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EFFECT OF CULTIVAR AND YEAR ON PHYLLOCHRON IN WINTER BARLEY

ABSTRACT: Development and growth of leaves in cereals significantly affects grain yield since dry matter accumulation depends on the leaf area that intercepts light. Phyllochron (PHY) is defined as time interval between the emergences of successive leaves on the main stem. The aim of this study was to determine the effect of year and cultivar on phyllochron in winter barley. Twelve cultivars of winter barley differing in origin and time of anthesis were tested during six growing seasons (GS), from 2002/03 to 2007/08. The highest PHY across GSs was determined in the two-rowed cultivar Cordoba (81.6°Cd) and the lowest in the two-rowed cultivar Novosadski 581 (71.0°Cd). The early cultivars had fast leaf development, the medium cultivars medium and the late cultivars slow development, 72.5°Cd, 75.6°Cd and 78.9°Cd, respectively. The tested cultivars showed significant variability in the PHY, which can be used for selecting most adaptable genotypes for specific growing conditions.

KEYWORDS: Barley, *Hordeum vulgare*, phyllochron, heritability, variance

INTRODUCTION

The phyllochron (PHY) is defined as the thermal time interval between the emergence of successive leaf tips, expressed as growing degree days – GDD or degree days - °Cd (Johnen et al., 2012). It is a measure of plant development that could be used to assess how the plant has responded to environmental conditions or to predict how it is going to respond to them. To estimate the daily interval between growth stages, photothermal units or growing degree days are usually used. PHY is an alternative approach for measuring the period between growth stages. Its advantages are that it is more flexible than the other approaches and that it integrates developmental processes within the plant.

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PHY is a result of combination of genetic and environmental factors, which interact to produce plant leaves in a predictable manner. PHY has been widely accepted by crop modelers for predicting plant development and by producers for determining the timing of management practices such as irrigation, fertilization or pesticide application. The effect of environmental changes on the rate of leaf emergence in barley ought to be understood in order to make accurate predictions concerning the cropping technology.

Air temperature is the main factor affecting PHY (Rickman and Klepper, 1991). Other environmental factors (daylength, water stress, carbohydrate reserves and nutrient stress) have been shown to have little effect on PHY in grasses (Borràs-Gelonch et al., 2010). Long photoperiod increases the rate of leaf emergence, i.e., it decreases PHY in wheat and barley (Mirschel et al., 2005). Water and nitrogen deficits decrease PHY. Leaf emergence rate in wheat depends on the cultivar and sowing date (Miralles et al., 2001), resulting in fewer leaves per plant in later sowing dates. Arduini et al., (2010) found that the rate of leaf emergence is defined early in the life cycle.

The purpose of this study was to analyze the effect of cultivar and year on PHY of winter barley and to compare leaf emergence in cultivars with different thermal requirements until anthesis.

MATERIALS AND METHODS

Cultivars and crop management. Twelve barley cultivars which differed in origin, pedigree and agronomic traits were used in this study. A 6-year experiment was conducted from 2002/03 to 2007/08 growing seasons (GS) at the experimental field of Institute of Field and Vegetable Crops in Novi Sad (45°20'N, 15°51'E, altitude 86 m) on a Chernozem soil and under rainfed conditions. Planting density was 300 viable seeds per m^2 for six-rowed barleys and 350 viable seeds per m^2 for two-rowed barleys. To avoid negative effects of diseases and pests, the experiment was sprayed with the fungicide Tilt 250 EC in Zadoks phase 64 and with the insecticide Karate zeon. Weed control was performed by hand. Degree days with a T_b of 0° C were calculated according to Pržulj (2001).

Statistical analysis. All the data were subjected to the analysis of variance using Statistica 9.0 program (StatSoft, Tulsa, OK, USA). When differences among earliness groups (early, medium early, late) were tested, four cultivars from each group were considered as replication for detection of PHY duration.

RESULTS AND DISCUSSION

Phenological development and PHY in cereals are the result of genetic background and environmental factors (McMaster, 2005). PHY is controlled by two factors (cultivar and year), and their interaction (Table 1). Although differences in PHY were observed among the cultivars (Tables 1, 2), PHY-based ranking of cultivars could not be performed.

Table 1. Mean squares and percentage of variance components of the phyllochron (PHY) for winter barley

Source	df	PHY
Cultivar	11	176.78**
Year	5	1929.41**
C xY	55	41.54**
% of variance components		
Cultivar		23.09
Year		30.18
C xY		40.45
Heritability		0.77

** – Significant at the 0.01 level

If it is accepted that PHY is shorter in late sowing (M i g l i e t t a , 1991), one could conclude that sowing was late in 2003/04, 2004/05 and 2005/06, since PHY was 70.9, 71.7, and 70.9°Cd respectively (Table 2). However, sowing was in regular time and shorter PHY was a result of unfavorable growing conditions, first of all temperature and water, from sowing until flag leaf emergence. High soil temperature at the time of seed emergence only shortens the duration of germination and seedling emergence. It had no effect on either the PHY or phenological development in wheat and barley (M c M a s t e r and W i l h e l m , 2003).

The early cultivars Skorohod and Novosadski 581 had the lowest °Cd requirements, or the shortest PHY, and the late cultivars Novator, Kredit, Monaco, and Cordoba had the highest °Cd requirements or the longest PHY (Table 2). The early cultivars showed no consistency in the relationship between PHY and earliness, while the medium early and late two-rowed barley cultivars were found to have a longer PHY. While B o r r à s e t a l . (2009) determined that two-rowed spring barley cultivars have a short PHY, J u s k i w et al. (2001) found them to have a long PHY. PHY in spring barley varied in dependence of genotype and combination of temperature and daylength, but it invariably increased as temperature increased or daylength decreased.

In this study, the average PHY was 75.7°Cd, with a range from 71.0 to 81.6°Cd (Table 2). In relation to spring barley, the observed PHY was longer than the mean of 64.5°Cd for Alaska growing conditions (D o f i n g and K a r l s s o n, 1993) and shorter than the means of 77.2°Cd for North Dakota environment (F r a n k and B a u e r, 1995) and 107°Cd for winter wheat grown in Central Great Plains, USA (M c M a s t e r et al., 1992).

The time from sowing to emergence was 138 °Cd (P r ž u l j et al., 2012), which was about two PHYs. J u s k i w et al. (2001) attributed one PHY to the development of coleoptiles and another PHY to the first true leaf.

J u s k i w et al. (2001) found that PHY is prone to error because temperature and daylength are known to affect the leaf emergence rate. Our results confirm this statement, where error for PHY of a specific leaf was rather

Table 2. Phyllochron (°Cd) for twelve winter barley cultivars across six growing seasons (GS)

Cultivar	GS						Average
	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	
Kompolti-4 (E, 6R)	73.0	63.2	68.8	73.7	87.9	71.9	73.1
Skorohod (E, 6R)	70.1	68.0	68.1	63.9	86.0	71.3	71.2
Novosadski 525 (E, 2R)	72.3	71.9	72.9	70.7	90.0	70.5	74.7
Novosadski 581 (E, 2R)	70.7	65.4	68.6	68.4	83.5	69.4	71.0
Plaisant (M, 2R)	65.9	70.9	70.0	69.6	88.6	80.6	74.3
Gotic (M, 6R)	67.7	68.9	70.4	70.5	89.6	85.1	75.4
Sonate (M, 2R)	77.8	68.7	75.0	69.7	91.2	75.4	76.3
Boreale (M, 2R)	77.3	69.5	72.6	70.6	90.3	76.2	76.1
Novator (L, 2R)	71.8	73.3	70.4	70.7	90.8	85.4	77.1
Kredit (L, 2R)	76.8	72.3	69.8	72.0	94.3	86.9	78.7
Monaco (L, 6R)	82.1	78.0	70.7	74.2	92.8	75.6	78.9
Cordoba (L, 6R)	81.1	81.3	83.3	77.2	94.0	72.6	81.6
Average	73.9	70.9	71.7	70.9	89.9	76.7	75.7
		Cultivar	Year	CxY	CV		
LSD	0.05	0.9	0.7	2.7	1.9%		
	0.01	1.2	0.9	3.0			

E-early, M-medium, L-late, 2R- two-rowed, 6R- six-rowed

high, ranging from 13.63% to 33.47% of total variation (Table 3). Leaves 13th and 14th were exceptions, with the errors of 8.85% and 4.69%, respectively. There was a paradox associated with these two leaves: the lower the degree of freedom, the lower the error. It might be due to the lower variability for leaves 13th and 14th of the analyzed cultivars since those that had lower values of PHY (Novosadski 581, Novosadski 525, Scorohod, Sonate and Boreale) did not have 13th and 14th leaves and were not included in statistical calculations. The values of PHY heritability were rather high, although cultivar participation in total variation was less than 10% (Table 3).

When the cultivars were sorted according to earliness, PHY was determined by maturity class and growing season (Table 4). The interaction maturity class x year was not significant for PHY (Table 4), i.e., the early cultivars invariably had the shortest PHY and the late ones had the longest PHY regardless of the year (Tables 2, 5).

The rate of leaf emergence as a function of leaf number increased throughout the growing season from about 50°Cd for the first leaf to 100°Cd for the last leaves. The rate of change fitted the quadratic equitation with the R^2 value ≥0.93 (Figure 1). It greatly depended on GS which participated in the total variation with >30% (Table 1). Some studies indicated that the rate of leaf emergence or PHY was constant in both wheat and barley from seedling emergence to the emergence of the flag leaf (Kamali and Boyd, 2000; Juskiw et al., 2001; Juskiw and Helm, 2003). Other studies showed

Table 3. Percentages of the components of variance and heritability for the PHY of individual main stem leaves across 12 winter barley cultivars and six growing seasons (2002/03-2007/08)

Leaf	Total df	Variance component				Percentage of variance components				h_b^2
		σ_G^2	σ_Y^2	σ_{GY}^2	Error	Cultivar	Year	C xY	Error	
1st	215	1.55	68.46	0.00	35.22	1.47	65.06	0.00	33.47	0.44
2nd	215	3.34	84.47	0.00	28.73	2.86	72.49	0.00	24.65	0.69
3rd	215	2.70	74.87	2.85	16.10	2.80	77.57	2.96	16.68	0.66
4th	215	4.81	79.06	5.56	17.74	4.49	73.77	5.19	16.55	0.72
5th	215	5.13	57.55	9.12	13.20	6.04	67.70	10.73	15.53	0.69
6th	215	5.51	49.41	8.45	16.29	6.92	62.03	10.61	20.45	0.70
7th	215	4.93	49.48	12.62	12.00	6.23	62.61	15.97	15.19	0.64
8th	215	5.44	50.86	11.49	13.70	6.67	62.42	14.10	16.81	0.67
9th	215	3.86	53.77	13.82	12.57	4.60	63.99	16.45	14.96	0.56
10th	209	5.74	50.51	13.33	14.50	6.83	60.07	15.85	17.25	0.65
11th	209	4.75	54.41	18.32	12.23	5.29	60.65	20.42	13.63	0.56
12th	182	6.56	72.76	19.85	16.61	5.67	62.84	17.14	14.35	0.61
13th	104	15.79	97.61	36.52	14.56	9.60	59.35	22.20	8.85	0.70
14th	53	11.67	316.73	5.81	16.43	3.33	90.33	1.66	4.69	0.84
Flag leaf	215	20.77	114.95	36.30	32.95	10.13	56.08	17.71	16.08	0.72

Table 4. Mean squares of phyllochron (PHY) for three maturity classes of winter barley

Source	df	PHY
Maturity class	2	257.88**
Year	5	643.35**
Maturity class x year	10	12.61^{ns}
% of variance components		
Maturity class		28.28
Year		30.21
Maturity class x year		0.00
Heritability		0.96

** – significant at the 0.01 level, ns – non significant

that PHY varied with plant development and that the pattern of leaf emergence was bilinear rather than linear. A change in PHY may occur between leaves 6 and 8 (Miralles et al., 2001). Flood et al. (2000) suggested that variation in PHY may be due to ontogenetic changes, the changes occurring around the double ridge stage. Miralles and Richards (2000) found a linear relationship under long days and a bilinear relationship for leaf emergence under short days.

Table 5. Phyllochron for the three maturity classes (E-early, M-medium, L-late) across 6 growing seasons (GS)

Maturity class	GS						Average
	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	
E	71.5	67.1	69.6	69.2	86.9	70.8	72.5
M	72.2	70.5	72.0	70.1	89.9	79.3	75.6
L	77.9	75.3	73.5	73.5	93.0	80.1	78.9
Average	73.9	70.9	71.7	70.9	89.9	76.7	75.7
		Maturity cl.	Year	Mc x Y	CV		
LSD	0.05	2.2	3.1	5.5	5.1%		
	0.01	3.0	4.2	7.3			

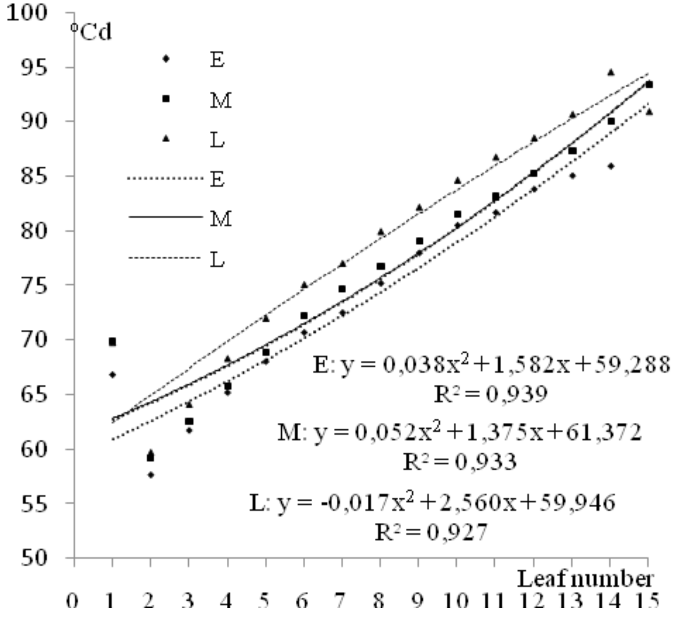

Figure 1. Phyllochron across four early (E), four medium (M) and four late (L) winter barley cultivars across six growing seasons

CONCLUSION

Under the conditions of the Novi Sad region, the average phyllochron of leaves on the main stem of winter barley was 75.7°Cd. The phyllochron in the early cultivars was shorter by 6.4°Cd than in the late ones. Since PHY is determined by the genotypes, growing conditions and interaction between cultivar and growing conditions, selection of appropriate cultivars for different growing conditions is important task of barley growers.

REFERENCES

Arduini, I.; Ercoli, L.; Mariotti, M.; Masoni, A. (2010): Coordination between plant and apex development in *Hordeum vulgare* ssp. *distichum*. *Comptes Rendus Biologies*, 5: 454–460.

Borràs, G.; Romagosa, I.; Van Eeuwijk, F.; Slafer, G. A. (2009): Genetic variability in duration of pre-heading phases and relationships with leaf appearance and tillering dynamics in a barley population. *Field Crop Research*, 113: 95–104.

Borràs-Gelonch, G.; Slafer, G. A.; Casas, A. M., Van Eeuwijk, F.; Romagosa, I. (2010). Genetic control of pre-heading phases and other traits related to development in a double-haploid barley (Hordeum vulgare L.) population. *Field Crop Research*, 119: 36–47.

Dofing, S. M.; Karlsson, M. G. (1993): Growth and development of uniculm and conventional-tillering barley lines. *Agron. J.*, 85: 58– 61.

Flood, R. G.; Moody, D. B.; Cawood, R. J. (2000): The influence of photoperiod on barley development. *Cereal Res. Commun.*, 28: 371–378.

Frank, A. B.; Bauer, A. (1995): Phyllochron differences in wheat, barley and forage grasses. *Crop Sci.*, 35: 19–23.

Juskiw, P. E.; Jame, Y. W.; Kryzanowski, L. (2001): Phenological development of spring barley in a short-season growing area. *Agron. J.*, 93: 370–379

Juskiw, P. E.; Helm, J. H. (2003): Barley response to seeding date in central Alberta. *Can. J. Plant. Sci.*, 83: 275–281.

Johnen, T.; Boettcher, U.; Kage, H. (2012): A variable thermal time of double ridge to flag leaf emergence phase improves the predictive quality of a CERES-Wheat type phenology model. *Computers and Electronics in Agriculture*, 89: 62–69.

Kamali, M. R. J.; Boyd, W. J. R. (2000): Quantifying the growth and development of commercial barley cultivars over two contrasting growing seasons in Western Australia. *Aust. J. Agr. Res.*, 51: 487–501.

McMaster, G. S.; Wilhelm, W. W.; Morgan, J. A. (1992): Simulating winter wheat shoot apex phenology. *J. Agric. Sci.* (Cambridge), 119: 1–12.

McMaster, G. S.; Wilhelm, W. W. (2003): Phenological responses of wheat and barley to water and temperature: improving simulation models. *J. Agric. Sci.* (Cambridge), 141: 129–147.

McMaster, G. S. (2005): Phytomers, phyllochrons, phenology and temperate cereal development. *J. Agric. Sci.* (Cambridge), 43: 1–14.

Mirschel, W.; Wenkel, K. O.; Schultz, A.; Pommerening, J.; Verch, G. (2005): Dynamic phonological model for winter rye and winter barley. *European Journal of Agronomy*, 23: 123–135.

Miglietta, F. (1991): Simulation of wheat ontogenesis: I. Appearance of main stem leaves in the field. *Clim. Res.*, 1: 145–150.

Miralles, D. J., Richards, R. A. (2000): Responses of leaf and tiller emergence and primordium initiation in wheat and barley to interchanged photoperiod. *Ann. Bot.*, 85: 655–663.

Miralles, D. J., Ferro, B. C., Slafer, G. A. (2001). Developmental responses to sowing date in wheat, barley and rapeseed. *Field. Crop Res.*, 71: 211–223.

P r ž u l j, N. (2001): Cultivar and year effect on grain filling of winter barley. *Plant Breeding and Seed Science*, 45: 45–58.
P r ž u l j, N.; M o m č i l o v i ć, V.; P e r o v i ć, D.; N o ž i n i ć, M. (2012): Variation in phenological development of winter barley. In: G. Zhang et al. (*Eds*) *Proceedings od 11th International Barley Genetics Symposium*, pp. 252–259, 15–20 april 2012, Hangzhou, China.
R i c k m a n, R. W.; K l e p p e r, B. L. (1991): Tillering in wheat. In: Hodges T. (ed). *Predicting crop phenology*. Boston: CRC. pp 73–83.

УТИЦАЈ СОРТЕ И ГОДИНЕ НА ФИЛОХРОН ОЗИМОГ ЈЕЧМА

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РЕЗИМЕ: Развиће и раст листова жита значајно утиче на принос зрна јер акумулација суве материје зависи од лисне површине која апсорбује сунчеву светлост. Филохрон се дефинише као временски интервал између појаве сукцесивних листова на главном стаблу. Циљ овог истраживања је да се одреди ефекат године и сорте на дужину филохрона код озимог јечма. Дванаест сорти озимог јечма различитих по пореклу и времену до цветања тестирано је током шест производних сезона, од 2002/03. до 2007/08. на локалитету „Нови Сад“. Најдужи филохрон (81.6 °Cd) имала је сорта дворедог јечма „Кордоба“, а најкраћи (71.0 °Cd) сорта дворедог јечма „Новосадски 581“. Ране соте имале су најбржи, средње ране, средњи и касне сорте најспорији пораст листова. Код раних сорти просечна вредност филохрона износила је 72.5 °Cd, средње раних 75.6 °Cd и касних 78.9 °Cd. Тестиране сорте показале су значајну варијабилност у дужини филохрона, што може представљати основу у избору најадаптабилнијих генотипова у одређеним условима спољне средине.

КЉУЧНЕ РЕЧИ: јечам, *Hordeum vulgare*, филохрон, херитабилност, варијанса, филохрон