The Effect of Climate Change in Poland on the Phenological Phases of Onion (*Allium cepa* L.) between 1966 and 2005

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Summary

The aim of this paper is to analyze the changes in air temperature between 1966 and 2005 and their effect on the phenological phases of onion, on an example of a mid-late Polish variety. To this end, we used monthly and seasonal measurements of air temperature in Poland (mean, minimum and maximum) during the onion growing season (March-September), collected from 50 meteorological stations. We also used phenological and agrotechnical data from 17 experimental stations, recorded between 1966 and 2005. Based on a linear regression function, we determined the trends of phenological phases, agrotechnical dates, the agrophenological seasons for the onion, the mean and extremes for air temperature in the months from March to September, and also across the whole March to September growing season. We also determined changes over the 40 examined years of measurements. If these trends persisted - slightly earlier emergence and leaf bending onions of mid-late varieties will develop in different light, temperature and humidity. The consequence of these changes will be increasingly shorter growing seasons and probably more difficult conditions for the onion crop in Poland.

Key words

Allium Cepa L., trends in phenology of onion, air temperature changes in Poland

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Introduction

At the end of 20th century and the beginning of the 21st century, various reports confirmed rapid changes in air temperature both in Europe and in the rest of world. An increase in the monthly air temperature, measured by meteorological stations, was confirmed by Knight and Staneva (2002), Ventura et al. (2002), Chmielewski et al. (2004) and others, and in Poland by Lorenc (2000), Kożuchowski and Żmudzka (2002), Michalska and Kalbarczyk (2005) and Kożuchowski and Degirmendžić (2005). Climate change, apart from empirical data measured at meteorological stations, is confirmed by local and global climate models, satellite pictures of the Earth's surface, dendroclimatic surveys (Feliksik et al., 2005; Kuchar, 2005; Schröder et al., 2006; Wu et al., 2007; Szwejkowski et al., 2008) and examinations of snow, ice and ice cores (Masson et al., 2000; Kozlov and Berlina, 2002).

Air temperature is one of the most important meteorological elements, deciding the rate of a plant's growth and development (Sysoeva et al., 1997; Scheifinger et al., 2003; Chmielewski et al., 2005). The sensitivity of a plant to air temperature changes with the plant's age, and may also be slightly modified by some agrotechnical operations (Kalbarczyk and Kalbarczyk, 2004). The oscillations of air temperature in consecutive years modify the plot of phenological phases and thus influence the size and quality of crops. An increase in air temperature accelerates the occurrence of phenological phases in plants and may shorten the length of the growing season (Chmielewski et al., 2004; Kalbarczyk, 2006; Lobell et al., 2007; Wang et al., 2008; Xiao et al., 2008). Onion, a plant with relatively late ripening, is especially sensitive to weather conditions during emergence and leaf bending, which to a great extent affects the crop yield. In the climatic conditions of Poland, the mean time of a growing season is 145 days, with emergence observed 30 days after sowing, and the beginning of leaf bending after 120 days (Kalbarczyk, 2008). Publications on the effect of climate change on the plot of phenological phases are still not sufficient for full understanding of the process (Ahas et al., 2000; Menzel, 2000; Dalezios et al., 2002; Mazurczyk et al., 2003; Chmielewski et al., 2004; Tao et al., 2006) and there have been no such surveys concerning field vegetables, such as the onion.

Therefore the aim of this paper was to analyze changes in air temperature from 1966 to 2005 and their influence on the phenological phases of onion, using an example of Polish mid-late varieties.

Material and methods

This paper uses measurements from 50 stations of the Polish Institute of Meteorology and Water Management, covering the monthly air temperature (mean, minimum and maximum) in Poland from March to September, and across the whole season between March and September, from 1966 to 2005. Air temperature data was read from Agrometeorological Bulletins (1966-2002) and Bulletins of the State Hydrological and Meteorological Service (2003-2005), made partly available by the Polish Institute of Meteorology and Water Management in Warsaw. The temporal structure of air temperature (mean, minimum, maximum) between 1966 and 2005 was described statistically using mean (x), standard deviation (S), minimum (Min) and maximum (Max), linear trend, and also deviation from the mean for the standard period between 1966 and 1985 (ΔTa). Temperature changes per decade were calculated using linear regression equations for dependencies between the mean, minimum, and maximum air temperatures based on measurements from the 50 stations of the Polish Institute of Meteorology and Water Management.

This paper also uses the results of phenological observations of the field onion, carried out by 17 Polish experimental stations of the Research Center for Cultivar Testing (COBORU) between 1966 and 2005 (except 2003 when no observations were made). The phenological observations covered the end of emergence (Ee) and the beginning of leaf bending (Blb). This paper also uses agrotechnical dates, concerning sowing (Sg) and harvest (H). In order to standardize the onion development terms, each phase determined according to COBORU was also described on a BBCH numerical scale that is used by EU countries, using a key for the determination of phenological phases of mono- and dicotyledonous (Meier, 2001).

Information was collected for the most common mid-late varieties that were examined in a given year, which became a group standard for the described plant. Experiments between 1966 and 2005 were carried out on typical soils for onion cultivation: wheat complexes very good and good, and a very good rye complex. Full fertilization with manure was used, 30-50 t·ha^{-1}, which was ploughed in autumn; mean mineral fertilization in spring was 370 kg per ha with 120 kg N, 80 kg P_2O_5, and 170 kg K_2O.

The temporal structure and deviations from the long-term mean of agrotechnical and phenological dates for the examined plant were calculated in the same manner as for air temperature. We used a single regression analysis to determine how the times of emergence and leaf bending depended on the mean air temperature before their occurrence, and in order to determine respective linear trends for the phenological phases, agrotechnical dates and agrophenological seasons in 1966-2005. The parameters of the regression function were determined using the least square method. A hypothesis on the significance of the regression, i.e. the correlation coefficient, was examined with an F-Snedecor's test, and the significance of regression coefficients using a Student's t-test. Matching of the regression function to the empirical data was examined using the correlation coefficient (*r*) (Sobczyk, 1998).

Results

Variability of mean, minimum and maximum air temperature

From 1966 to 2005, the mean air temperature in Poland in the growing season of mid-late onion varieties (March-September) was 12.5^{0}C, and ranged from 10.7^{0}C in 1980 to 14.3^{0}C in 2002 (Table 1, Fig. 1). The coolest month of the ex-

Table 1. Statistical parameters and linear trend of average season and monthly air temperature (in ^{0}C) in Poland, 1966-2005

Season/month	X 1966–1985[a]	X 1966–2005	S	Min	Max	Trend (^{0}C per decade)
March–September	12.2	12.5	0.8	10.7	14.3	0.26**
March	2.6	2.7	2.2	–2.7	7.1	0.2 n.s.
April	7.0	7.6	1.3	4.9	11.6	0.49***
May	12.8	13.1	1.5	9.3	16.3	0.32*
June	15.9	16.0	1.1	14.0	18.5	0.09 n.s.
July	17.3	17.7	1.5	14.7	21.0	0.35*
August	17.0	17.5	1.2	15.1	20.6	0.42***
September	13.1	13.1	1.4	10.3	16.0	0.02 n.s.

X – mean (average of 50 stations from the Institute of Meteorology and Water Management), [a] standard period, S – standard deviation, Min – minimum, Max – maximum. Trends are significant with *P<0.10, **P<0.05, ***P<0.01, n.s. – non-significant.

amined season was March, with an average of 2.7^{0}C, and the hottest was July with an average of 17.7^{0}C. The extremes of air temperature over the whole growing season ranged from (mean minimum) -11.6^{0}C in March to 5.0^{0}C in July, and (mean maximum) from 16.5^{0}C in March and 30.5^{0}C in August (Table 2). The greatest fluctuations in air temperature were observed for March, with the mean standard deviation equal 2.2^{0}C, standard deviation for mean minimum 4.7^{0}C, and for mean maximum 3.5^{0}C.

In the March-September season, we observed a significant increase in mean air temperature, with a linear trend of 0.26^{0}C per 10 years (r = 0.38, P<0.05), which over 40 years amounted to around 1.0^{0}C (Table 1, Fig. 1). In the analyzed seasons we also observed a significant increase in the mean maximum air temperature by about 2.7^{0}C over the entire examined period of 1966-2005 (Table 2). In the season of March-September, the mean temperature was the same as

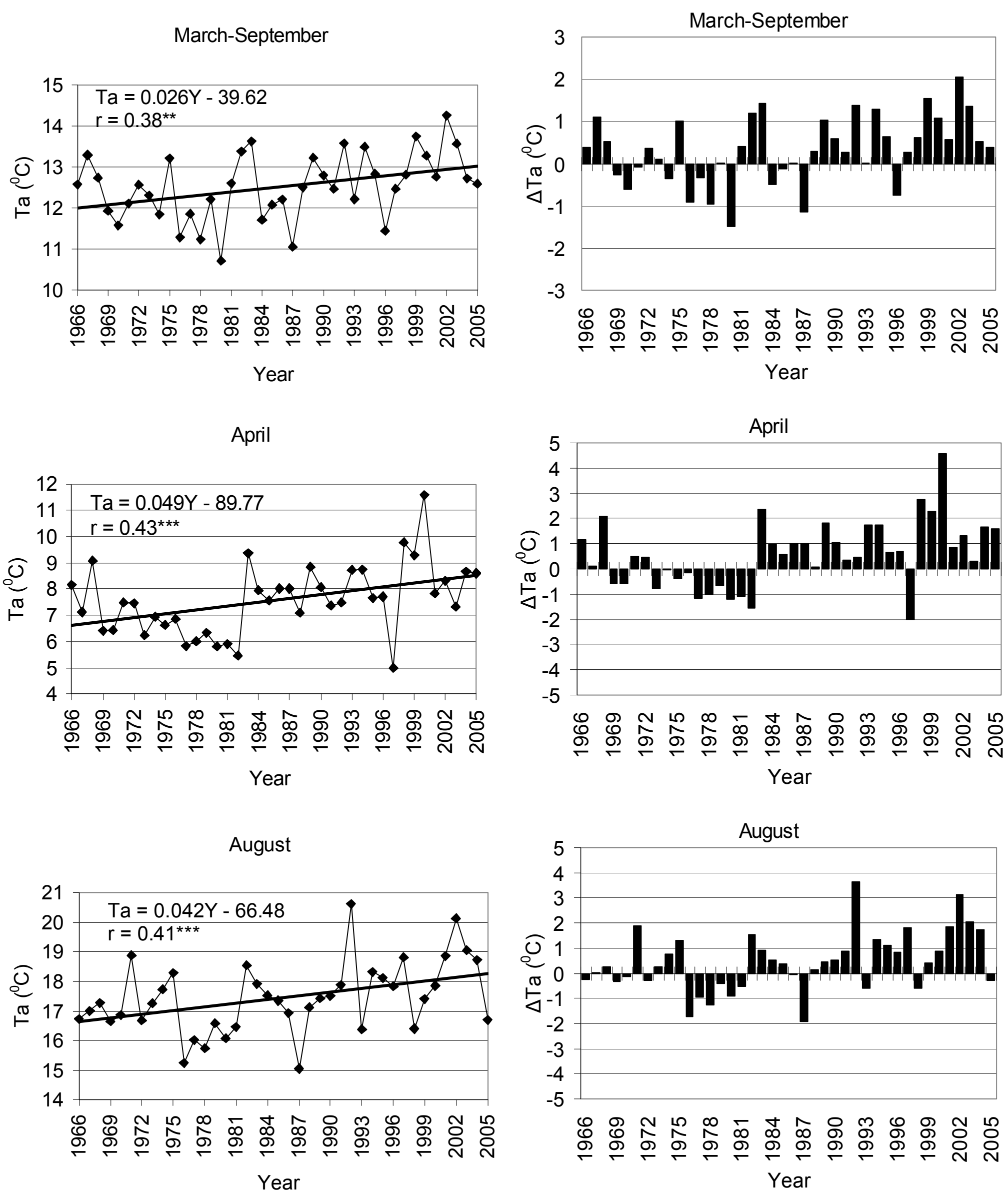

Figure 1.
Average season (Ta_{03-09},) and monthly (Ta_{04}, Ta_{08}) air temperature for Poland, 1966-2005, left: season or monthly means, right: anomalies compared to the 1966-1985 standard period. Trends are significant with **P<0.05, ***P<0.01

Table 2. Statistical parameters and the linear trend of mean minimum and maximum air temperature (^{0}C) in seasons and individual months in Poland, 1966-2005

Month	Air temperature	X	S	Min	Max	Trend (^{0}C per decade)
March–September	a	−11.8	4.4	−24.3	−6.3	0.57 n.s.
	b	31.7	1.6	28.0	36.2	0.67***
March	a	−11.6	4.7	−24.3	−5.2	0.59 n.s.
	b	16.5	3.5	7.4	22.7	0.11 n.s.
April	a	−6.5	1.5	−9.4	−3.2	0.12 n.s.
	b	2.2	2.6	18.2	28.4	0.39*
May	a	−2.0	1.7	−5.6	2.1	0.26 n.s.
	b	26.8	2.0	22.3	30.3	0.35*
June	a	2.2	1.8	−1.8	6.6	0.33 n.s.
	b	29.2	2.0	25.7	34.1	0.25 n.s.
July	a	5.0	1.4	2.5	9.6	0.45**
	b	30.4	2.4	25.1	35.8	0.44 n.s.
August	a	3.8	1.5	0.3	7.2	0.61***
	b	30.5	2.0	26.9	36.2	0.59**
September	a	−0.6	1.9	−4.8	3.4	0.45*
	b	25.8	2.2	21.0	30.0	−0.41 n.s.

a – mean minimum temperature, b – mean maximum temperature. Other explanations see Table 1.

in the standard period (mean between 1966 and 1985) three times, only 12 times was it lower, and it was higher no less than 25 times. An especially intense increase in the mean seasonal air temperature in Poland was observed from the end of 1980s, and from 1988 almost all years were warmer than during the standard period (mean for 1966-1985). The only exceptions were 1993 (mean identical with the standard period) and 1996 (0.8^{0}C colder) (Fig. 1).

The increase in mean air temperature in Poland during the onion growing season was observed mainly in four months: April, May, July and August (Table 1). The greatest significant increases in the mean air temperature occurred in April (0.49^{0}C/10 years, P<0.01) and August (0.42^{0}C/10 years, P<0.01), and smaller ones in July (0.35^{0}C/10 years, P<0.1) and May (0.32^{0}C/10 years, P<0.1). In March, June and September, the increase in mean air temperature was also positive but not statistically significant and ranged from only 0.02^{0}C/10 years in September to 0.2^{0}C/10 years in March. A significant increase in monthly air temperature in Poland was confirmed not only by the mean air temperature, but also by the mean extrema (Table 2). An increase in the mean minimum air temperature was observed at the end of the onion growing season, in July (0.45^{0}C/10 years, P<0.05), August (0.61^{0}C/10 years, P<0.01) and in September (0.45^{0}C/10 years, P<0.1), and an increase in mean maximum in April (0.39^{0}C/10 years, P<0.1), May (0.35^{0}C/10 years, P<0.1) and August (0.59^{0}C/10 years, P<0.05).

Similar to the mean air temperature for the whole season March-September, the individual months from this season also showed a stronger increase in air temperature from the end of 1980s. In April, the mean air temperature was observed 27 times to be higher than the mean in the standard period, and of these, 19 were in the last twenty years (1986-2005) (Fig. 1). The greatest difference from the norm from 1966-1985 was observed in 2000 (4.6^{0}C), and then in 1998 (2.8^{0}C).

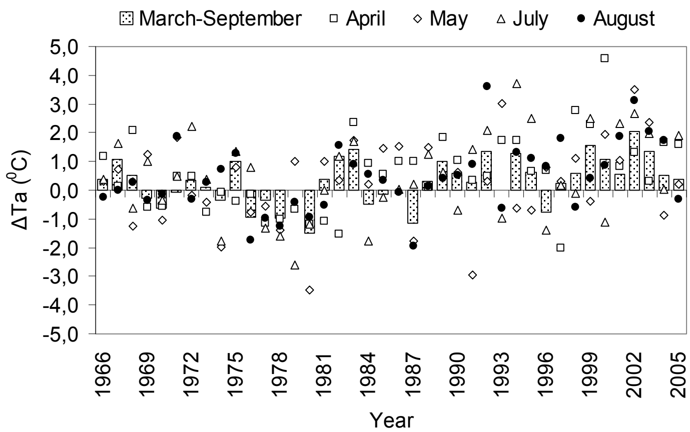

Figure 2. Anomalies from the norm (average in 1966-1985) for the mean air temperature from March to September, and in some months of the examined season – those with the observed significant linear trend – in April, May, July and August (Poland)

In August, that is the month with an equally high increase in the mean air temperature as April, we observed a mean temperature higher than the norm 27 times, with 15 in the last twenty years. The highest positive deviation from the norm was recorded in 1992 (3.6^{0}C), and the next in 2002 (3.1^{0}C).

Figure 2 presents the deviations of the mean air temperature from the norm (mean for 1966-1985), concerning the whole season March-September and some individual months for which we found a significant linear trend (April, May, July and August). Only eight years out of the examined 40, that is 1967, 1983, 1988, 1989, 1992, 2001, 2002 and 2003, had a parallel positive deviation from the mean air temperature in the whole season and the four aforementioned months. In these eight years, three years had the greatest positive deviation in May (1988, 2002, 2003), two years in April (1983, 1989), two years in July (1967, 2001) and 1 year in August (1992). For example, in the warmest March-September season, which occurred in 2002, mean air temperature in April was 1.3^{0}C higher than in the standard period (1966-1985), in May by 3.5^{0}C, in July by 2.7^{0}C and in August by 3.1^{0}C.

The effect of the mean air temperature on the plot of phenophases

Phenological phases of mid-late onion varieties in Poland occur on average in May and August; the end of emergence on 10 May, and the beginning of leaf bending on 4 August (Table 3). The earliest and the latest observed dates differed usually by one to two weeks from the mean dates, and the greatest differences concerned the latest years. The analysis of the linear trend showed a slight annual acceleration of emergence and leaf bending despite the significant increase in mean air temperature in spring (April and May) and summer (July and August) (Table 1). The trend of both these phenological phases was significant at P<0.05 – the emergences were earlier at a rate of 0.8 days/10 years, and leaf bending 1.1 days/10

Table 3. Statistical indexes of agrotechnical[b] dates and phenological phases of onion in Poland, 1966-2005

Agrophase	BBCH scale	X (DOY) 1966–1985[b]	X (DOY) 1966–2005	Date (day)	S (DOY)	Min (DOY)	Max (DOY)	Trend (day/10a)
Sg	b	96.5	100.4	9–04	6.9	26–03	22–04	–0.3 n.s.
Ee	09 009	133.4	130.6	10–05	5.0	2–05	21–05	–0.8**
Blb	48 408	221.1	218.0	4–08	7.5	27–07	17–08	–1.1**
H	b	250.2	246.2	2–09	6.5	21–08	15–09	–0.4 n.s.

X – mean (average of 17 stations from the Research Centre for Cultivar Testing), Sg – sowing, H – harvesting, BBCH–code: 09 009 – end of emergence (Ee), 48 408 – beginning of leaf bending (Blb). DOY – day of the year. Other explanations see Table 1.

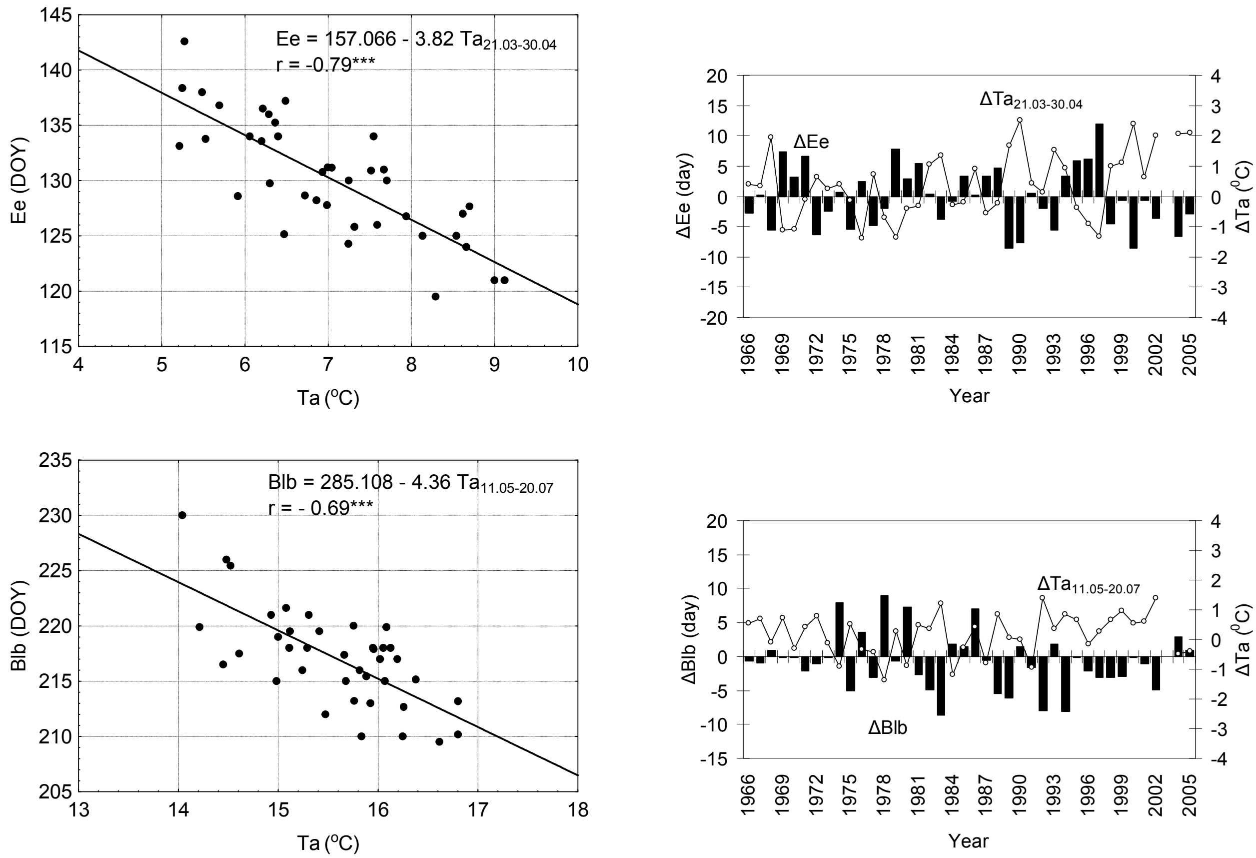

Figure 3. Left: relation between phenological phases of onion (Ee, Blb) and mean air temperature ($Ta_{21.03\text{-}30.04}$, $Ta_{11.05\text{-}20.07}$) in Poland, 1966-2005 and right: deviations of the dates of phenophases (ΔEe, ΔBlb) and mean air temperature ($\Delta Ta_{21.03\text{-}30.04}$, $\Delta Ta_{11.05\text{-}20.07}$) from the average over 1966-1985. Correlation coefficients are significant with ***P<0.01. DOY – day of the year

years. The times of sowing and harvest of onion had an insignificant negative trend, as observed between 1965 and 2005.

The examined onion phenophases were most correlated at P<0.01, with the mean air temperature from the period of 6-9 weeks before the earliest date of their occurrence (Fig. 3). The time of end of emergence was the strongest and negatively correlated with the mean air temperature between 21 March and 30 April, and the beginning of leaf bending between 11 May and 20 July. The correlation coefficients for these dependences were -0.79 and -0.69, respectively. The equations of linear regression show that the increase in mean air temperature by 1^0C between 21 March and 30 April, caused end of emergence to occur 3.8 days earlier, and leaf bending 4.4 days earlier, between 11 May and 20 July. The comparison of the times of phenophases between 1966 and 2005 with the standard period (1966-1995) in the light of the mean air temperature plot, showed earlier and earlier occurrence of the phenophases (Fig. 3), similar to the results of the analysis of the trends of emergence and leaf bending (Table 1). In the last twenty years (except 2003), we observed negative deviations 11 times for the emergences (from the standard period), and 15 times for leaf bending. With regard to emergence, the greatest negative deviations from the mean were observed in 1989, 2000 (by 8.6 days each), 1990 (7.6 days) and 2004 (6.5 days). The greatest positive deviation of mean air temperature from the norm occurred in 1990, between

Table 4. Statistical indexes of onion development stages in Poland, 1966-2005

Duration of agrophase	X (day)	S (day)	Min (day)	Max (day)	Trend (day/10a)
Sg–Ee	31.8	6.2	16	45	−1.7*
Ee–Blb	85.6	8.3	72	105	−0.7*
Blb–H	28.9	6.3	16	43	−1.2 n.s.

Other explanations see Tables 1 and 3.

21 March and 30 April, and was 2.5⁰C. The greatest negative deviation from the norm of the date of leaf bending, which occurred in 1983, was accompanied by a mean air temperature greater by 1.2⁰C than the norm, between 11 May and 20 July. Considerable deviations were also observed in 1994 (8.1 days) and 1992 (7.9 days), which were accompanied by a mean air temperature higher than in the standard period by 0.4 and 1.4⁰C, respectively.

The consequence of the changes in the time of phenophases is the changing duration of onion development stages (Table 4). Significant changes in the length of these stages between 1966 and 2005 were proved statistically for two interphases, sowing – end of emergence, and end of emergence – beginning of leaf bending. The former shortened by 1.7 day/10 years ($P<0.1$), and the latter by 0.7 day/10 years ($P<0.1$).

Discussion

Significant differences in air temperature, measured at meteorological stations in Poland between the 20th and 21st centuries for the individual months of the growing season of mid-late onion varieties (March-September) have been confirmed by e.g.: Kożuchowski and Degirmendžić (2005), Michalska and Kalbarczyk (2005) and Zawora (2005). Zawora (2005), using data from 44 stations of the Institute of Meteorology and Water Management, observed a 0.6⁰C increase in the mean annual air temperature in Poland in the 1990s, in comparison with a base period of 1961-1990; the greatest in August (by 1.1⁰C) and April (1.0⁰C), and the smallest in September (by 0.1⁰C). Kożuchowski and Degirmendžić (2005) analyzed the changes in air temperature between 1991 and 2000 compared with a base period between 1931 and 1960 in five regions of Poland, and not only using means, but also sums >0, >5 and >15⁰C and the number of days with temperature <0⁰C and >15⁰C, confirming its increase in the consecutive months of the onion growing season. Their studies (Kożuchowski and Degirmendžić, 2005) indicated that in all regions of Poland one can observe an increase in the sums of air temperature (>0, >5, >15⁰C), and the greatest concerning the sums >0⁰C in the area of south-western Poland. Michalska and Kalbarczyk (2005) showed a significant positive trend of mean air temperature in Szczecin Lowland (NW Poland) in almost all the months of the onion growing season with the greatest in August. An increase in air temperature in the consecutive months of the onion growing season was observed also in other European countries, e.g.: in Germany (Chmielewski et al., 2004; Schröder et al., 2006), Italy (Ventura et al., 2002), Czech Republic and Slovakia (Brázdil et al., 1995). For example, in Germany (between 1961 and 2000), the greatest increase in the mean air temperature was observed in August (by 0.64⁰C/10 years) (Chmielewski et al., 2004), which was similar to changes recorded in Poland. In the Czech Republic (1961-1992), an increase in mean air temperature in spring and summer was 0.24⁰C/10 years, and in Slovakia 0.16⁰C/10 years (Brázdil et al., 1995).

The changing air temperature caused differences in the plot of development in plants, both wild and cultivated (Ahas et al., 2000; Sparks et al., 2000; Chmielewski and Rötzer, 2002; Chmielewski et al., 2004; Kalbarczyk and Kalbarczyk, 2004; Tao et al., 2006). Changes in the dates of phenophases of cultivated plants were observed in Poland not only for onions, but also for mid-early potatoes. According to Kalbarczyk and Kalbarczyk (2004) a significant negative trend (at $P<0.05$) between 1972 and 1995 was visible for the main phenophases of potato: emergence, flowering and haulm drying. Similar to emergences and leaf bending of the mid-late onion varieties observed in Poland, and also in other areas of the world, a negative correlation between the date of phenophases and air temperature has been recorded. It not only concerned the mean air temperature, but also minimum and maximum (Ahas et al., 2000; Kozlov and Berlina, 2002; Chmielewski et al., 2004; Lu et al., 2006; Schieber, 2007). A negative dependence between the phase of full blossom in some plants, such as *Pulmonaria officinalis, Dentaria bulbifera, Dalium odoratum, Veronica officinalis, Mycelis muralis* and *Campanula trachelium,* and the sums of air temperature in the period prior to blossom, was also proved in middle Slovakia, with the most pronounced dependence between *Dentaria bulbifera* and the temperature in March-April (r = -0.91, $P<0.01$, n = 10) (Schieber, 2007). Also in Russia, on the Kola Peninsula, between the date of a given phenophase in some plants and the mean air temperature between June and August, a negative dependence was observed, i.e. for the ripening of cloudberry (r = -0.69, $P<0.001$) and ripening of cowberry (r = -0.52, $P<0.001$) (Kozlov and Berlina, 2002). Similar surveys have also been performed in urbanized areas, e.g. in the city of Beijing where research concerned the dependences between the blossom of four tree species (*Prunus davidina, Prunus armeniaca, Syringa oblata, Robinia pseudoacacia*) and the mean, minimum and maximum air temperature in the 30 day long period before this phenophase. The time of blossom was 2-3 days earlier per 10 years, depending on the species (Lu et al., 2006). The earlier phases, resulting from climatic warming, have also been reported in Germany (Chmielewski et al., 2004), Estonia (Ahas et al., 2000) and many other countries (Brázdil et al., 1995, Kozlov and Berlina, 2002). An increase of mean air temperature in Germany by 1.0⁰C, between February and April, resulted in the earlier blossom of apple and cherry, 4.6 and 4.7 days/10 years, respectively (Chmielewski et al., 2004). In Estonia, the same increase in mean air temperature before a phenophase, depending on the species and the region of that country, resulted in an earlier pollination of maple (2.1

days/10 years) and earlier waxy ripeness of rye by a remarkable 6.9 days/10 years (Ahas et al., 2000).

The observed reactions of cultivated plants to the changes in phenology induced by climate changes are radically different depending upon the examined species: sometimes the crop increases, sometimes it reduces (Tao et al., 2006; Wang et al., 2008; Xiao et al., 2008). For example, an increase in the maximum air temperature in spring in middle China actually results in an earlier time of sowing, blossom and ripening of wheat, which decreases the crop. The same air temperature in spring in the NE part of that country also results in an earlier time of sowing and blossom, but also in a later time of ripening of corn which consequently increases the crop (Tao et al., 2006).

Conclusion

Between 1966 and 2005 in Poland, we observed a significant increase in the monthly mean air temperature during the onion growing season (March-September), the greatest change in temperature occurring each April (0.49^0C/10 years, $P<0.01$), the second greatest each August (0.42^0C/10 years, $P<0.01$) and the next greatest each July (0.35^0C/10 years, $P<0.1$), which lead to an earlier emergence and leaf bending each year. The size of these changes was greater the later in the phenophase they concerned. Emergence was earlier by 0.8 day/10 years, and leaf bending by 1.1 day/10 years. The time of emergence was most correlated with the mean air temperature between 21 March and 30 April, and the time of leaf bending between 11 May and 20 July. An increase in mean air temperature by 1^0C in the analyzed seasons caused emergence to occur 3.8 days earlier and leaf bending 4.4 days earlier. If these trends persisted - slightly earlier emergence and leaf bending onions of mid-late varieties will develop in different light, temperature and humidity. The consequence of these changes will be increasingly shorter growing seasons and probably more difficult conditions for the onion crop in Poland.

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