statistical parameters and linear trend of average monthly and season air temperature (in °C) in Poland, 1966–2005

Month/season	$\bar{x}$	S	Min	Max	Trend (°C/decade)
May–October	14.6	0.8	12.9	16.3	0.21**
May	13.1	1.5	9.3	16.3	0.32*
June	16.0	1.1	14.0	18.5	0.09
July	17.7	1.5	14.7	21.0	0.35*
August	17.5	1.2	15.1	20.6	0.42***
September	13.1	1.4	10.3	16.0	0.021
October	8.6	1.6	5.7	11.8	0.035

$\bar{x}$ – mean (average of 53 stations from the Institute of Meteorology and Water Management), S – standard deviation, Min – extreme minimum, Max – extreme maximum. Trends are significant with $^{*}P < 0.10$, $^{**}P < 0.05$, $^{***}P < 0.01$

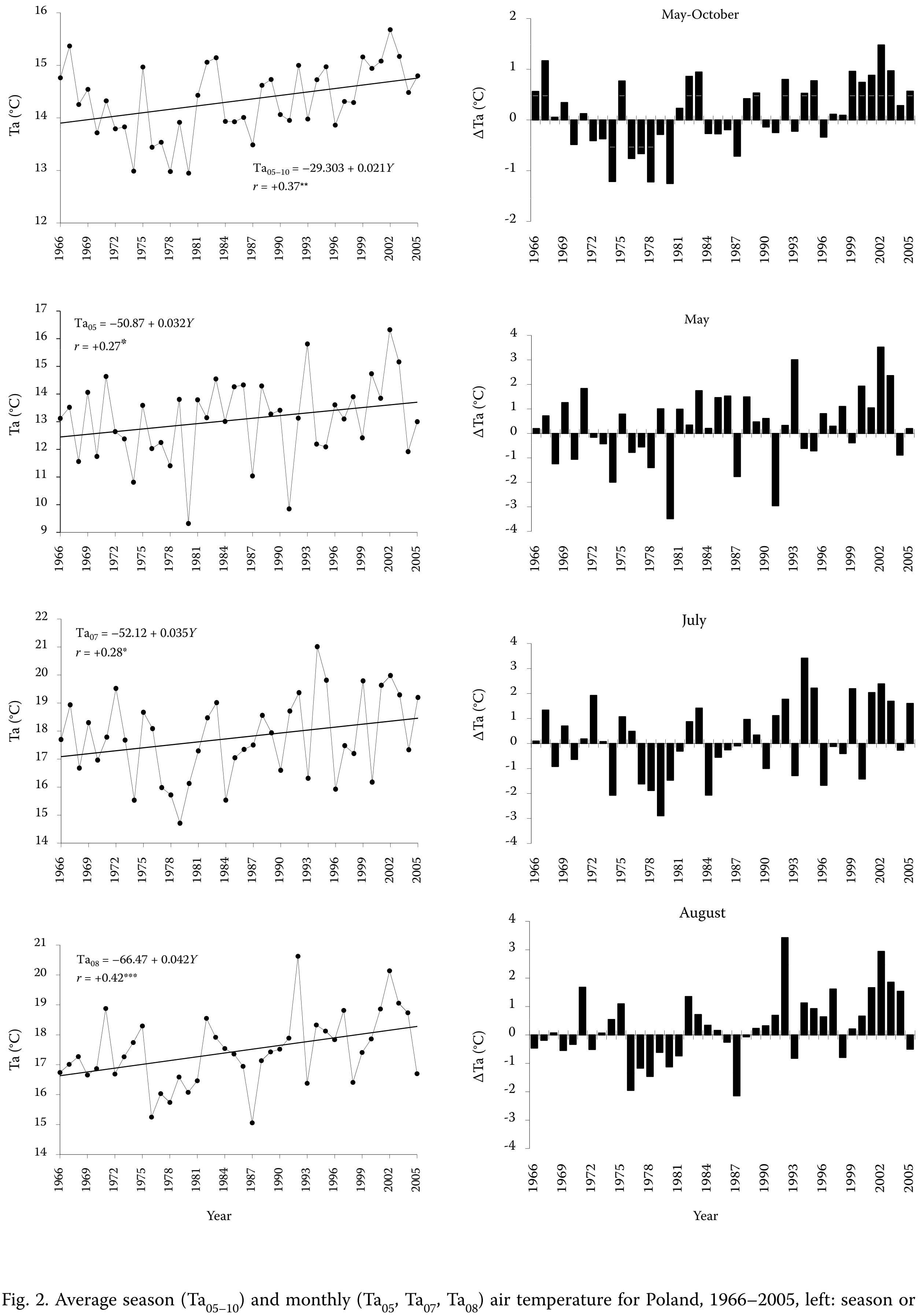

Fig. 2. Average season (Ta_{05-10}) and monthly (Ta_{05}, Ta_{07}, Ta_{08}) air temperature for Poland, 1966–2005, left: season or monthly means, right: anomalies compared to the 1966–1995 standard period. Trends are significant with $^{*}P < 0.10$, $^{**}P < 0.05$, $^{***}P < 0.01$

ska and Kalbarczyk (2005), on the other hand, proved a significant, positive trend in average air temperature in the Szczecin Lowland (North-West Poland) in May, in July and August. Kożuchowski and Degirmendžić (2005) assessed air temperature changes in five regions of Poland not only on the basis of the value of the average but also on the basis of the sums: > 0°C, > 5°C and > 15°C and the number of days with temperature > 15°C, confirming its increase in some months of the cucumber vegetation season – the highest in August by 0.6°C.

Influence of average air temperature on the course of agrophenology

Changeable thermal conditions of air in subsequent years (Table 1, Fig. 2) cause diversification of the course of development stages of both wild-growing and crop plants (Sparks et al. 2000; Chmielewski, Rötzer 2002; Chmielewski et al. 2004; Tao et al. 2006). Changes in the dates of phenophases could be observed also in Poland for the medium-early potato variety. According to Kalbarczyk and Kalbarczyk (2004) a significant, at the level of $P < 0.05$, negative trend over 1972–1995 was shown by main phenophases of the potato plant: emergence, flowering and haulm drying.

Phenological phases of field cucumber in Poland fell, on average, on the period of June–July: the end of emergence – 3rd June, the beginning of flowering – 7th July and fruit setting – 12th July (Table 2). Both the earliest and the latest dates of subsequent dates of cucumber development stages usually differed by 1–3 weeks from the average dates, and higher differences pertained to the latest dates and not the earliest ones. The analysis of the linear trend of cucumber phenophases showed a statistically significant, at the level of $P < 0.01$, negative temporal tendency, i.e., acceleration, year by year, of emergence, flowering and fruit setting. The changes were more significant in the later phenophases – for emergence average acceleration of the date amounted to 1.2 days/10 years, for flowering –1.9 days/10 years, and for fruit setting –2.1 days/10 years. The consequence of the acceleration of phenological phases, excluding a significant change in the date of sowing, was also the acceleration of cucumber harvesting – the beginning by 3.1 days/10 years and the end by as many as 6.4 days/10 years.

All the considered cucumber phenophases were correlated in a strongest way, at the level of $P < 0.01$, with average air temperature from a period of one or two months preceding an average date of their occurrence (Fig. 3). The date of the end of emergence was the most negatively correlated with average air temperature in May and the dates of the beginning of flowering and fruit setting in the period of May–June. The correlation coefficient amounted to: –0.59, –0.65 and –0.67 for emergence, flowering and fruit setting, respectively.

It results from the equations of the linear regression (Fig. 3) that an increase in air temperature in May by 1°C caused acceleration, by nearly 2 days, of the date of emergence, and average air temperature in the May–June period by approximately 4 days each, in the case of the date of flowering and fruit setting. The comparison of the date of phenophase occurrence in subsequent years of the 40-year research period with the average period (the average for 1966–1995), against a background of thermal conditions of air, showed increasingly early, year by year, occurrence of the dates of the analyzed phenophases, which was also indicated by the analysis of the trend. Since the beginning of the 1990's we were able to observe a distinct prevalence of negative deviations of the dates of phenophases in subsequent years. In the last 15 years (excluding 2003

Table 2. Statistical indexes of agrotechnical[a] dates and phenological phases of cucumber in Poland, 1966–2005

Agrophase	BBCH scale	$\bar{x}$ (DOY)	Date (day)	S (DOY)	Min (DOY)	Max (DOY)	Trend (day/decade)
Sg	[a]	137.4	16/05	1.9	134	142	n.s.
Ee	09,009	155.8	3/06	4.7	147	165	–1.2*
Bf	61,601	189.0	7/07	5.9	175	207	–1.9**
Bfs	71,701	194.5	12/07	6.0	180	214	–2.1***
Bh	[a]	204.1	22/07	7.3	191	223	–3.1***
Eh	[a]	247.3	3/09	11.1	227	271	–6.4***

$\bar{x}$ – mean (average of 29 stations from the Research Centre for Cultivar Testing), n.s. – non-significant, Sg – sowing, Bh – beginning of harvest, Eh – end of harvest, BBCH-code: 09,009 – end of emergence (Ee), 61,601 – beginning of flowering (Bf), 71,701 – beginning of fruit setting (Bfs), DOY – day of the year. Other explanations see Table 1

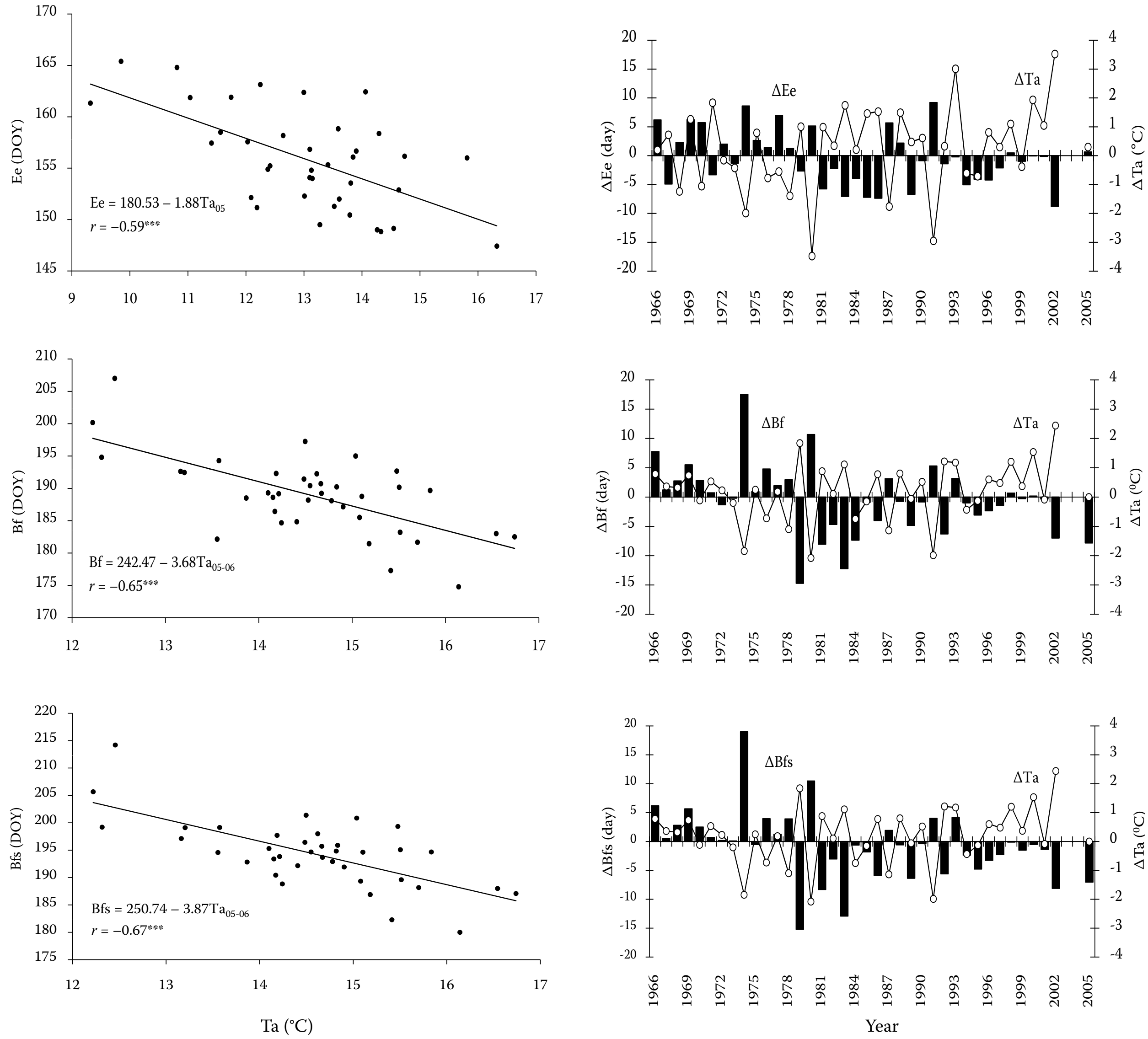

Fig. 3. Left: relation between phenological phases of cucumber (Ee, Bf, Bfs) and average air temperature (Ta_{05}, Ta_{05-06}, Ta_{05-06}) in Poland, 1966–2005 and right: deviations of the dates of phenophases (ΔEe, ΔBf, ΔBfs) and average air temperature (ΔTa_{05}, ΔTa_{05-06}, ΔTa_{05-06}) from the average over 1966–1995. Trends are significant with $^{***}P < 0.01$, DOY – day of the year

and 2004) negative deviations of the dates of phenophases from the average value were recorded as many as 9 times out of 13 cases; the highest one in 2002 – in the case of emergence by nearly 9 days, for flowering by 7 days and for fruit setting by 8 days.

Changeable duration of the periods of cucumber interphases in subsequent years is the consequence of the change of phenophase dates (Table 3). Significant changes concerning the duration of field cucumber periods over 1966–2005 were proved statistically, at the level of $P < 0.01$, for two interphases, sowing-end of emergence and beginning of harvesting-end of harvesting, which were shortened by –1.8 days/10 years and –3.7 days/10 years, respectively.

Apart from the regression analysis, the generalized cluster analysis was used to evaluate the effect

Table 3. Statistical indexes of cucumber development stages in Poland, 1966–2005

Duration of agrophase	X (day)	S (day)	Min (day)	Max (day)	Trend (day/decade)
Sg-Ee	18.5	4.3	13	27	–1.8***
Ee-Bf	33.2	4.1	21	42	n.s.
Bf-Bfs	5.5	1.5	4	12	n.s.
Bfs-Bh	9.6	3.8	4	25	n.s.
Bh-Eh	43.2	8.2	27	58	–3.7***

Explanations see Tables 1 and 2

Table 4. Statistical characteristics of cucumber phenophases and thermal conditions by separated clusters, 1966–2005

Cluster number	Number of years	Development stages (day)						Air temperature (°C)			
		mean			deviation from the average[b]			mean		deviation from the average[b]	
		Ee	Bf	Bfs	Ee	Bf	Bfs	May	May–June	May	May–June
1	11	160.2	194.1	199.0	5.3	5.9	5.6	11.6	13.7	–1.2	–0.6
2	21	152.8	186.3	191.8	–1.6	–1.5	–1.4	13.5	14.7	0.7	0.4
3	6	147.7	179.9	184.4	–6.4	–8.5	–9.5	14.3	15.5	1.5	1.2

[b]Deviation from the average over 1966–1995; other explanations see Table 1

of air temperature changes on the course of field cucumber phenophases. On the basis of the cluster analysis three sets of years characterizing a different course of cucumber phenological phases and thermal conditions of air in Poland were isolated (Table 4). The results show that all dates of phenological phases (the end of emergence, the beginning of flowering, the beginning of fruit setting) and average air temperature in May and in the May–June period statistically significantly, at the level of $P < 0.01$, differentiated isolated clusters; the date of the end of emergence and air temperature in the May–June period were the most significant.

As shown in Table 4, cluster 1 encompassed 11 years, cluster 2–21 years, and cluster 3–6 years. The earliest dates of cucumber phenological phases and, at the same time, the highest air temperatures in the analysed periods were determined for cluster 3, and the latest dates of phenophases and the lowest temperatures for cluster 1. In the years grouped in cluster 3, the earliest average dates of phenophases were recorded as follows: emergence 28th May, flowering 29th June, fruit setting 3rd July; the highest average air temperature was recorded both in May –14.3°C and in the May–June period –15.5°C. Deviations of the dates of phenological phases from the average (the average for 1966–1995) amounted to: – 6.4 days for the date of emergence, –8.5 days for the date of flowering and –9.5 days for the date of fruit setting. Air temperature deviations, on the other hand, amounted to +1.5°C in May and +1.2°C in the May–June period.

The difference in air temperature between the set of years with the latest dates of phenophases (cluster 1) and the earliest ones (cluster 3) amounted to 2.7°C in May and 1.8°C in the May–June period, and the difference in the dates of cucumber phenophases between these clusters amounted to 11 days in the case of emergence, 14 days in the case of flowering and 15 days in the case of fruit setting.

CONCLUSION

Over 1966–2005 in Poland, an increase in average air temperature in the period of the vegetation season of cucumber (May–October) was proved. The highest increase was observed in the case of air temperature in August (+0.42°C/10 years, $P < 0.01$), followed with July (+0.35°C/10 years, $P < 0.1$) and May (+0.32°C/10 years, $P < 0.1$); it contributed to acceleration of phenophases (emergence, flowering and fruit setting) and the dates of harvesting. The changes were more significant in the later phenophases – for emergence, average acceleration of the date amounted to +1.2 days/10 years, for flowering +1.9 days/10 years, and for fruit setting +2.1 days/10 years. If the current tendencies hold, i.e. slight acceleration of phenophases (emergence, flowering, fruit setting) and growing acceleration of the dates of harvesting (the beginning by +3.1 days to 10 years, and the end by 6.4 days/10 years), it will lead to the shortening of the fructification period and it may deteriorate conditions for achieving good cucumber yields in Poland.

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Received for publication October 17, 2008
Accepted after corrections January 19, 2009

Změny teploty vzduchu a fenologické fáze okurky seté (*Cucumis sativus* L.) v letech 1966–2005 v Polsku

ABSTRAKT: Cílem práce bylo určit, zda a jak často sledované tendence ve změnách teploty vzduchu ovlivňují data fenofází okurky seté (nakládačky) pěstované v Polsku. Práce zahrnovala shromáždění měsíčních a sezonních dat průměrné teploty vzduchu ve vegetační sezoně okurky z 53 stanic Ústavu meteorologie a vodohospodářství a fenologických a agrotechnických dat získaných z 28 stanic Výzkumného centra pro testování kultivarů (COBRU) z celého Polska za období 1966–2005. Závislost mezi daty fenologických fází a průměrnou teplotou vzduchu byly stejně jako trend a rozsah těchto fází během čtyřicetiletého období výzkumu (1966–2005) určeny na základě lineární regresní analýzy. Byla rovněž použita zobecněná shluková analýza, a to pro seskupení let s podobným průběhem fenofází okurky (vzcházení, kvetení, tvorba plodů) a teplotních podmínek (teplota vzduchu) v období předcházejících těmto fázím. Pokud se udrží dosavadní tendence, tj. mírné urychlení fenofází: vzcházení (+1,2 dne/10 let), kvetení (+1,9 dne/10 let), tvorba plodů (+2,1 dne/10 let) a vzrůstající urychlení dat sklizně (začátek +3,1 dne/10 let, konec +6,4 dne/10 let), povede to ke zkrácení období plodnosti a mohou se zhoršit podmínky pro dosažení dobrých výnosů okurky v Polsku.

Klíčová slova: okurka; fenologie; klimatické změny v Polsku; linearita vývoje

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