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TRENDS IN PHENOLOGY OF SPRING TRITICALE IN RESPONSE TO AIR TEMPERATURE CHANGES IN POLAND

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Abstract. The effect of air temperature on variability of phenophase dates and the length of spring triticale interphases was investigated by means of simple linear regression analysis. An increase in the mean temperature in Poland observed in 1965-2004, the biggest for the mean temperature in August (+0.53°C/10 years, P<0.01) and April (+0.50°C/10 years, P<0.01), caused significant, with P<0.01, acceleration of phenophase dates. The bigger the size of changes, the later the phenophase it concerned – for beginning of tillering the average acceleration of the date amounted to +1.8 day/10 years, for beginning of shooting +3,4 day/10 years, for beginning of heading +4.2 days /10 years, and for wax maturity as many as +10.2 days /10 years. The duration of periods of emergence-tillering and tillering-shooting in 1984-2004 became shortened by, respectively, -1.0 day/10 years and –1.5 day/10 years, and the period of heading-wax maturity by –5.9 day/10 years. On the basis of the generalized method of cluster analysis it was determined that the biggest yields of spring triticale crops can be obtained with earlier than average dates from sowing to beginning of heading, and close to average dates of wax maturity and harvesting, and also longer than average interphases: sowing-emergence, emergence-tillering, shooting-heading and periods: sowing-wax maturity and sowing-harvesting, and with close to average duration of periods: heading-wax maturity and wax maturity-harvesting.

Keywords: spring triticale, cluster analysis, phenophase, development period, yield

INTRODUCTION

Out of approximately 3.5 million ha of the area of triticale cultivation in the world, nearly one third is represented by Poland (1.2 million ha), of which about 110 thousand ha is the spring form (FAO 2004). Although economic importance of spring triticale is still relatively low, it is a species which, to a large extent, can replace wheat and spring barley – in terms of health properties, nutritive value of grain (especially for feeding pigs and poultry), volume of crop productivity and soil requirements it is competitive when compared to other spring crops (Arseniuk 2002).

The course of main phenological dates of spring triticale depends on the variability of weather conditions in the period which precedes them. At the end of the 20th century, there were numerous reports corroborating fast changes occurring in air temperature, measured by meteorological stations. An increase in mean monthly temperature, determined on the basis of changes occurring in this meteorological element in the second half of the 20th century in Poland, was confirmed by, e.g., Lorenc (2000), Boryczka and Stopa-Boryczka (2004), Fortuniak *et al.* (2001), Kożuchowski and Żmudzka (2002), Michalska and Kalbarczyk (2005).

Weather variability in successive years causes fluctuations of phenological dates from year to year, which strongly affects the volume of yields of crop plants, including triticale (Kalbarczyk 2002, 2006, Wang *et al.* 2008, Xiao *et al.* 2008). Observed reactions of crop plants to changes in phenological dates, occurring under the influence of climate changes, depending on the species and the region of the world are completely different – from an increase to a decrease in obtained yields (Wang *et al.* 2008., Xiao *et al*. 2008). In the case of spring triticale, which is characterised by quite late maturing, the course of weather is especially important at the end of vegetation (heading-wax maturity). Publications on the effect of climate changes on the course of agrophenophases of crop plants are relatively few (Gao *et al.* 1995, Chmielewski *et al.* 2004, Tao *et al.* 2006, Wang *et al.* 2008, Xiao *et al.* 2008); there are no such studies concerning spring triticale.

The goal of the work was to determine whether and how significantly the highly observed trends in air temperature changes affect phenological dates of spring triticale cultivated in Poland.

MATERIAL AND METHODS

The material for the analysis comprised the results of phenological observations for the standard of spring triticale (averages of all varieties in a given year), carried out at 39 experimental stations of the Research Centre for Cultivar Testing (COBORU) in whole Poland, in 1984-2004. These observations included dates of emergence (P_{09}), beginning of tillering (P_{21}), beginning of shooting (P_{31}), beginning of heading (P_{51}), wax maturity (P_{85}), and also agronomic dates – sowing (So) and harvesting (Ha). Designation of each phenological date given in brackets complies with the BBCH codes (Compendium …2002). Data from 56 stations of the Institute of Meteorology and Water Management (IMGW), including mean monthly air temperature of the months from March to September from 1965-2004, were also used.

Air temperature was characterised statistically giving the following values: the multi-year average, the deviations from multi-year average, the average in particular years from all 56 stations of IMGW and a trend in subsequent years, the average from the period from March to September in a structure of a month, two months and the whole period of March-September. For agrophenological dates and periods the following values were calculated: the average, the standard deviation, the minimum value, the maximum value and the linear trend.

The effect of air temperature on the dates of phenophases and the duration of interphases was investigated with the use of a simple linear regression analysis. The correlation coefficient r (0;1) served as a measure whether a regression function fitted the empirical data. Parameters of a regression function were determined with the method of least squares. The hypothesis of significance of regression, i.e. the correlation coefficient, was examined with the F-Snedecor test, and the significance of regression coefficients with the Student t-test (Sobczyk 1998).

Determination of the course of phenological dates and the duration of interphases conducive to the biggest yields of spring triticale was conducted on the basis of the generalized method of cluster analysis. Before the analysis the yield, the dates and the duration of interphases underwent normalisation based on the formula:

$$Z_j = \frac{X_j - Min(X_j)}{Max(X_j) - Min(X_j)} \tag{1}$$

where: $Max(X_j)$ and $Min(X_j)$ denote respectively the highest and the lowest value j of this variable. After such normalisation, all variables assumed values from the same range (0; 1) (Dobosz 2001).

The division of all observations of the analysed variables into clusters was conducted by means of the non-hierarchical method of k-means, in which the Euclidean distance was used, i.e., the geometric distance in multidimensional space (Hartigan 1975, Holden and Brereton 2004). Grouping of observations with the method of k-means consisted in moving the observations from a cluster to another cluster to maximise variance between particular clusters, at the same time minimising variance inside the examined clusters. The test of the v-fold cross-validation was used to determine the number of clusters. The significance of differences between isolated clusters was assessed by means of the variance analysis using the Fisher test at the level of $P<0.05$ (Dobosz 2001).

All statistical calculations were made using the statistical package “Statistica 8.0”.

RESULTS AND DISCUSSION

Average air temperature of months from March to September in 1964-2004 in Poland amounted to 12.5°C. In subsequent years one could observe an increase in its value, the linear trend amounted to +0.31°C per each 10 years (P<0.01), which in the whole multi-year period gave an increase by 1.24°C (Fig. 1). An especially high increase in air temperature was observed from the end of the 1980s, from 1988 almost all years were warmer than the multi-year average. The exception were years 1996, which was colder by 1.0°C than the average, and 1993 – colder by 0.3°C. In particular months of the triticale vegetation season, in which there occurred a statistically significant air temperature trend, an increase in temperature was higher than for the average from the whole period from March to September (Fig. 2). The highest increase occurred in the case of average temperature of August (+0.53°C/10 years, P<0.01) and April (+0.50°C/10 years, P<0.01). It was also statistically confirmed that there occurred an increase in May (+0.43, P<0.05) and July (+0.36, P<0.1). Like in the case of average temperature from the whole period from March to September, also in the case of particular months we could observe a higher air temperature increase from the end of the 1980s. In April positive deviations from multi-year average prevailed already from 1983, after which temperatures lower than average occurred until 2004 only 5 times, while only in 1997 the temperature was lower than average by –2.5°C. In the remaining cases the difference did not exceed –0.5°C. In August the prevalence of positive deviations could be observed from 1989, after which negative deviations until 2004 occurred twice, in 1993 and 1998, equalling approximately –1.0°C each. In months in which an increase in temperature was not so high, that is in May and in July, the prevalence of positive deviations was visible since the mid-1990 s.

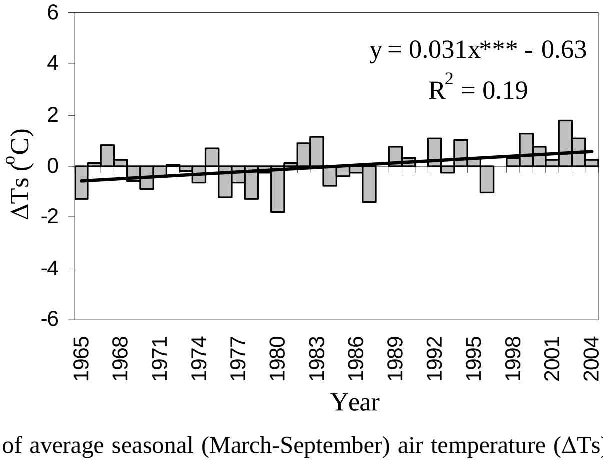

Fig. 1. Anomalies of average seasonal (March-September) air temperature (ΔTs) for Poland compared to mean of the 1965-2004 standard. Significance level: *** P<0.01

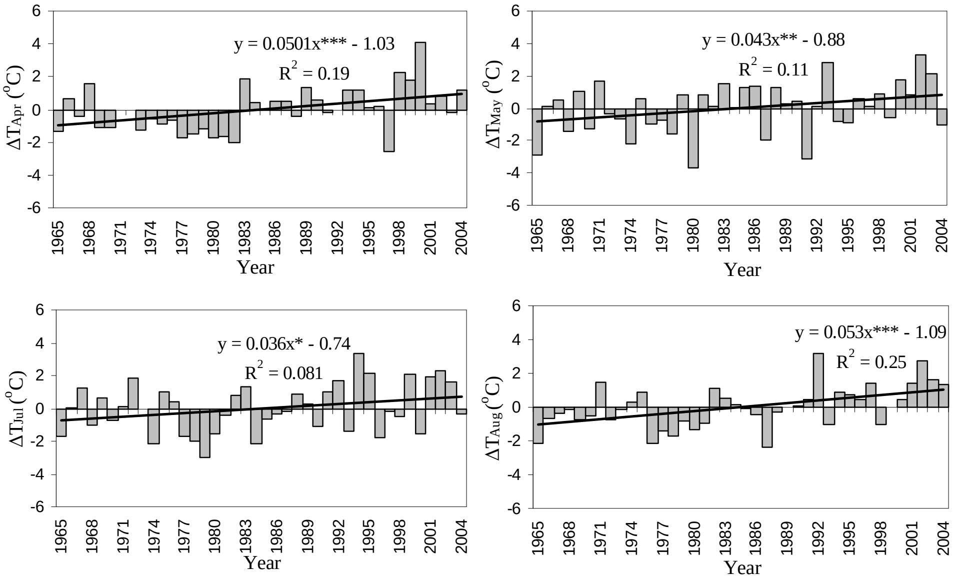

Fig. 2. Anomalies of average monthly air temperature (ΔT_{Apr}, ΔT_{May}, ΔT_{Jul}, ΔT_{Aug}) compared to means of the 1965-2004 standard period for Poland, equal to: 7.5°C (April), 13.0°C (May), 17.7°C (July), 17.4°C (August). Significance level: *** P<0.01, ** P<0.05, * P<0.1

Weather conditions, changing in subsequent years, primarily thermal conditions, caused diversification of the course of plant development stages, both for wild growing plants and for crop plants (Lomas 1995, Sparks *et al.* 2000, Chmielewski and Rötzer 2002, Chmielewski *et al.* 2004, Tao *et al.* 2006). Changes in the dates of phenophases could be observed also in spring triticale cultivated in Poland (Kalbarczyk 2002, Raszka 2002).

In 1984-2004, the main phenological dates of spring triticale (emergence: P_{09}, beginning of tillering: P_{21}, beginning of shooting: P_{31}, beginning of heading: P_{51}, wax maturity: P_{85}) on average occurred in the period from the third decade of April to the first decade of August (Fig. 3). In the particular years, considerable diversification of the dates of phenophases was observed – the earliest and the latest dates of emergence, beginning of shooting and beginning of heading differed by over one month, and the earliest and the latest date of wax maturity by over two months. It was observed that in subsequent years there occurred significant, with P<0.05, acceleration of almost all dates of phenophases, excluding emergence. The bigger the size of changes, the later phenophase it concerned: for tillering average acceleration of the date amounted to 1.8 day/10 years, for shooting 3.4 days/10 years, for heading 4.2 days/10 years and for wax maturity as many as 10.2 days/10 years. Increasingly early phenological dates occurred since the end of the 1980s, just as did the changes in the course of air temperature in subsequent years.

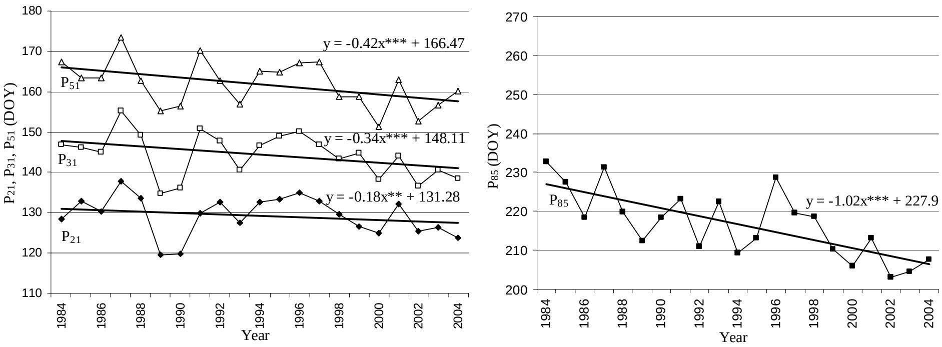

Fig. 3. Average dates of beginning of tillering (P_{21}), beginning of shooting (P_{31}), beginning of heading (P_{51}) and wax maturity (P_{85}) of spring triticale in Poland, 1984-2004. DOY: day of the year, significance level of trend: *** $P<0.01$, ** $P<0.05$, * $P<0.1$

All considered phenophases were most strongly correlated, with $P<0.01$, with average air temperature from the period of approximately two months preceding the average date of their occurrence (Tab. 1). The dates from emergence to beginning of shooting were most strongly correlated with average temperature from March and April, those of beginning of heading with temperature from April and May, and wax maturity with temperature from June and July. The correlation coefficient oscillated from -0.61 to -0.74, an increase in air temperature by 1°C caused the acceleration of the dates from emergence to beginning of shooting by approximately 2-3 days, the date of beginning of heading by 4 days, and wax maturity by over 5 days.

Table 1. Correlation coefficients (r) between average air temperature in a chosen period (month or season) ($T_{m/s}$) and the date of phenophases (P) or the duration of development periods (Dp) of spring triticale in Poland, 1984-2004

P	Month or season	r (P, $T_{m/s}$)	Temperature response ($\Delta P/\Delta T_{m/s}$) (day/°C)
P_{09}	Mar-Apr	–0.65***	–2.8
P_{21}	Mar-Apr	–0.61***	–2.4
P_{31}	Mar-Apr	–0.61***	–2.6
P_{51}	Apr-May	–0.74***	–4.0
P_{85}	Jun-Jul	–0.63***	–5.3
Dp		r (Dp, $T_{m/s}$)	($\Delta Dp/\Delta T_{m/s}$) (day/°C)
P_{09}-P_{21}	May	–0.31***	–0.7
P_{21}-P_{31}	May	–0.42***	–1.0
P_{51}-P_{85}	Jun-Jul	–0.59***	–4.2

ΔP – date of phenophase change (day), ΔDp – duration of development period change (day), ΔT – air temperature change (°C), m s^{-1} – month or season, significance level *** $P<0.01$, BBCH-code: P_{09} – emergence, P_{21} – beginning of tillering, P_{31} – beginning of shooting, P_{51} – beginning of heading, P_{85} – wax maturity.

Comparison of the dates of the occurrence of phenophases in subsequent years with the average multi-year date showed that even in a relatively short period, namely 20 years, of conducting phenological observations of spring triticale from year to year we can notice increasingly early average dates of phenophases. Since the end of the 1990s distinct prevalence of negative deviations of the dates of phenophases in subsequent years, in comparison to their average multi-year averages from 1984-2004, was visible (Fig. 4).

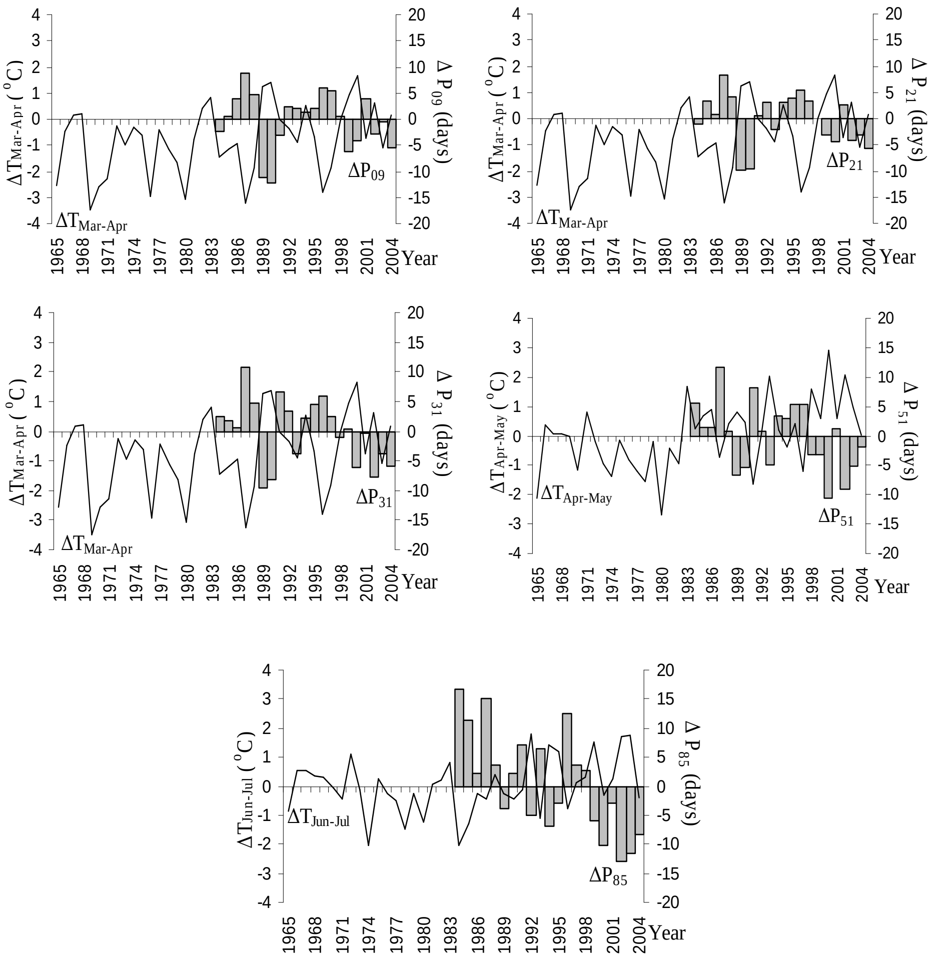

Fig. 4. Anomalies in emergence (ΔP_{09}), beginning of tillering (ΔP_{21}), beginning of shooting (ΔP_{31}), beginning of heading (ΔP_{51}) and wax maturity (ΔP_{85}) of spring triticale and in average air temperature from March to April ($\Delta T_{Mar\text{-}Apr}$), from April to May ($\Delta T_{Apr\text{-}May}$), from June to July ($\Delta T_{Jun\text{-}Jul}$) in Poland, 1965-2004

A consequence of the changes in the dates of phenophases is changeable duration of phenophases in subsequent years (Fig. 5). Differences in the length of development periods in particular years may amount to even over 20 days in the case of interphases from emergence to heading, which lasted on average 15-17 days (P_{09}-P_{21}, P_{21}-P_{31}, P_{31}-P_{51}) and over 50 days for the period of heading-wax maturity, which lasted on average 54 days. The length of the periods of emergence-tillering and tillering-shooting in 1984-2004 shortened by, respectively, –1.0 day/10 years and –1.5 day/10 years, and the period of heading-wax maturity, on average 3.5 times longer than the previous ones, shortened by –5.9 days/10 years. Only for the period of shooting-heading no statistically significant changes in the duration were confirmed, which probably results from a similar value of acceleration of the dates of shooting and heading. The analysis of deviations of period duration in subsequent years in comparison with the average multi-year value showed that also in the case of the length of development periods one could observe their distinct shortening, especially at the end of the investigated multi-year period (Fig. 6). In the case of the period of emergence-tillering, periods lasting shorter than average occurred from 1996 (1999 was an exception), all periods of tillering-shooting since 2000 were shorter than average, and in the case of the period of heading-wax maturity periods shorter than average occurred since 1991, after which only 4 times the duration of the period was longer than average (in: 1993, 1996, 1998, 2000).

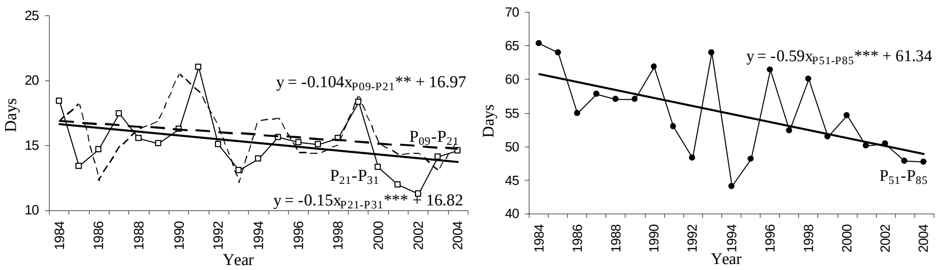

Fig. 5. Average duration of phases: emergence-tillering (P_{09}-P_{21}), tillering-shooting (P_{21}-P_{31}), heading-wax maturity (P_{51}-P_{85}) of spring triticale in Poland, 1984-2004. Significance level of trend: *** *P*<0.01, ** *P*<0.05

The length of the periods were negatively correlated ($P<0.01$) with average air temperature in May (P_{09}-P_{21} and P_{21}-P_{31}) and with average air temperature in June and July (P_{51}-P_{85}, table 1). The value of the correlation coefficient equalled from –0.31 (P_{09}-P_{21}) to –0.59 (P_{51}-P_{85}). An increase in air temperature in May by 1^{o}C in comparison with the multi-year average caused shortening of the periods of emergence-tillering and tillering-shooting by, respectively, 0.7 and 1.0 days, the same increase in average air temperature in June and July caused shortening of the period of heading-wax maturity by over 4 days (Tab. 1).

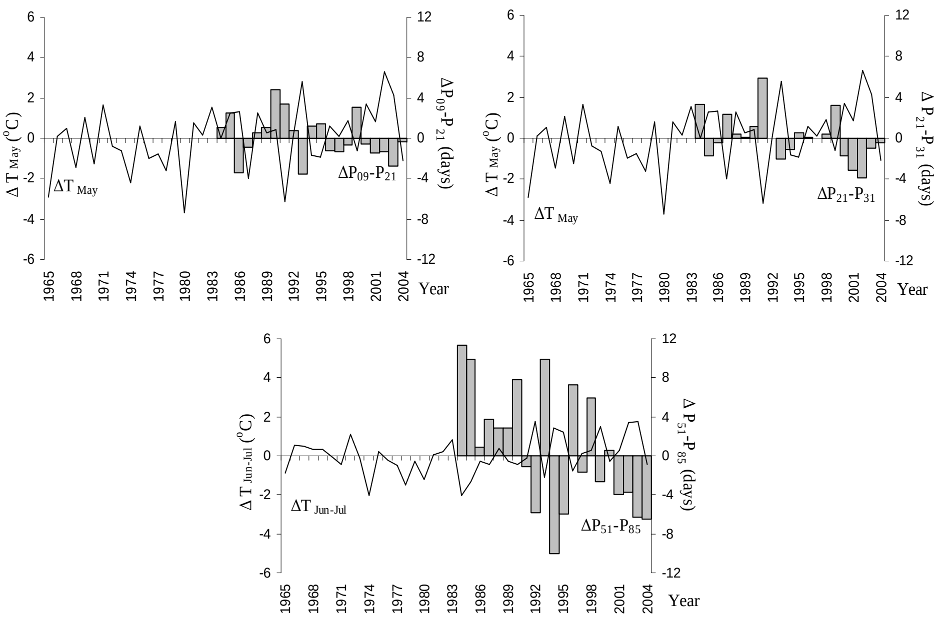

Fig. 6. Anomalies in duration of phases: emergence-tillering (ΔP_{09}-P_{21}), tillering-shooting (ΔP_{21}-P_{31}), heading–wax maturity (ΔP_{51}-P_{85}) of spring triticale and in the average air temperature in May (ΔT_{May}), from June to July ($\Delta T_{Jun\text{-}Jul}$) in Poland, 1965-2004

The influence of the dates of phenophases and the length of development stages on the yields of spring triticale crops, as described in literature (Koziara 1996, Kalbarczyk 2006), manifests itself mostly through beneficial effect of longer than average development periods and the whole period of sowing-harvesting on the yields. This is possible thanks to the earlier occurrence of initial phenophases and the later occurrence of final phenophases.

The conducted cluster analysis showed that the highest yields of spring triticale (cluster No.1) can be obtained with earlier than average dates from sowing to heading (So, P_{09}, P_{21}, P_{31}, P_{51}) and similar to average dates of wax maturity and harvesting (P_{85}, Ha) (Tab. 2). The highest yields were caused by longer than average interphases So-P_{09}, P_{09}-P_{21}, P_{31}-P_{51} and periods So-P_{85} and So-Ha, and similar to average duration of periods P_{51}-P_{85} and P_{85}-Ha. All dates and lengths of periods significantly (P<0.01) differentiated clusters, however the highest values of statistics F occurred in the case of the dates of heading, wax maturity and shooting, and in the case of the considered duration of periods – for the period of sowing-harvesting and next for sowing-wax maturity. Separated clusters were weakest differentiated by the duration of the following periods of wax maturity-harvesting and also tillering-shooting and shooting-heading, which is shown by the distance bet-

Table 2. Statistical parameters of phenological and agronomic dates and durations of development periods, describing isolated clusters of various yield volume

Cluster	n	Yield (t ha^{-1}) x	Yield (t ha^{-1}) S		Dates So	P_{09}	P_{21}	P_{31}	P_{51}	P_{85}	Ha
1	89	5.96	1.38	mn	13.03	2.04	20.04	7.05	26.05	16.07	3.08
				mx	10.04	30.04	12.05	30.05	21.06	24.08	3.09
				x	28.03	15.04	2.05	18.05	7.06	2.08	16.08
				S	5.9	6.2	5.1	5.1	5.4	7.1	8.1
2	109	5.09	1.34	mn	25.03	15.04	29.04	9.05	25.05	6.07	22.07
				mx	22.04	2.05	22.05	2.06	21.06	9.08	25.08
				x	8.04	24.04	8.05	22.05	9.06	26.07	10.08
				S	5.4	3.8	4.5	4.9	5.4	6.3	6.9
3	126	5.58	1.09	mn	4.04	16.04	3.05	16.05	3.06	30.07	10.08
				mx	30.04	9.05	30.05	11.06	27.06	9.09	22.09
				x	16.04	29.04	14.05	30.05	16.06	14.08	28.08
				S	5.6	4.7	4.7	5.0	5.2	8.3	8.9
1-3	324	5.54	1.30	mn	13.03	2.04	20.05	7.05	25.06	6.07	22.07
				mx	30.04	9.05	30.05	11.06	27.06	9.09	22.09
				x	8.04	23.04	9.05	24.05	11.06	4.08	19.08
				S	9.6	7.5	6.8	7.1	6.7	10.9	11.2

Periods

So-P_{09}	P_{09}-P_{21}	P_{21}-P_{31}	P_{31}-P_{51}	P_{51}-P_{85}	P_{85}-Ha	So-P_{85}	So-Ha
10.0	9.0	7.0	10.0	41.0	3.0	111.0	126.0
29.0	28.0	33.0	34.0	73.0	33.0	148.0	160.0
17.7	17.1	16.0	20.2	55.7	14.3	126.8	141.1
4.0	4.6	4.5	4.2	6.5	6.8	7.4	7.9
7.0	5.0	5.0	7.0	24.0	3.0	91.0	107.0
30.0	24.0	26.0	30.0	65.0	45.0	134.0	142.0
16.0	14.2	14.2	17.8	46.8	15.5	109.8	123.8
4.9	3.7	3.9	4.8	6.5	7.7	8.1	8.4
7.0	8.0	7.0	5.0	40.0	1.0	99.0	115.0
24.0	26.0	29.0	29.0	81.0	40.0	145.0	158.0
12.8	15.1	16.0	17.4	58.4	13.9	119.7	133.4
3.6	3.8	4.1	4.3	8.6	7.8	10.3	9.8
7.0	5.0	5.0	5.0	24.0	1.0	91.0	107.0
30.0	28.0	33.0	34.0	81.0	45.0	148.0	160.0
15.2	15.4	15.4	18.3	53.7	14.5	118.3	132.3
4.6	4.1	4.2	4.6	8.9	7.5	11.1	11.2

n – number of observations, mn – minimum, mx – maximum, x – mean, S – standard deviation, agronomic dates: So – sowing, Ha – harvest, BBCH-code: P_{09} – emergence, P_{21} – beginning of tillering, P_{31} – beginning of shooting, P_{51} – beginning of heading, P_{85} – wax maturity.

ween clusters presented in Figure 7. Whereas the observed positive temperature trends in the early spring may positively affect the volume of the yields of spring triticale, thanks to the possibility of earlier sowing and earlier occurrence of subsequent phenophases, which is conducive to better tillering of plants, strong trends of air temperature observed in June and July in Poland cause the acceleration of maturing and in consequence shortening of the whole development period of triticale, which may have a negative impact on the volume of the yields. Persistence of the current tendencies, i.e., the lack of or slight acceleration of initial phenophases (emergence, tillering) and growing acceleration of subsequent dates (shooting, heading, wax maturity) leading to shortening of development periods, deteriorates the conditions for obtaining good yields of spring triticale in Poland.

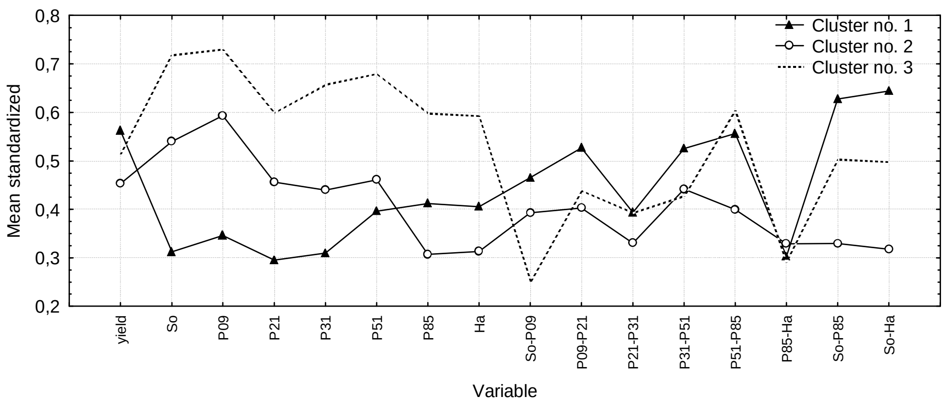

Fig. 7. Average normalisation of the yield, phenological and agronomic dates and the duration of development periods of spring triticale in 3 clusters isolated with the use of cluster analysis. So: sowing, Ha: Harvest, BBCH-code: P_{09}: emergence, P_{21}: beginning of tillering, P_{31}: beginning of shooting, P_{51}: beginning of heading, P_{85}: wax maturity

CONCLUSIONS

1. The observed air temperature changes in the second half of the 20th century in Poland caused acceleration of phenophase dates of spring triticale; dates of heading and wax maturity changed the most.
2. The lack or slight acceleration of initial phenophases (emergence, beginning of tillering) and growing acceleration of successive dates (beginning of shooting, beginning of heading, wax maturity) led to shortening of development periods of spring triticale, which was especially strong in the case of the heading-wax maturity interphase.

3. Persistence of the current trends of changes in the dates and duration of development periods may deteriorate the conditions for obtaining good crop yields of spring triticale in Poland.

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ZRÓŻNICOWANIE CZASOWE TERMINÓW FENOLOGICZNYCH PSZENŻYTA JAREGO NA TLE ZMIENNYCH WARUNKÓW TERMICZNYCH POWIETRZA W POLSCE

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S t r e s z c z e n i e. Wpływ temperatury powietrza na zmienność terminów fenofaz i długość międzyfaz pszenżyta jarego zbadano za pomocą analizy regresji prostej liniowej. Obserwowany w latach 1965-2004 wzrost średniej temperatury powietrza Polsce, największy w przypadku średniej temperatury sierpnia (+0,53^{o}C/10 lat, P<0,01) i kwietnia (+0,50^{o}C/10 lat, P<0,01), powodował istotne przy P<0,01 przyspieszenie terminów fenofaz. Wielkość zmian była tym większa, im późniejszej fenofazy dotyczyła – dla początku krzewienia średnie przyspieszenie terminu wyniosło +1,8 dnia/10 lat, dla początku strzelania w źdźbło +3,4 dnia/10 lat, dla początku kłoszenia +4,2 dnia/10 lat, a dla dojrzałości woskowej aż +10,2 dnia/10 lat. Długość okresów wschody-krzewienie i krzewienie-strzelanie w źdźbło w latach 1984-2004 uległa skróceniu o, odpowiednio, –1,0 dnia/10 lat i –1,5 dnia/10 lat, natomiast okresu kłoszenie-dojrzałość woskowa o –5,9 dnia/10 lat. Utrzymanie się dotychczasowych tendencji – brak lub niewielkie przyspieszenie początkowych fenofaz (wschody, krzewienie) i narastające przyspieszenie kolejnych terminów (strzelanie w źdźbło, kłoszenie, dojrzałość woskowa), prowadzące do skrócenia okresów rozwojowych, może pogorszyć warunki osiągania dobrych plonów pszenżyta jarego w Polsce.

S ł o w a k l u c z o w e: pszenżyto jare, analiza skupień, fenofaza, okres rozwojowy, plon