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RELATIONSHIP BETWEEN PHENOLOGICAL AND METEOROLOGICAL DATA AS AN IMPORTANT INPUT INTO SPRING BARLEY PHENOLOGICAL MODEL

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Abstract

In this study, phenological and meteorological data have been used to interpret the relationship and influence of weather on current phenological stages of spring barley. The analyses were focused mainly on the stages closely connected with yield and grain filling period – tillering (BBCH 21), heading (BBCH 55) and yellow ripeness (BBCH 85). The aims of this paper were to: (1) calculate the trend in phenological development of spring barley from CHMI phenological stations in period 1991–2012 at different climatic zones; (2) evaluate the trend in number of days between phenological stages; (3) evaluate the sums of growing degree days above threshold above 5 °C (GDD) and precipitation totals to phenophase onset calculated since the phenological stage of emergence (BBCH 10); (4) calculate Pearson's correlation coefficient (PCC) between phenological stage and meteorological parameter. The highest positive PCC was found between GDD and phenological stages of heading and yellow ripeness at Doksany and Strážnice stations situated in lowlands. The average value of GDD to phenological stage heading is within the range from 418.4 to 500.1 °C. The sums of precipitation totals fluctuate from 73.9 mm (Doksany station) to 123.2 mm (Chrastava station). The results of this study suggest that GDD can be a more suitable parameter for phenological model of spring barley development than precipitation total.

Keywords: phenophase, precipitation, spring barley, Czech Republic, BBCH code

INTRODUCTION

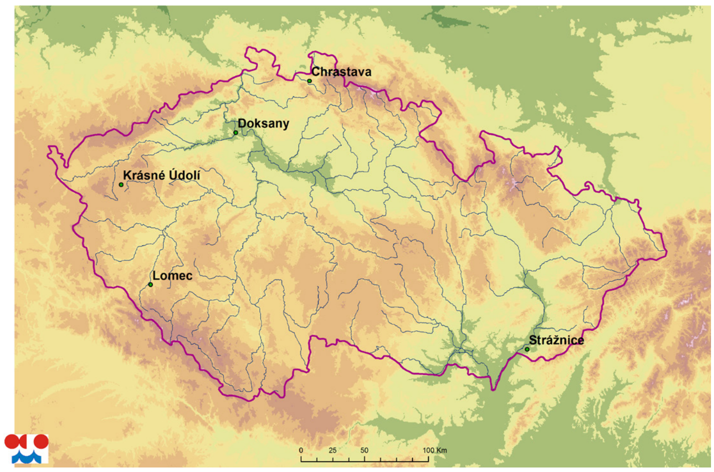
Phenology, the study of the timing of recurring biological cycles and their connection to climate, has emerged as an important focus for ecological research because phenological events are regarded as good indicators of climate change (e.g. Schwartz 1996; Menzel *et al.*, 2006). The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) stated that phenology can be used as a simple and integrative indicator on how species and ecosystems respond to Climate Change (Yu *et al.*, 2016). Development and growth are two concepts which are often used in crop modelling (Wang and Engel, 1998). The plant development is significantly influenced by the condition of the environment e.g. The regime of air temperature. "Cause factors" of plant growth (e.g. temperature, water and nutrient supply) as well as the "reactions" of plants (e.g. phenological behaviour, spectral response) can be used to describe the development of crops and the formation of yield and quality. Even though yield components of cereals are partly determined in the vegetative stage, the actual process of grain formation and filling takes place between the heading and yellow ripeness stages (Schelling *et al.*, 2003). The biological temperature minimum (value which indicates the beginning or ending of growth) is important in the plants life. In the moderate climate is this threshold usually 5 °C. The onset of particular phenological phases is driven by temperature expressed as the sum of effective or active temperature. Yield is markedly affected by the length of the vegetation season. Not only the short growing season, but also the modest number of effective growing days challenge farmer's capacity to cope with climatic constraints (Trnka *et al.*, 2011). The concept of, Growing Degree Days (GDD = accumulated temperature above a base value, Russelle *et al.* (1984), can be used to describe the duration of the development stage (Schelling *et al.*, 2003). Understanding of the effects of climate change on phenological phases of a crop species may help optimize agricultural management schemes to increase productivity, e.g. timely information about the production of spring barley is of great significance for farmers as well as for malting industry. The actual process of grain formation and filling takes place between the heading and yellow ripeness phenological stages. Most of the published results are based on laboratory or field trials. This paper investigates the observed results and measurements from the phenological network of the Czech Hydrometeorological Institute (CHMI).

The aims of this paper were to: (1) calculate the trend in phenological development of spring barley from CHMI phenological stations in period 1991–2012 at different climatic zones; (2) evaluate the trend in number of days between phenological stages; (3) evaluate the sums of growing degree days above threshold above 5 °C (GDD) and precipitation totals to phenophase onset calculated since the phenological stage of emergence (BBCH 10); (4) calculate Pearson's correlation coefficient (PCC) between phenological stage and meteorological parameter.

MATERIALS AND METHODS

Study area

The study was performed in the western, northern, southern and central part of the Czech Republic, districts: Krásné Údolí, Lomec, Chrastava, Doksany, and Strážnice (Fig. 1, Tab. I).

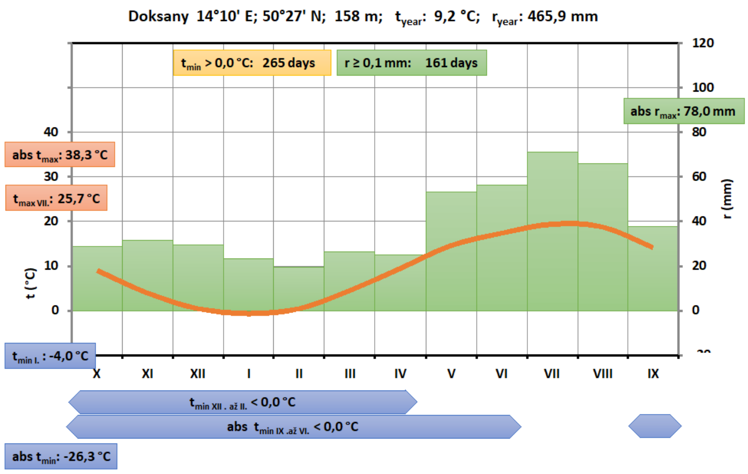


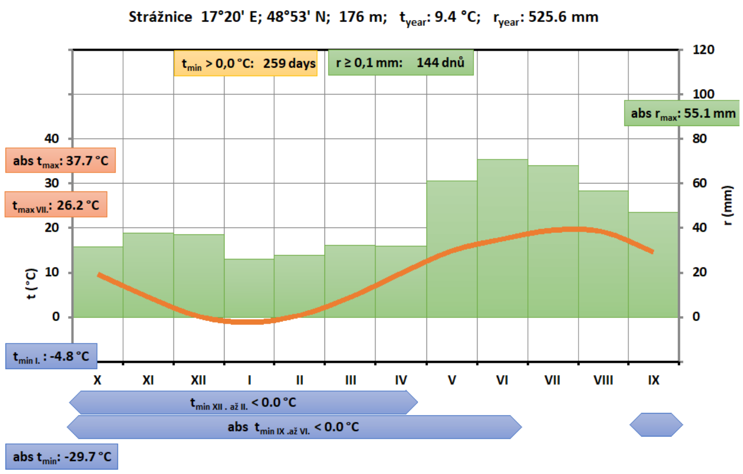
1: *Distribution of CHMI stations.*

I: *Geographical informations of phenological and climatological stations.*

Station		Altitude (m a.s.l.)	Longitude	Latitude	Quitt's classification (Tolasz et al., 2007)
Doksany	**(phenological station)**	155	14°10‘	50°27‘	W2 warm region
	(climatological station)	158	14°10‘	50°27‘	
Strážnice	**(phenological station)**	177	17°19‘	48°54‘	W2 warm region
	(climatological station)	176	17°20‘	48°53‘	
Chrastava	**(phenological station)**	310	14°59‘	50°49‘	MW1
	Liberec (climatological station)	398	15°01‘	50°46‘	moderately warm region
Lomec	**(phenological station)**	450	13°16‘	49°22‘	MW11
	Klatovy (climatological station)	421	13°18‘	49°23‘	moderately warm region
Krásné Údolí	**(phenological station)**	630	12°55‘	50°04‘	MW3 moderately warm region
	(climatological station)	650	12°55‘	50°04‘	

2: *Climagrams chracterized climate conditions of the station:*
A – Doksany; B – Strážnice; C – Chrastava (Liberec); D – Lomec (Klatovy); E –Krásné Údolí.





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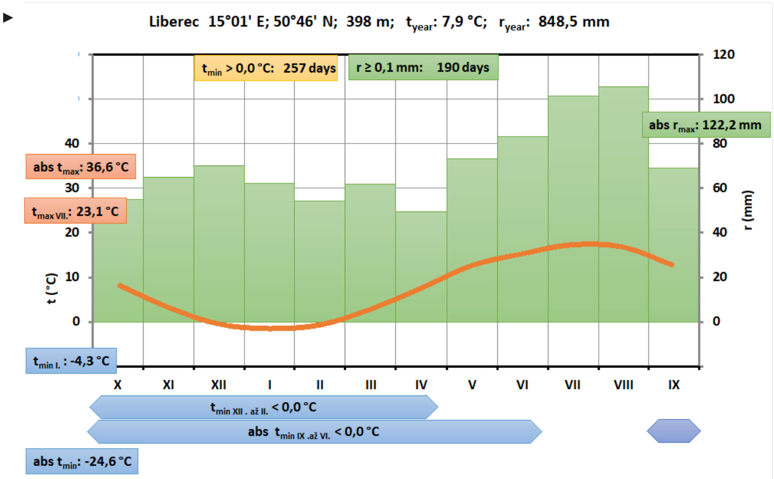
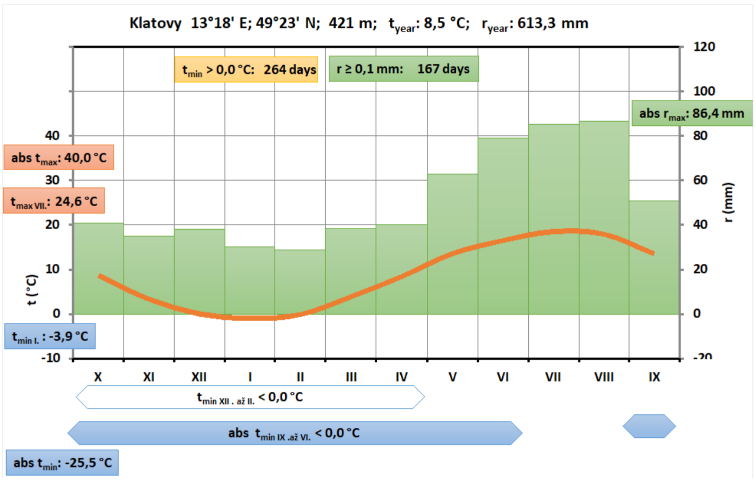
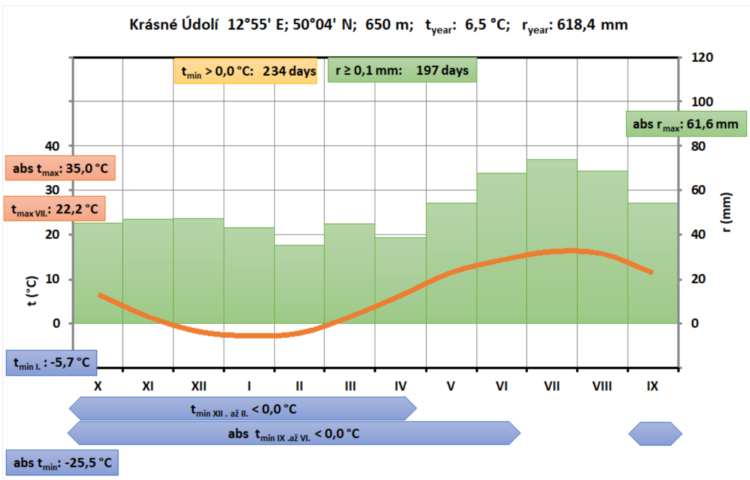






Notes of climagrams: red line - t = average monthly air temperature (°C); green columns - r = average monthly precipitation total (mm); above: tyear = average year air temperature (°C); ryear = average year precipitation total (mm); left: abs tmax = absolute maximum of air temperature; tmax VII. = average monthly maximum of air temperature of the warmest month; tmin I. = average monthly minimum of air temperature of the coldest month; abs tmin = absolute minimum of air temperature; bellow: tmin XII.–II. < 0.0 °C = months with average minimum of air temperature < 0.0 °C; abs tmin IX.–VI. < 0.0 °C = months with absolute minimum of air temperature < 0.0 °C; right: abs rmax = absolute maximum of daily precipitation total; yellow square: tmin > 0.0 °C = average count of days with air temperature > 0.0 °C; green square: r ≥ 0.1 mm = average count of days with total precipitaion ≥ 0.1 mm.

The climate conditions of each locality are characterized by climagrams (Fig. 2A, B, C, D and E). We used a modified Walter–Lieth climagram (e.g. Kožnarová and Klabzuba, 2010, Hájková *et al.*, 2013) based on the long-term average data 1981–2010.

Phenological data

Phenological data were obtained from database PHENODATA from phenological stations (Table 1). These stations have been managed under the administration the Czech Hydrometeorological Institute (CHMI) - Department of Biometeorological Applications in Prague. CHMI have maintained a network of phenological stations recording phenological stages of field crops following CHMI methodological instructions (Anonymous 2009, Coufal *et al.* 2004) till the year 2012. Unfortunately, since January 1st, 2013, was the field phenological network cancelled.

There were observed subsequent phenological stages at spring barley (*Hordeum vulgare* L.): emergence, tillering, beginning of leaf sheath elongation, first node, second node, booting, heading, beginning of flowering, end of flowering, milky ripeness, yellow ripeness, full ripeness and date of sowing and harvest as well (Hájková *et al.*, 2012). BBCH code are deduced according to Meier (2001). The varieties of spring barley used in the evaluation are mentioned in Tab. II. Unfortunately, it is not possible to ensure the same variety during the whole period. And furthermore, it is not possible to determine the early or late crop varieties before 2000, we only found the variety Akcent as semi-late. We realize, that the varieties oscillates from early to late one, but the differences between varieties in particular years should not be greater than $\pm$2 days.

Climatic and statistical analysis

For the calculation of pheno-climatological characteristics were used mean air temperature and precipitation totals (so-called “technical series”) from CHMI climatological stations (see Tab. I) in daily step. For the data processing of “technical series”, the software packages AnClim (Štěpánek, 2010a), LoadData and ProClimDB (Štěpánek, 2010b) were used. Both types of software offer complex solution, from tools for handling databases, through data quality control to homogenization of time series, as well as time series analyses, extreme value evaluation and model output verification.

Thermal time (cumulative heat), often expressed in growing degree-days (GDD). GDD is calculated by substracting a base temperature from the daily mean temperature ($t_{avg} = (t_{07} + t_{14} + 2t_{21})/4$) and GDD values less than zero are set to zero. The summation over time is related to development of plants, insects, and disease organisms. The reference temperature (base temperature) below which development either slows or stops is species dependent. For example, cool season plants (e.g. spring wheat and barley, canning pea etc.) base temperature is 5 °C (Glickman ed., 2000):

$$GDD = t_{avg} - t_{base},$$

where:

t_{base} = cardinal temperature minimum for plants = 5 °C.

We have used accumulated growing degree-days (GDD) – sum of GDD from day of year DOY_1 to DOY_2.

Here, DOY_1 was set as date of emergence (BBCH 10) and DOY_2 was the day of year that marks the end of time period for GGD calculation – in our case it was date of tillering (BBCH 21), heading (BBCH 55) and yellow ripeness (BBCH 85).

PCC was used to examine the linear relationships between the climatic parameters (GDD and precipitation totals) and phenological events of spring barley. The sums of meteorological parameters were calculated since the stage tillering. The statistical calculations were done by tools of Microsoft Excel.

II: *Variety of spring barley*

Station	Variety
Strážnice	Jaspis, Korál, Krystal, Novum, Forum, Amulet, Olbram, Tolar
Doksany	Jaspis, Bonus, Korál, Galan, Perun, Akcent, Forum, Signal
Chrastava	Malvaz, Svit, Akcent, Heris
Krásné Údolí	Kredit, Orbit, Akcent, Krona, Nordus, Signal
Lomec	Perun, Bonus, Terno, Rubín, Bonus, Favorit, Rapid

RESULTS AND DISCUSSION

Statistical data of spring barley development (BBCH 21, BBCH 55 and BBCH 85) for the selected stations are in Tab. 3. The stage of tillering (BBCH 21), heading (BBCH 55) and yellow ripeness (BBCH 85) for spring barley (different species) showed large differences in the examined period. On the basis of the results obtained, we can report that the average timing of tillering in the 22-year period was in the frame from 23rd April (the lowest station Strážnice in southern Moravia) to 9th May (the highest station in western Bohemia). The dependence on elevation is visible from the results. Median acquires the same values as average except Doksany and Chrastava station. The standard deviation is within the range from 6.0 to 7.9. The earliest onset of tillering was on 4th April 2007 at Strážnice station. The average date of heading (BBCH 55) is within the range 1st June and 20th June. The difference between two lowest stations is 5 days on average. The standard deviation has values from 6.1 to 7.8. And the average date of yellow ripeness (BBCH 85) fluctuates from 9th July to 3rd August. Standard deviation is similar to the same values of SD as in BBCH 21 and BBCH 55 – from 5.8 to 8.4. The linear trend analysis in 22 years showed subsequent results: at the lowest stations comes tillering (BBCH 21) later (2.9 days at Strážnice station; 1 day at Doksany station) and at other stations earlier (–6.9 days at Chrastava station; –12 days at Krásné Údolí station; -0.3 day at Lomec station). Heading (BBCH 55) and yellow ripeness (BBCH 85) have negative linear trend at all stations. Strážnice station (–10.4 days by heading; –5.7 days by yellow ripeness), Doksany station (–6.7 days by heading; –8.1 days by yellow ripeness), Chrastava station (–10.0 days by heading; –8.9 days by yellow ripeness), Krásné údolí station (–8.0 days by heading; –11.5 days by yellow ripeness) and Lomec station (–1.7 days by heading; –1.1 day by yellow ripeness).

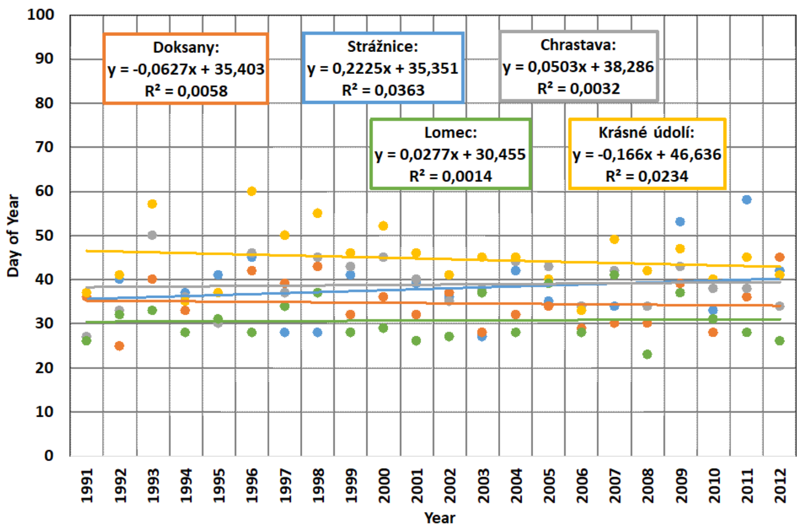
The accumulated growing degree-days (GDD) method is a wdely used measure of heat accumulation for plant growth in agricultural and ecological studies (e.g. Yu *et al.* 2016; Chuine *et al.* 1999). The results of GDD of spring barley are mentioned in Tab. IV, Fig. 4. The average value of GDD from emergence to heading oscillates from 418.4 °C to 500.1 °C. The highest value is at Lomec station. And from heading to yellow ripeness are values of GDD within the range 430.4 °C to 504.0 °C, the highest values are on the lowest station (Strážnice). This development correlates with temperatures evaluation within the year. The linear trend for 22 years (except Krásné Údolí station positive) is as follow: Strážnice station (77.3 °C), Doksany station (7.4 °C), Chrastava station (23.3 °C), Krásné Údolí (-25.0 °C) and Lomec station (119.5 °C).

III: *Statistical characteristics of date of tillering (BBCH 21), heading (BBCH 55) and yellow ripeness (BBCH 85)*

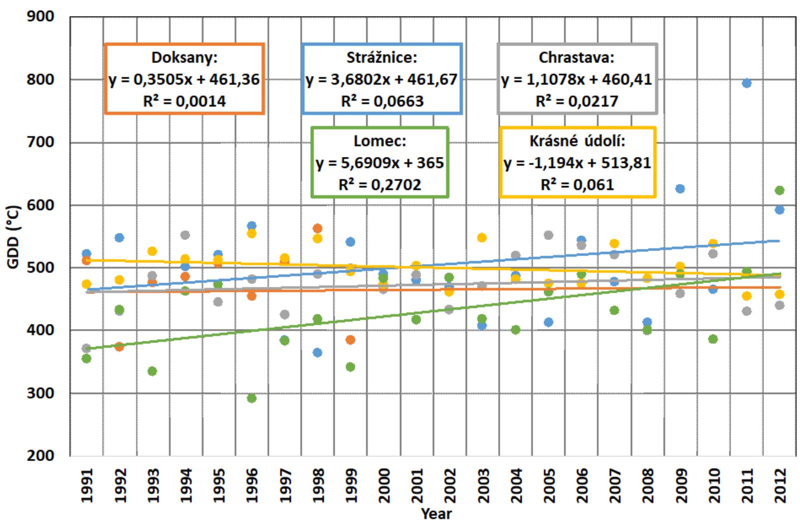
Station	Average	Median	Upper quartile	Lower quartile	Standard deviation	Minimum	Maximum	Variation range	Variation coefficient
				Tillering (BBCH 21)					
Strážnice	23. 4.	23. 4.	19. 4.	29. 4.	7.9	4. 4.	9. 5.	35	0.070
Doksany	25. 4.	26. 4.	22. 4.	30. 4.	6.0	11. 4.	5. 5.	24	0.052
Chrastava	7. 5.	8. 5.	4. 5.	11. 5.	6.1	23. 4.	19. 5.	26	0.048
Krásné Údolí	9. 5.	9. 5.	30. 4.	12. 5.	7.1	24. 4.	19. 5.	25	0.056
Lomec	9. 5.	9. 5.	4. 5.	13. 5.	6.7	28. 4.	24. 5.	26	0.052
				Heading (BBCH 55)					
Strážnice	1. 6.	31. 5.	27. 5.	6. 6.	7.7	19. 5.	18. 6.	30	0.051
Doksany	6. 6.	6. 6.	2. 6.	10. 6.	6.1	23. 5.	15. 6.	23	0.039
Chrastava	16. 6.	16. 6.	11. 6.	21. 6.	7.8	3. 6.	1. 7.	28	0.047
Krásné Údolí	19. 6.	19. 6.	14. 6.	24. 6.	7.6	6. 6.	3. 7.	27	0.045
Lomec	20. 6.	20. 6.	15. 6.	25. 6.	6.7	9. 6.	30. 6.	21	0.039
				Yellow ripeness (BBCH 85)					
Strážnice	9. 7.	10. 7.	1. 7.	14. 7.	8.4	24. 6.	23. 7.	29	0.044
Doksany	11. 7.	11. 7.	6. 7.	16. 7.	7.2	24. 6.	26. 7.	32	0.034
Chrastava	25. 7.	26. 7.	19. 7.	29. 7.	7.6	8. 7.	13. 8.	36	0.037
Krásné Údolí	3. 8.	3. 8.	27. 7.	6. 8.	7.5	21. 7.	23. 8.	33	0.035
Lomec	20. 7.	20. 7.	17. 7.	26. 7.	5.8	12.7.	2. 8.	21	0.029

IV: *Statistical characteristics of GDD from emergence (BBCH 10) to heading (BBCH 55) and GDD from heading (BBCH 55) to yellow ripeness (BBCH 85).*

Station	Average	Median	Upper quartile	Lower quartile	Standard deviation	Minimum	Maximum	Variation range	Variation coefficient
GDD from emergence (BBCH 10) to heading (BBCH 55)									
Strážnice	445.0	445.0	408.1	476.6	79.7	304.6	605.5	300.9	0.179
Doksany	484.5	476.6	440.9	528.3	64.2	389.8	627.7	237.9	0.133
Chrastava	449.5	449.5	415.8	469.3	53.3	344.7	569.2	224.5	0.119
Krásné Údolí	418.4	415.0	397.9	444.8	33.2	348.2	493.2	145.0	0.079
Lomec	500.1	500.1	461.8	538.6	51.9	395.1	587.2	192.1	0.104
GDD from heading (BBCH 55) to yellow ripeness (BBCH 85)									
Strážnice	504.0	489.6	466.4	542.7	92.8	364.7	794.3	429.6	0.184
Doksany	465.4	475.4	416.9	492.9	61.2	373.3	622.6	249.3	0.131
Chrastava	473.2	473.2	433.9	513.5	48.8	370.9	551.3	180.4	0.103
Krásné Údolí	500.1	500.1	474.7	523.1	31.4	454.1	554.3	100.2	0.063
Lomec	430.4	430.4	389.4	480.2	71.1	291.5	622.6	331.1	0.165



3: *Days between heading (BBCH 55) to yellow ripeness (BBCH 85)*



4: *GDD from heading (BBCH 55) to yellow ripeness (BBCH 85)*

Water has a great importance in plant development and mainly in recent years when, unfortunately, the drought more and more occurs. The highest water supply for spring barley development was detected at Chrastava station (Liberec region) and the lowest Doksany station (Polabská lowland) (Tab. V). The linear trend for studied 22 year's period (Fig. 5) showed these results: Strážnice station (37.6 mm), Doksany station (–2.7 mm), Chrastava (16.6 mm), Krásné Údolí (–41.3 mm) and Lomec (31.0 mm).

Number of days between the phenological stages are also important as an input into model (Tab. VI). The analyses showed, that the highest number of days between heading and yellow ripeness was at Krásné údolí station (44.7 days on average) the lowest value was at Lomec station (30.8 on average). The trend in number of days between heading and yellow ripeness (Fig. 3) is positive at Strážnice station (4.7 days), Chrastava station (1.1 day) and Lomec station (0.6 day). Doksany and Krásné údolí stations have negative linear trend (–1.3 days and –3.5 days).

Tab. VII represents the Pearson's correlation coefficient between phases. The highest value was found at GDD to stage onset at Strážnice station and also at Doksany station in tillering and yellow ripeness. And surprisingly, between the precipitation totals and heading and yellow ripeness at Strážnice and Doksany stations were evaluated relatively high positive coefficients. The negative values were investigated in GDD at Krásné Údolí and Lomec stations. Schelling *et al.* (2003) examined relationship between weather parameters and the duration of grain filling at spring barley and oats in Germany and found out that this period was associated with low temperatures, high rainfall and most air conditions.

Many authors (e.g. Schelling *et al.*, 2003) have successfully tested temperature models for all phases (sowing-emergence-heading–-yellow ripeness) and t_{base} was fixed at 5 °C.

V: *Statistical characteristics of precipitation totals from emergence (BBCH 10) to heading (BBCH 55) and totals from heading (BBCH 55) to yellow ripeness (BBCH 85).*

Station	Average	Median	Upper quartile	Lower quartile	Standard deviation	Minimum	Maximum	Variation range	Variation coefficient
Precipitation totals from emergence (BBCH 10) to heading (BBCH 55)									
Strážnice	91.1	82.1	46.6	112.3	54.5	34.5	239.1	204.6	0.598
Doksany	73.9	75.4	62.1	87.4	32.6	17.4	165.6	148.2	0.441
Chrastava	123.3	114.8	86.3	144.7	59.6	40.5	235.5	195.0	0.483
Krásné Údolí	101.8	101.8	81.7	131.2	35.1	39.5	158.5	119.0	0.345
Lomec	96.9	83.2	71.1	105.1	44.5	31.1	222.0	190.9	0.459
Precipitation totals from heading (BBCH 55) to yellow ripeness (BBCH 85)									
Strážnice	87.1	75.9	58.3	110.8	46.7	21.8	182.3	160.5	0.536
Doksany	83.9	90.0	56.9	107.1	37.6	22.2	169.1	146.9	0.448
Chrastava	127.8	130.4	82.4	165.3	63.0	32.0	282.3	250.3	0.493
Krásné Údolí	104.8	104.8	70.8	133.5	43.9	36.9	197.0	160.1	0.419
Lomec	84.0	86.6	55.4	101.9	35.5	30.8	169.1	138.3	0.423

VI: *Statistical characteristics of number of days from heading (BBCH 55) to yellow ripeness (BBCH 85).*

Station	Average	Median	Upper quartile	Lower quartile	Standard deviation	Minimum	Maximum	Variation range	Variation coefficient
Strážnice	37.9	37.0	33.3	41.0	7.6	27.0	58.0	31	0.199
Doksany	34.7	34.7	30.5	38.5	5.3	25.0	45.0	20	0.153
Chrastava	38.9	38.0	34.3	43.0	5.7	27.0	50.0	23	0.148
Krásné Údolí	44.7	45.0	40.3	48.5	7.1	33.0	60.0	27	0.158
Lomec	30.8	29.0	28.0	33.8	4.9	23.0	41.0	18	0.158

VII: *Pearson's correlation coefficient between GDD and Sums of precipitation totals and tillering (BBCH 21), heading (BBCH 55) and yellow ripeness (BBCH 85)*

Station	GDD			Precipitation totals		
	Tillering (BBCH 21)	Heading (BBCH 55)	Yellow ripeness (BBCH 85)	Tillering (BBCH 21)	Heading (BBCH 55)	Yellow ripeness (BBCH 85)
Strážnice	0.713	0.663	0.704	0.123	0.441	0.409
Doksany	0.635	0.384	0.531	0.021	0.557	0.533
Chrastava	0.099	0.049	0.286	0.349	0.205	0.100
Krás. Údolí	–0.037	–0.216	0.159	0.117	0.031	0.160
Lomec	–0.038	–0.205	–0.179	0.189	0.390	-0.180

CONCLUSIONS

This paper examines development stages of spring barley which are closely connected with yield and grain filling period – tillering (BBCH 21), heading (BBCH 55) and yellow ripeness (BBCH 85). The aims of this paper were to calculate the trends in phenological development of spring barley from data of CHMI phenological stations in period 1991–2012 at different climatic zones. Further on was evaluated the trend in number of days between phenological stages, the sums of accumulated growing degree days above threshold above 5 °C (GDD) and precipitation totals to phenophase onset calculated. The calculations were made since the phenological stage of emergence (BBCH 10). To find the highest dependence phenological stage on meteorological parameter was used the Pearson's correlation coefficient (PCC).

The average value of GDD from emergence (BBCH 10) to heading (BBCH 55) is at tested stations within the range from 418.4 to 500.1 °C, from heading to yellow ripeness the values oscillate from 430.4 to 504.0 °C. Precipitation totals fluctuate from 73.9 mm to 123.2 mm (from BBCH10 to BBCH 55) and from 83.9 to 127.8 mm (from BBCH 55 to BBCH 85). The highest values of PCC were found by GDD at phenological stages at Strážnice station and also at Doksany station in tillering and yellow ripeness. And surprisingly, between the precipitation totals and heading and yellow ripeness at Strážnice and Doksany stations were evaluated also relatively high positive coefficients. These both stations are located in warm region. The negative values of PCC were investigated in GDD at Krásné Údolí and Lomec stations in all meteorological parameters.

Some authors (e.g. Robertson *et al.*, 2009) found in their studies, that the development rate of field crops correlates positively to temperature between a base and an optimum temperature the development rate starts to decline.

Peltonen-Sainio and Jauhiainen (2014) documented shifts of spring cereals toward earlier sowing had no consistent impact on timing of crop maturity and harvest at high latitudes. However, crops required fewer days, though more accumulated degree-days, to mature after delays in sowing.

The results of this study suggest that GDD can be a more suitable parameter for phenological model of spring barley development than precipitation total. It is necessary to analyze also relationship with day length and more phenological stations to get inputs into phenological model for spatial evaluation.

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