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Interrelationships between Phenology and Grain Yield of Winter Barley in Semiarid Environment

- Original scientific paper -

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Abstract: Each yield component of barley is determined by developmental events during specific phenological phases. The number of spikes per unit area is established from tillering to jointing. The number of kernels per spike is established from jointing, i.e., it starts from double-ridge of apical meristem development and sets shortly after anthesis. Duration and rate of grain filling (GF) determines kernel weight. The objectives of this study were to examine the variation and relationships among phenology and yield components.

Twenty-four winter barley cultivars were used in this investigation. The stage of leaf development of the main culm was referenced to the Haun scale. All phenological measurements were assessed using growing degree days (GDD) with a base temperature of 0˚C. The relationship between kernel weight and GDD accumulated from anthesis for each plot was determined by fitting the quadratic polynomial.

The duration from planting to flag leaf elongation stage was 1223 GDD across two-rowed varieties and 1304 GDD across six-rowed varieties. The variety NS 519 had the shortest GF period (648 GDD), the variety Marinka the longest (940 GDD). GF rate was mainly determined by genotype (44.3% of total variation) and GxY interaction (31.1% of total variation). GF rate across two-rowed varieties was rather higher (7.251 mg 100 GDD^{-1}) than across six-rowed varieties (6.395 mg 100 GDD^{-1}). The duration of the vegetative and generative phases should be balanced, since neither too early nor too late a flowering will bring maximum yields. Our results show that the pre-heading period varied more than the GF period in the tested varieties. Selection for shorter vegetative period and longer GF period is recommended in the development of varieties for semiarid conditions of growing.

Key words: Grain filling, grain yield, components phenology, vegetative period, winter barley (*Hordeum vulgare* L).

Introduction

Each yield component of barley is determined by developmental events occurring during specific phenological phases. Number of spikes per unit area is establishing from tillering to jointing. In winter barley, tillering typically starts in the fall and it finishes in the spring. Number of tillers depends on genetic factors, i.e., tillering capacity, ecological factors, which ensure the realization of tillering capacity, and the interaction of these two factors, ***Davidson*** and ***Chevalier***, 1990. Number of kernels per spike, the second most important yield component, sets in the period from double-ridge stage of apical meristem till shortly after anthesis, ***Kirby*** and ***Appleyard,*** 1981. In this period, rate and duration of spikelet development and floret generation as well as the effectiveness of pollination define the final number of kernels. Generally, spikes develop between single ridge stage and flag leaf elongation. Kernel weight is the third most important yield component. During first two weeks after anthesis, the number of kernel cells is determined, ***Brocklehurst,*** 1977 and, after that, kernel weight is determined by the duration and rate of grain filling (GF), ***Wiegand*** and ***Cuellar***, 1981. Plant genotype and environment, fist of all temperature and moisture, control the process of kernel filling, ***Sofield et al***., 1977.

According to our knowledge, limited data are available about relationships between phenology and yield components of winter barley in semiarid regions of southeastern Europe. The objectives of this study were to examine (i) the variation of phenology and yield components and (ii) the relationships between growth and yield components.

Material and Methods

Twenty-four winter barley cultivars, twelve two-rowed and twelve six-rowed, differing in origin, duration of vegetative and generative phases and other physiological traits were used in this investigation. The trials consisted of two identical blocks. The experimental design of each block was randomized complete block in three replicates. Each plot consisted of six rows 15 cm apart and 5m long ($5m^2$). Seedling dates were October 4, 1999, October 3, 2000, and October 8, 2001. The sowing rates were 200 seeds m^{-2} for the six-rowed and 250 for the two-rowed cultivars. Shortly after emergence, five random plants in the second row, 30 cm away from plot border, were tagged for observation during the growing season. The stage of leaf development of the main culm was referenced to the Haun scale, ***Haun***, 1973, at intervals of 3-4 days from emergence to heading. The Haun scale is based on the number of leaves and sequence of leaf insertion on the main stem. All phenological measurements were assessed using growing degree days (GDD) with the base temperature of 0˚C.

At anthesis, 60 main spikes from each plot of the first trial that flowered at the same day were tagged. Samples of five tagged spikes/plant were collected from each plot at 3-4 days intervals beginning five days after anthesis till harvest maturity for determination GF rate and above ground dry matter accumulation. The relationship between kernel weight and GDD accumulated from anthesis to physiological maturity was determined for each plot by fitting the quadratic polynomial $W=a+bt+ct^2$, where W is kernel dry weight, t is time (GDD) from anthesis and a, b, c are regression coefficients, ***Pržulj***, 2001.

The second trials was used for the determination of grain yield components in each year and plot, i.e., number of spikes m^{-2}, number of kernels spike-1, kernel weight spike-1, and grain yield. Analysis of variance for each trait was conducted by using MSTAT-C program. Variance components were estimated using expected mean squares to compare the relative magnitude of main effect and interaction variances, ***Comstock*** and ***Moll***, 1963. Simple correlation coefficients were calculated for the relationships between vegetative period and grain yield components and GF period and grain yield components.

Results and Discussion

Durations of periods from planting to flag leaf elongation stage and from planting to heading were determined mainly by genotype of the tested varieties, although year and GxY interaction also significantly affected these phenological phases (Table 1). Genotype controlled the largest part of the variation, as confirmed by high heritability (0.90). The duration from planting to flag leaf elongation stage was 1223 GDD across the two-rowed varieties and 1304 GDD across the six-rowed varieties (from Table 2). The duration from planting to heading ranged from 1337 GDD, in the two-rowed barley variety NS 331, to 1554 GDD, in the six-rowed variety Gerbel (Table 2). Across years and varieties, the two-rowed type of barley accumulated during this period 87 GDD less than the six-rowed type (Table 1). A general conclusion can be drawn that the two-rowed varieties from Novi Sad, i.e., from the place where the experiment was conducted, had shorter periods from planting to flag leaf elongation and planting to heading than the two-rowed barley varieties from Germany, France, England, and Holland which headed 3 to 10 days later. The six-rowed varieties also exhibited significant differences in the duration of vegetative period but these differences amounted to a few days only and they were not consistent in relation to the geographic origin of the varieties.

Duration of GF stage depended of year, variety and specific behavior of the varieties in the tested years (P<0.01). The interaction genotype x year determined the main part of variation (50.6%) of this trait. The variety NS 519 had the shortest GF period (648 GDD), the variety Marinka the longest (940 GDD). There was no consistency between variety origin and GF duration, i.e., among both Serbian and foreign varieties there were genotypes with either short or long GF periods. GF rate was mainly determined by genotype (44.3% of total variation) and by GxY interaction (31.1% of total variation) (Table 1). GF rate across the two-rowed

Table 2. Effect of Cultivar and Year on Duration of Period From Planting to Flag Leaf Appearance, Planting to Heading, Flag Leaf Appearance to Heading, Grain Filling (GF) Duration, Grain Filling Rate (mg 100GDD^{-1}), Number of Spikes per m^2, Number of Kernels per Spike, Kernel Weight per Spike, and Grain Yield (kg ha^{-1}) in 24 Winter Barley Cultivars across Three Years

Uticaj sorte i godine na dužinu perioda od setve do pojave zaliska, setve do klasanja, pojave zaliska do klasanja, dužina nalivanja zrna, brzina nalivanja zrna, broj klasova po m^2, broj zrna po klasu, težina zrna po klasu i prinos zrna kod 24 sorte ozimog ječma tokom tri godine

Cultivar (origin and spike type) Sorta (poreklo i tip klasa)	Planting to flag leaf Setva do pojave zaliska	Planting to heading Setva do klasanja	GF duration Dužina nalivanja zrna	GF rate (mg 100) (GDD^{-1}) Brzina nalivanja zrna	Spikes m^{-2} Klas/m^2	Kernels spike^{-1} Zrna po klasu	Kernel wt. spike^{-2} (mg) Težina zrna po klasu	Grain yield (kg ha^{-1}) Prinos zrna
1 *	1190	1351	662	7.379	579	25	1.35	6672
2	1179	1351	700	7.012	565	25	1.26	6700
3	1163	1337	660	6.917	578	25	1.19	6539
4	1075	1343	648	7.385	630	28	1.33	6022
5	1217	1399	687	7.605	702	25	1.45	6817
6	1239	1447	748	7.497	636	26	1.44	6728
7	1178	1365	657	7.469	748	22	1.31	6322
8	1261	1472	758	7.347	564	28	1.35	7151
9	1266	1440	664	7.485	536	24	1.46	6236
10	1286	1447	677	7.231	678	24	1.19	6406
11	1307	1527	753	6.928	683	28	1.40	5639
12	1310	1523	940	6.724	457	38	1.76	5464
13	1304	1492	700	7.264	462	47	2.79	6817
14	1292	1507	729	6.717	378	54	2.70	6761
15	1305	1502	660	6.861	411	50	2.43	6939
16	1238	1460	665	6.862	343	50	2.56	6172
17	1335	1517	763	6.175	368	51	2.32	6622
18	1302	1460	656	6.561	437	55	2.69	5021
19	1265	1439	702	6.376	430	51	2.18	5861
20	1348	1554	826	5.459	350	58	2.63	6277
21	1320	1499	855	5.728	421	55	2.44	8367
22	1328	1498	675	6.501	437	54	2.68	7994
23	1326	1523	690	5.874	451	55	2.32	3989
24	1288	1460	710	6.361	385	63	2.84	7539
$LSD_{0.05}$	19	22	16	0.184	42	3.1	0.25	680
$LSD_{0.01}$	25	30	21	0.243	62	4.1	0.33	898
2000	1235	1423	789	6.448	640	45	2.15	9413
2001	1295	1465	683	6.851	452	36	1.86	5404
2002	1260	1476	676	7.166	438	39	1.88	4565
$LSD_{0.05}$	7	8	6	0.065	17	1.1	0.09	241
$LSD_{0.01}$	9	11	7	0.086	22	1.4	0.12	318

*1) NS 183 (SMN, 2R), 2) NS 293 (SMN , 2R), 3) NS 331 (SMN, 2R), 4) NS 519 (SMN, 2R), 5) Sonate (DEU, 2R), 6) Hanna (DEU, 2R), 7) Marylin (DEU, 2R), 8) Melusine (FRA, 2R), 9) Belivia (FRA, 2R), 10) Waveney (GBR, 2R), 11) Mallard (GBR, 2R), 12) Marinka (NLD, 2R), 13) NS 27 (SMN, 6R), 14) NS 313 (SMN, 6R), 15) Galeb (SMN, 6R), 16) NS 717 (SMN, 6R), 17) Katja (DEU, 6R), 18) Majo (DEU, 6R), 19) Robur (FRA, 6R), 20) Gerbel (FRA, 6R), 21) Kozir (RUS, 6R), 22) Michailo (RUS, 6R), 23)Kearney (USA, 6R), 24) Dundy (RUS, 6R)

varieties was higher (7.251 mg 100 GDD^{-1}) than across the six-rowed varieties (6.395 mg 100 GDD^{-1}). The negative correlation between the number of kernels per spike and GF rate confirms this finding (Table 3). Sonate and NS 27 had the fastest GF rates within the two-rowed and six-rowed varieties, respectively. The slowest GF rates were found in Marinka among the two-rowed varieties and Kearney among the six-rowed varieties. GF duration was under strong ecological influence (h^2=0.55) but GF rate was under strong genetic influence (h^2=0.80). ***Van Sanford***, 1985, ***Campbell et al,.*** 1990, ***Hunt et al.,*** 1991, found that genetic factors determine to a larger extent the rate of GF while environmental factors, first of all temperature, determine to a large extent the duration of GF. ***Nass*** and ***Reiser***, 1975, ***Gebeyehou et al,.*** 1982, and ***Wong*** and ***Baker***, 1986 reported a positive correlation between an effective filling period and grain yield, but **van *Sanford***, 1985, and ***Darroch*** and ***Baker***, 1990, pointed out that high kernel weight is associated with a high rate of GF. In a previous study, ***Pržulj***, 2001, found that in semiarid conditions the environment favors a higher rate and shorter duration of GF, i.e., cultivars with faster rate and shorter duration of GF produce higher yields. The duration of the vegetative and generative phases should be balanced, since neither too early nor too late a flowering will bring maximum yields. Choosing genotypes with a high GF rate, whose developmental dynamics is suitable for particular growing conditions, represents a safe way to develop stable, adaptable and high-yielding cultivars. A negative correlation exists between GF duration and rate which have an opposite effect on grain yield.

Number of spikes m^{-2} was influenced by all three factors approximately to the same measure, while the other two yield components were mainly determined by the genotype, as confirmed by a high heritability value (Table 1). Close to 80% of grain yield variability was due to ecological factors, as confirmed by a rather low heritability value. The two-rowed varieties had a higher number of spikes m^{-2}, a lower number of kernels $spike^{-1}$ and a lower kernel weight $spike^{-1}$ than the six-rowed varieties. Number of spikes m^{-2} was negatively correlated with the periods from planting to flag leaf elongation and from planting to heading. This apparently puzzling statement could be explained by the ability of barley to self-regulate stand density. Indeed, varieties with a long period from planting to heading develop a large number of tillers and a large number of kernels per spike in the course of fall and spring. In 2000 and 2002, the droughts that occurred after tillering reduced the number of spikes that had already been formed, which caused a situation that the later-heading varieties had a lower spike number m^{-2} than the early-heading ones.

This explains the negative correlation between the length of vegetative period and grain yield. All three yield components, spikes m^{-2}, kernels $spike^{-1}$, and kernel weight $spike^{-1}$, were in positive correlation with grain yield (Table 3).

Our results showed that the tested varieties differed more in the duration of the pre-heading period than in the duration of the GF period. Selection for reduced vegetative period and increased GF period is recommended in the development of varieties for semiarid conditions of growing.

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Odnos fenoloških faza i prinosa zrna kod ozimog ječma u semiaridnim uslovima

- Originalni naučni rad -

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Rezime

Komponente prinosa ječma formiraju se u određenim fenološkim fazama: broj klasova tokom bokorenja, broj zrna po klasu tokom vlatanja pa do završetka cvetanja, a masa zrna od formiranja zrna do fiziološke zrelosti. Cilj ovog istraživanja bio je da se utvrdi odnos između fenoloških faza i komponenti prinosa kod 24 sorte ozimog ječma. Faze razvoja lista glavnog stable određene su na osnovu skale po Haun-u. Kao vremenska skala kod fenoloških opažanja korišćena je suma temperatura većih od 0°C (GDD). Odnos između mase zrna i sume temperature u toku perioda rasta određen je pomoću kvadratne jednačine.

Prosečna suma aktivnih temperatura od nicanja do pojave lista zastavičara bila je 1223 GDD kod dvoredih sorti i 1304 GDD kod šestoredih sorti ječma. Sorta NS 519 imala je najkraći (648 GDD) a sorta Marinka najduži period nalivanja zrna (940 GDD). Period nalivanja zrna uglavnom je zavisio od sorte (44,3% od ukupne varijanse) i interakcije GxY (31,1% od ukupne varijanse). Intenzitet nalivanje zrna kod dvoredih sorti (7.251 mg 100 GDD^{-1}) bio je značajno veći nego kod šestoredih sorti (6,395 mg 100 GDD^{-1}). Kako bi se ostvario maksimalan prinos i kvalitet, trajanje vegetativne faze, tokom koje se formira broj klasova i zrna, i generativne faze, tokom koje se formira veličina i masa zrna, treba da bude uravnotežen. Naši rezultati su pokazali da kod ječma u semiaridnim uslovima dužina perioda do klasanja varira više nego dužina perioda nalivanja zrna. Selekcija sorti sa kraćim vegetativnim periodom i dužim periodom nalivanja zrna preporučuje se prilikom izbora sorti namenjenih za gajenje u semiaridnim uslovima.

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