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ASSESSING WHEAT PERFORMANCE USING ENVIRONMENTAL INFORMATION

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The partial least squares (PLS) regression model was applied to wheat data set with objective to determining the most relevant environmental variables that explained biomass per plant and grain yield genotype × environment interaction (GEI) effects. The data set had 25 wheat genotypes (20 landraces + 5 cultivars) tested for 4 years in two different water regimes: rainfed and drought. Environmental variables such as maximum soil temperature at 5 cm in April and May, soil moisture in the top 75 cm in March, and sun hours per day in May accounted for a sizeable proportion of GEI for biomass per plant. Similar results were obtained for grain yield: maximum soil temperature at 5 cm in April, May and June, and sun hours per day in May were related to the factor that explained the largest portion (>38%) of the GEI. Generally,

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wheat landraces are able to better exploit environments with higher temperatures and lower water availability during vegetative growth (March-June) than cultivars.

Key word: biomass, GEI, grain yield, PLS regression, wheat

INTRODUCTION

Grain yield is a major selection criterion for improved adaptation to environmental stresses in many wheat breeding programs. It is commonly limited by seasonal rainfall, rainfall distributions and temperature. Many studies have assessed interactions of a genotype and a production environment on wheat grain yield (ANNICCHIARICO, 1997; VARGAS et al., 2001; LILLEMO et al., 2004; KAYA et al., 2006). On the other hand, several studies established the importance of total biomass to increase yield in wheat (REYNOLDS et al., 1999; SHEARMAN et al., 2005), especially in drought stress conditions (van GINKEL et al., 1998; QUARRIE et al., 1999; DODIG, 2005).

Wheat in Serbia is mainly grown under varied rainfed and water stress conditions. With predicted climate change in southern Europe (WAGGONER, 1993) the frequency of dry years, and therefore drought will increase. Beside the decrease in yield, the most important consequence of drought is the increase in genotype × environment interaction (GEI) (BLUM, 1988). GEI is described as the differential response of cultivars to environmental changes. An understanding of the environmental causes is of fundamental importance for understanding GEI, for assessing the association between phenotypic and genotypic values, and for enhancing the selection of superior and stable genotypes (CROSSA et al., 1999).

GEI has been studied, described, and interpreted by means of several statistical models (CROSSA, 1990). When additional information on external environmental variables such as meteorological data or soil variables is available the partial least square (PLS) regression (AASTVEIT and MARTENS, 1986) can be used to determine which of these variables influence GEI. VARGAS et al. (1999) studying advantages and/or disadvantages of several statistical models for studying and interpreting GEI with a large number of external and/or cultivar variables in wheat trials. Results of their study indicated that PLS regression model was effective in detecting the environmental variables that explained a sizeable proportion of GEI variability.

In this study, we applied PLS regression model to 25 wheat genotypes grown under rainfed and drought stress conditions with the objective of determining the most important environmental factors that influence the genotype × environment interaction of biomass per plant and grain yield. We also discussed cultivars vs. landraces response to environmental changes.

MATERIAL AND METHODS

The data set used in this study represents total biomass per plant (g) and grain yield (kg ha^{-1}) of 20 wheat landraces and 5 wheat cultivars (Table 1) tested for 4 yr (1998-2001) under three treatments: fully irrigated plots (IP), rainfed plots (RP) and under a rain-out plot shelter (drought plots-DP). In this study we included only RP and DP treatments. The rain-out shelter was erected above the plots at the end of the winter period (end of February-beginning of March) when most of the genotypes were at the tillering stage. Amounts of precipitation (mm) during the vegetative period (March-June) were 205.4, 263.3, 74.6 and 284.4 for 1998-2001, respectively. The sowing dates were 1 November 1997, 28 October 1998, 26 October 1999, and 21 October 2000. In each year, the experiment was set up in a randomized complete block design with three replicates. In the first two years, each genotype was sown in a single 1 m row at 20 cm spacing in three replications, with a sowing rate of 60 seeds per row. In the second two years, plots consisted of three 1 m long rows at 20 cm spacing in three replications, with a sowing rate of 80 seeds per row.

Table 1. Genotype name, type and country origin of the genotypes grown in rainfed and drought trials over 4 year (1997-2001)

Genotype	Type	Origin	ID*
Arena	cultivar	Serbia	1
Kraljevica	cultivar	Serbia	2
Pobeda	cultivar	Serbia	3
Rusija	cultivar	Serbia	4
Evropa 90	cultivar	Serbia	5
BL-91	landrace	Bosnia and Herz.	6
BL-386	landrace	Bosnia and Herz.	7
BL-357	landrace	Bosnia and Herz.	8
BL-376	landrace	Bosnia and Herz.	9
BL-209	landrace	Bosnia and Herz.	10
Bl-1	landrace	Bosnia and Herz.	11
BL-21	landrace	Bosnia and Herz.	12
BL-63	landrace	Bosnia and Herz.	13
BL-108	landrace	Bosnia and Herz.	14
BL-177	landrace	Bosnia and Herz.	15
BL-183	landrace	Bosnia and Herz.	16
BL-210	landrace	Bosnia and Herz.	17
BL-214	landrace	Bosnia and Herz.	18
BL-306	landrace	Bosnia and Herz.	19
U-1	landrace	Croatia	20
U-2	landrace	Croatia	21
Bl-11	landrace	Bosnia and Herz.	22
BL-49	landrace	Bosnia and Herz.	23
BL-262	landrace	Bosnia and Herz.	24
BL-274	landrace	Bosnia and Herz.	25

*This identifier relates to genotype numbers on the biplots

The dependent variable (biomass per plant and grain yield) ***Y*** matrix was of size 8 × 25 (8 rows corresponding to treatments and 25 columns corresponding to cultivars). There were 21 explanatory covariables in the ***Z*** matrix of size 8 × 21 (treatments × environmental factors): mean minimum temperature [°C] (mT), mean maximum temperature [°C] (MT), mean soil moisture in the top 75 cm [%] (sm), mean sun hours per day (sh), mean maximum soil temperature at 5 cm [°C] (mst) and winter period (December-February) precipitation [mm] (wpp). All covariables (except wpp) were measured during the growth cycle in March (3), April (4), May (5) and June (6).

Table 2. Values of environmental covariables (Cov) by treatment (RP-rainfed plots and DP-drought plots) in period 1998-2001

	Treatment							
Cov.	DP98	DP99	DP00	DP01	RP98	RP99	RP00	RP01
MT3[†]	14.5	15.0	15.9	15.6	12.5	13.3	14.6	14.5
MT4	22.2	21.9	24.8	19.1	19.6	18.9	22.3	18.0
MT5	26.9	27.8	31.4	28.2	23.4	23.8	28.1	24.4
MT6	34.5	33.8	37.2	32.7	28.5	26.7	34.2	27.7
mT3	-1.0	1.5	-0.3	3.5	-1.9	0.8	-1.2	2.7
mT4	6.0	6.3	6.6	5.4	4.8	5.0	5.2	3.5
mT5	9.5	10.3	9.7	10.5	9.1	9.4	9.0	9.5
mT6	14.1	14.8	12.6	12.9	12.9	13.4	11.6	11.7
sm3	21.6	21.9	18.8	21.1	21.2	20.9	18.4	19.5
sm4	21.8	21.4	19.3	19.2	19.8	18.8	16.3	17.4
sm5	21.6	20.1	17.3	17.2	18.4	17.4	13.8	15.8
sm6	19.0	17.8	15.9	14.8	14.6	13.8	12.2	13.3
sh4	6.3	4.6	5.6	4.1	6.3	4.6	5.6	4.1
sh5	5.7	4.9	6.6	4.5	5.7	4.9	6.6	4.5
sh6	5.9	7.0	10.0	6.9	5.9	7.0	10.0	6.9
sh7	9.4	7.4	10.4	7.9	9.4	7.4	10.4	7.9
mst3	9.4	9.7	11.2	13.4	9.4	9.7	11.2	13.4
mst4	18.2	17.2	24.6	18.2	18.2	17.2	24.6	18.2
mst5	24.6	25.2	34.7	28.7	24.6	25.2	34.7	28.7
mst6	33.8	32.5	43.5	30.7	33.8	32.5	43.5	30.7
wpp	142	81	137	64	142	81	138	64

[†] MT, mean maximum temperature; mT, mean minimum temperature; sm, mean soil moisture in the top 75 cm; sh, mean sun hours per day; mst, mean maximum soil temperatures at 5 cm; wpp, winter period precipitation (December-February); 3, March; 4, April; 5, May; 6, June.

Based on two data matrix ***Y*** and ***Z*** (which is previously double-centred i.e. column centred) we applied the partial least square (PLS) regression model (AASTVEIT and MARTENS, 1986; TALBOT and WHEELWRIGHT, 1989; VARGAS et al., 1998). The general idea of this procedure is to relate several ***Y*** variables to several ***Z*** variables (AASTVEIT and MARTENS, 1986). In the context of plant breeding trials ***Y*** matrix represented grain yield or biomass per plant data several genotypes tested across several environments (or treatments) and ***Z*** matrix represented additional information (about environments or genotypes) collected during this trials. Both data matrices can be expressed as:

$$\boldsymbol{Y} = \boldsymbol{TQ}' + \boldsymbol{F} \text{ and } \boldsymbol{Z} = \boldsymbol{TP}' + \boldsymbol{E}.$$

where matrix ***T*** contains the ***Z*** scores; matrix ***P*** contains the ***Z*** loadings; matrix ***Q*** contains the ***Y*** loadings and ***F*** and ***E*** is the residual of variation. VARGAS et al. (1998) stated that the relationship between ***Y*** and ***Z*** is transmitted through the latent variables (or dimensions) ***T***. The number of latent variables (***T***), which optimally predict variation in the Y matrix, is determined using cross validation procedure (STONE, 1974). Results of the PLS procedure will be presented using the biplot graph (GABRIEL, 1971) and interpreted by means of the “inner-product” principle (KROONENBERG, 1995). The partial least squares regression procedure was performed using Statistica 7.1 software (StatSoft, Inc. 2004).

RESULTS AND DISCUSSION

For both biomass per plant and grain yield, the analysis of variance showed that the genotype × treatment interaction was highly significant (P<0.001). The main effect of treatments explained 67 and 34% of the total sum of squares, whereas differences between genotype means contributed 14 and 45% and the genotype × treatment interaction 19 and 21% for biomass per plant and grain yield, respectively (data not shown). The cross-validation procedure for the number of significant dimensions suggests that only one dimension (latent vector) out of eight possible is of relevance for prediction.

Biomass per plant. - Results from the PLS procedure showed that the first and second dimensions explained 31.6 and 13.5% of the GEI in ***Y*** for biomass per plant, respectively. For this trait, the variance of explanatory variables maximum soil temperature at 5 cm in May (mst5), soil moisture in top 75 cm in March (sm3), sun hours per day in May (sh5), and maximum soil temperature at 5 cm in April (mst4) that was explained by the first PLS dimension is large (>75%) (Table 3). These variables were associated with Dimension 1, which explained a large proportion of the GEI, and, except for sm3, they had positive loadings with the first dimension. Other environmental variables such as soil moisture in the top 75 cm in May (sm5), maximum soil temperature at 5 cm in June (mst6), and minimum temperature in June (mT6) were also explained well by the first PLS dimension (>50%). On the other hand variability of minimum temperature in March, April and May (mT3, mT4, and mT5), sun hours per day in March (sh3), and winter period precipitation (wpp) was not explained well by the first dimension (<5%). The first PLS dimension explained 17 to 50% of the variability of the remaining explanatory variables (Table 3).

Table 3. Proportion of total variance of X covariables (Cov) explained by the first dimension (Dim. 1) and loadings of X environmental covariables with first dimension

Biomass per plant			Grain yield		
Cov.	Loadings	Dim. 1 (%)	Cov.	Loadings	Dim. 1 (%)
mst5[†]	0.352	98.6	mst5	0.341	93.9
sm3	-0.322	85.1	MT5	0.321	63.8
mst3	0.314	32.4	MT3	0.314	40.1
MT3	0.293	34.4	mst4	0.307	93.4
sh5	0.285	83.6	MT6	0.285	50.2
mst4	0.278	79.0	sh5	0.281	87.6
mT6	-0.277	53.6	sm3	-0.267	69.8
sm5	-0.258	58.8	mst6	0.244	78.6
MT5	0.246	40.6	sh6	0.235	53.5
sm4	-0.245	50.0	mst3	0.232	10.8
mst6	0.195	55.9	MT4	0.209	48.1
MT6	0.179	22.0	mT6	-0.199	28.1
sh6	0.154	31.3	sh4	0.183	52.1
sm6	-0.149	26.0	sm5	-0.164	29.1
mT3	0.119	0.1	sm4	-0.138	21.6
sh3	-0.109	0.9	mT4	0.106	11.8
MT4	0.107	17.3	wpp	0.081	15.4
sh4	0.101	26.5	mT5	0.060	1.2
mT5	0.034	1.2	sm6	-0.045	6.0
wpp	-0.028	2.0	mT3	0.033	3.6
mT4	-0.025	0.2	sh3	0.006	2.6

[†] MT, mean maximum temperature; mT, mean minimum temperature; sm, mean soil moisture in the top 75 cm; sh, mean sun hours per day; mst, mean maximum soil temperatures at 5 cm; wpp, winter period precipitation (December-February); 3, March; 4, April; 5, May; 6, June.

Figure 1a depicts the first two PLS dimensions with all 25 wheat genotypes evaluated in the 8 treatments, plus 21 environmental covariables. It shows that the first dimension was dominated by differences between treatments with higher biomass per plant RP98 and RP99 i.e. DP98 and DP99 (Figure 1a and Table 2) vs. treatments with lower biomass per plant RP00 and RP01 i.e. DP00 and DP01. On the PLS biplot four subsets of correlated treatments can be distinguished: (RP98 and DP98), (RP99 and DP99), (RP00 and DP00) and (RP01 and DP01). This suggests that differences in biomass per plant among consecutive years are larger than differences among treatments within a year. From Figure 1a it can be also seen that the first dimension related the differences between high biomass treatments vs. low biomass treatments with contrast between soil moisture in top 75 cm from March to June (sm3, sm4, sm5, and sm6), minimum temperature in April and June (mT4 and mT6), sun hours in March (sh3), and winter period precipitation (wpp) (with negative first dimension loadings) vs. soil temperatures at 5 cm from March to June (smt3, smt4, smt5, and smt6), maximum temperature from March to June (MT3, MT4, MT5, and MT6), sun hours in April, May and

June (sh4, sh5, and sh6), and minimum temperature in March and May (mT3 and mT5) (with positive first dimension loadings). The environmental covariables that are located farther from the centre of the PLS biplot caused larger GEI. The smallest contribution to the GEI for biomass per plant had minimum temperature in April (mT4) (Figure 1a).

In general, the years with higher biomass per plant (1998 and 1999) in both treatments had more precipitation during winter period and higher soil moisture in top 75 cm during entire vegetative growth than the remaining two years. The years with lower biomass per plant (2000 and 2001) in both treatments were characterized by high maximum air and soil temperatures. Slightly more tested genotypes had a positive interaction with treatments in 1998 and 1999 than with treatments in the second two years (13 vs. 12). Most genotypes are concentrated in the upper left quadrant of the biplot and had a positive biomass interaction with relatively cool and wet year such as 1998. Only a few genotypes had a high positive biomass interaction with the warm and dry year 2000 (6, 11, and 19). CROSSA et al. (1999) found maximum temperature as most important covariable for explaining GEI for biomass in maize.

The first dimension clearly separates 10 landraces with the highest mean biomass over treatments (25, 24, 23, 16, 13, 22, 14, 17, 21, and 15) from 10 landraces with the lowest mean biomass over treatments (18, 10, 6, 19, 20, 9, 11, 7, 8, and 12). Landraces with high biomass were favoured by good water status during the entire vegetative growth and sun hours in March (tillering stage) and/or maximum temperature in June (grain filling). Low biomass landraces 6, 11, and 19 were less sensitive to high soil and moisture temperatures from April to June in RP00 and DP00. The positive interaction between low biomass landraces 18, 10, 20, 9, 7, 8 and 12 with RP01 and DP01 seems to be due to higher minimum and maximum temperatures in March and May. Cultivars also showed different sensitivity to treatments. Cultivars 1 and 3 were favoured by mT6 and soil moisture from March to June. This led to higher biomass in DP99 and RP99, respectively. Cultivar 5 had high biomass in RP98 probably because of higher sh3 and wpp. Cultivars 2 and 4 showed a positive biomass interaction with DP01 and RP01, respectively. These treatments scored for high minimum and maximum temperatures in March and May.

Grain yield. - Results from the PLS procedure showed that the first and second dimensions explained 31.2 and 18.4% of the GEI in ***Y*** for grain yield, respectively. For grain yield the first two dimensions explained slightly more of the variance in the GEI matrix than for biomass per plant (49.6 vs. 45.1%). For grain yield, the first PLS dimension explained a large proportion of the total variability of maximum soil temperature at 5 cm in May (mst5) (93.9%), maximum soil temperature at 5 cm in April (mst4) (93.4%), sun hours per day in May (sh5) (87.6%), and maximum soil temperature at 5 cm in June (mst6) (78.6%) (Table 3).

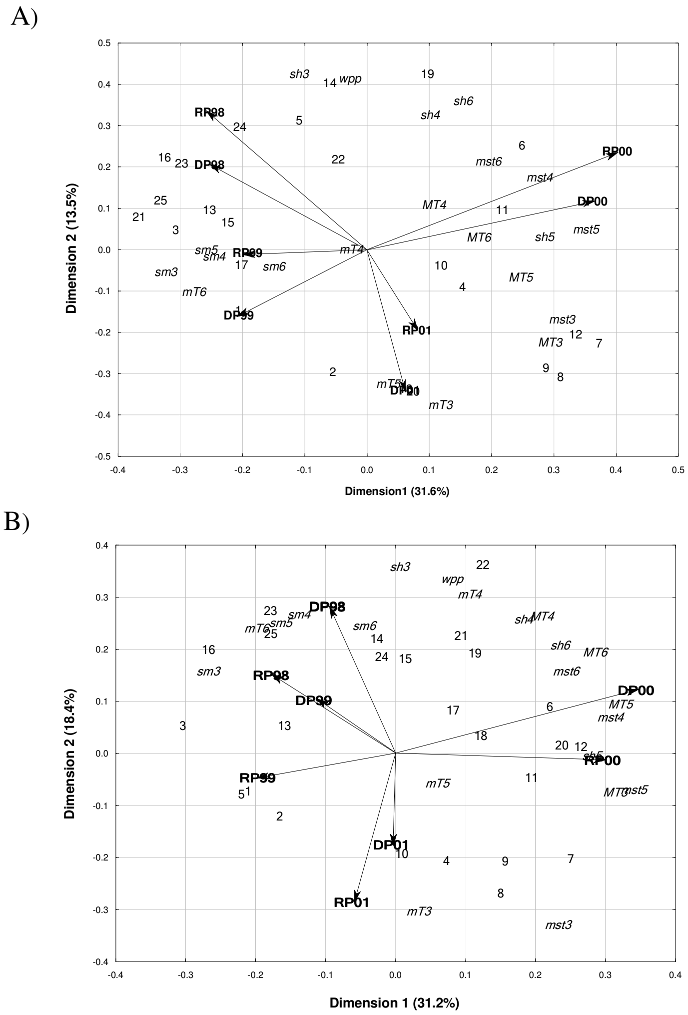

Fig.1. Biplot from PLS procedure for biomass per plant (A) and grain yield (B) for 25 wheat genotypes tested across 8 environments. Genotype codes are given in Table 1 and environmental covariables codes are in Table 2 and 3 footnote. Treatments are: RP = rainfed plots, DP = drought plots, 98 = 1998, 99 = 1999, 00 = 2000, 01 = 2001.

These variables had positive loadings with the first dimension. Other environmental variables such as soil moisture in the top 75 cm in March (sm3) and maximum temperature in May (MT5) were also explained well by the first PLS dimension (>60%). These variables had intermediate negative (sm3) and high positive (MT5) loadings with the first dimension. On the other hand variability of soil moisture in the top 75 cm in June (sm6), minimum temperature in March and May (mT3 and mT5), and sun hours per day in March (sh3) was not explained well by the first dimension and had values close to zero for the first dimension loadings. The first PLS dimension explained 15 to 54% of the variability of the remaining explanatory variables (Table 3).

In summary, maximum soil temperature at 5 cm in April and May (mst4 and mst5) were associated with a factor that explained a large proportion of the GEI in both traits. Besides, the variables soil moisture in the top 75 cm in March (sm3), maximum soil temperature at 5 cm in June (mst6), and sun hours per day in April (sh4) were explained in a relatively high proportion in both traits. On the other hand, winter period precipitation (wpp) and minimum temperature in March, April and May (mT3, mT4, and mT5) were associated with a factor that explained a small proportion of the GEI in both traits. For biomass per plant, the first dimension did not explain as much variability in sun hours per day in May (sh5) as it did for grain yield (31.3 vs. 87.6%). The remaining variables were explained, more or less, in intermediate and similar proportion by the first PLS dimension in both traits.

The PLS biplot for grain yield (Figure 1b) showed that, for treatments and environmental variables, the results were similar to those obtained for biomass per plant (Figure 1a). Dimension 1 is primarily a contrast between, on one hand, water availability in soil between March and June (sm3, sm4, sm5, and sm6) and minimum temperature during grain filling (mT6) and, on the other hand, maximum soil and air temperatures between March and June (mst3, mst4, mst5, mst6, and MT3, MT4, MT5, MT6, respectively) and sun hours during anthesis and grain filling (sh5 and sh6, respectively). REYNOLDS et al. (2002) showed that environmental factors such as sun hours and moisture influence the GEI of the three crops (triticale, durum and bread wheat) differently at different growth phase.

Table 4. Grain yield (kg ha^{-1}) and biomass per plant (g) averaged over all 25 genotypes for rainfed (RP) and drought (DP) plots in period 1998-2001

Trait	Treatment							
	DP98	DP99	DP00	DP01	RP98	RP99	RP00	RP01
Biomass	7.39	4.99	3.98	3.01	9.79	6.89	6.26	6.15
Yield	5.31	4.44	4.03	3.43	6.53	5.50	6.99	7.15

The PLS biplot for grain yield contains roughly three clusters of treatments. The first cluster is in the upper left quadrant of Figure 1b and includes RP98, DP98 and DP99 i.e. the two highest yielding years under the DP treatment and the third yielding year under the RP treatment (Table 4). Treatments in the first cluster were characterized by relatively high soil moisture content in the top 75 cm from March to June and lower minimum air and maximum soil temperatures in March and May. The high soil moisture content in DP98 and RP98 is probably due to high winter period precipitation (142 mm) (Table 2) and favourable precipitation during vegetative growth, respectively. The explanation for relatively high soil moisture content in DP99 could be in a lot of precipitation during the spring time in 1999. It is expected that with more precipitation, there will be fewer sun hours, lower temperature, and thus, reduced evaporation. Moreover, since the first two PLS factors do not explain all the GEI for grain yield, some distortions occurred, e.g., treatments DP98 and DP99 are in same direction as sm covariables. The second cluster is in the lower left quadrant and includes RP99, RP01, and DP01. The year 2001 had a very low winter soil moisture reserve i.e. precipitation (Table 2) that caused the lowest mean grain yield in DP01 (Table 4). Both years (1999 and 2001) were rainy, with fewer sun hours and reduced maximum (soil and air) temperatures (Table 2). The third cluster involves RP00 and DP00. The year 2000 was warmer, sunnier and drier than the average (Table 2).

Concerning the genotypes, most of them showed a positive grain yield interaction with the same treatment as for biomass per plant. Nevertheless, more landraces had positive interaction with warm and dry 2000 for grain yield than for biomass. For example, landraces 17 and 21 had positive interaction with RP99 for biomass, but for grain yield they were favoured by conditions in DP00. Or, landraces 18 and 20 had positive biomass interaction with treatments in 2001, but for grain yield interacted better with treatments in 2000. This suggests that different plant trait(s) than biomass allows these landraces to achieve relatively better yield in warm and dry conditions. Tested cultivars had significantly higher grain yield than landraces and there was no one with positive interaction with 2000. This is expected since many wheat breeding programs in Serbia had been carried out under non-limiting conditions. Cultivars 1, 2, 3, and 5 had positive yield interaction with treatments in 1998 and 1999 when a higher level of water in the soil was recorded. Nevertheless, the cultivar 4 exhibited a positive interaction with DP01 in which plants experienced water stress starting from tillering because of low wpp and high mT3 and smt3.

CONCLUSION

The PLS regression model was used to determine the most informative subset of environmental covariables affecting GEI for biomass per plant and grain yield in wheat. Results of this study indicated that mean maximum soil temperature in April and May, mean soil moisture in March, and mean sun hours per day in May were correlated to PLS factor that explained most of the GEI for biomass per plant. Similar results were obtained for grain yield. The environmental covariables that mostly explained GEI for this trait were mean maximum soil temperature in April and May, mean sun hours per day in May, and mean maximum soil temperature in June.

For both traits, results indicate that the relative performance of genotypes was strongly influenced by different sensitivity to soil moisture and maximum soil and air temperatures during different growth stages.

Generally, wheat landraces are able to better exploit warm and dry environments than cultivars. On the other hand cultivars are favoured by environments with higher soil moisture content during the vegetative growth (March to June). Having in mind global climate changes (decrease in annual precipitation and an increase in mean annual temperatures) it seems that some of the tested landraces could be regarded as useful for improving yield of new varieties for regional markets.

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ANALIZA OGLEDA SA GENOTIPOVIMA PŠENICE KORIŠĆENJEM FAKTORA SREDINE

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Izvod

U cilju utvrđivanja klimatskih i zemljišnih faktora kojima se najbolje može objasniti interakcija biomase i prinosa genotipova pšenice sa spoljašnjom sredinom primenjen je model regresije parcijlnih najmanjih kvadrata (PLS). Korišćen je set podataka iz ogleda sa 20 lokalnih populacija i 5 priznatih domaćih sorti pšenice. Genotipovi pšenice su tokom četiri godine (1998-2001) ispitivani u dva različita režima gajenja: prirodni uslovi i u uslovima suvog polja. Zaštitni krov iznad suvog polja svake godine je postavljen na kraju zimskog perioda (početkom marta), u fazi bokorenja biljaka.

Za oba anlizirana svojstva ANOVA je pokazala da je interakcija genotip × uslovi gajenja (tretman) visoko signifikantna ($P<0.001$). Rezultati PLS modela su pokazali da prva i druga dimezija (latentni faktori) objašnjavaju 31.9 i 12.5% interakcije genotipa sa spoljnom sredinom za biomasu po biljci, odnosno 31.2 i 18.4% za prinos zrna, respektivno. Faktori spoljašnje sredine kao što su maksimalna temperatura zemljišta na 5 cm dubine u aprilu i maju, vlažnost zemljišta u sloju od 75 cm u martu i trajanje dnevnog osunčavanja u maju mesecu u najvećoj meri doprinose interakciji genotipa sa uslovima gajenja za biomasu po biljci. Slični rezultati su dobijeni za prinos zrna, s tom razlikom da se umesto faktora vlažnost zemljišta u sloju od 75 cm u martu mesecu kao značajana pokazala temperatura zemljišta na 5 cm dubine u junu mesecu.

Generalno, lokalne populacije pšenice su ispoljile bolju prilagođenost sredinama sa visokim temperaturama (vazdušnim i zemljišnim) i manjom dostupnošću vode tokom vegetativnog perioda (mart-jun) od sorti pšenice.

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