***Pak. J. Bot.*, 50(2): 545-552, 2018.**

BROOMCORN [*SORGHUM BICOLOR* (L.) MOCNCH]PANICLE YIELD AS AFFECTED BY ENVIRONMENTAL VARIABLES AND AGRO-TECHNOLOGICAL TRAITS

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Abstract

The aim of this study was to access the overall effects of genotype, environment and genotype × environment interaction (GEI), as well as the importance of individual agro-technological traits in the broomcorn [*Sorghum bicolor* (L.) Moench] panicle yield formation. The performances of 11 broomcorn cultivars grown in eight different seasons are discussed in this paper. The restricted maximum likelihood (REML) variance component estimates model revealed that panicle yield was for the most part dependent on GEI (47.5%), which allowed identification of best genotypes for specific environments. The partial least squares regression (PLSR) model revealed that the most important climatic variables for optimal yield are precipitation in vegetation period and maximum air temperature in vegetation, followed by difference between maximum and minimum temperature in vegetation, growing degree days and sum of precipitation. Generally, lower temperature and higher precipitation parameters had beneficial effect on yield. Considering the individual agro-technological traits, the most important for panicle yield were weight of threshed and unthreshed panicle, as well as grain weight per panicle. As directly related to yield; length of the panicle, fibre length and number of fibres per panicle were also important. The best yield (Sava, 11.75 t ha^{-1}) and stability (Jumak, Prima) performances were recorded for locally adapted cultivars. The knowledge obtained in this study is valuable for the identification and understanding of key environmental and agro-technological factors that contribute to the yield of broomcorn panicle.

Key words: *Sorghum bicolor*, Agro-technological traits, GEI, REML.

Introduction

As one of the most important plants worldwide, sorghums [*Sorghum bicolor* (L.) Mocnch] are used for human food, animal feed, building material, fencing, and for brooms (Paterson *et al.*, 2009; Pereira, 2011; Zhang *et al.*, 2016). Broomcorn is a classic example of industrial use of sorghum since its panicle has only one use - as a raw material for brooms (Dahlberg *et al.*, 2011). Today, one of the main regions of broomcorn growing and corn brooms production is South East Europe, accordingly Serbia, Hungary, Turkey, Romania, Bulgaria and Ukraine (Berenji *et al.*, 2011). Institute of Field and Vegetable Crops from Novi Sad, Serbia, is one of the centres of broomcorn improvement. Serbian broomcorn breeding program was started more than 60 years ago. During the period, collection of over 450 accessions was compiled. Based on the genetic constitution and geographic origin of the included accessions, it can be considered as the world broomcorn germplasm collection. As the result of the breeding programs, 15 broomcorn cultivars with agronomic characteristics and technological features meeting the needs of broomcorn producers and corresponding brooms producers have been developed (Sikora & Berenji, 2010).

Contemporary broomcorn breeding program involves the development of varieties that, in addition to high yield and technological quality, exhibit extreme stability and a high level of tolerance to adverse environmental conditions. To achieve this goal it is necessary to choose the crossing of parental lines that are superior in these characteristics per se.

The breeding strategy for high yield is based on an average yield, which is formed under the influence of genotype (G), environment (E) and genotype × environment interaction (GEI). Detailed analysis of the GEI allows the reduction of the relationship between phenotype and genotype that simplifies the selection process. Yield in different localities or yield at one site in a number of different years (environmental conditions) can be taken as a basis for the analysis of environmental influence. If the analysis relates to one site and several years, the impact of environmental factors such as soil quality, time of sowing or plant nutrition is minimized.

GEI is well documented in other types of sorghum (Borrell *et al.*, 2000; Machado & Paulsen, 2001; Abu Aassar *et al.*, 2008; Sabadin *et al.*, 2012), however the information about this important issue in broomcorn are poor (Sikora & Berenji 2000). The main objectives of present study are to evaluate the (1) effect of the genotype, year (environmental variable) and genotype × year interaction on the yield variation of 11 broomcorn cultivars grown in the long-term trial, (2) impact of the analysed environmental variables on genotype × year interaction and (3) effect of agro-technological traits on broomcorn panicle yield. The results should help breeders to optimize selection strategy for improving yield and other important agro-technological traits for broomcorn intended for growing in temperate regions.

Materials and Methods

Plant material: The most important agro-technological quantitative features were analysed in 11 broomcorn cultivars of different origin. Material included three old (Jumak, Sava, Neoplanta +) and three contemporarySerbian cultivars (Reform, Prima, Tan Sava), four Hungarian (Szegedi szlovak, Szegedi 1023, Dia, Szilard) and one American cultivar (Deer 418). Serbian cultivars were developed at the Institute of Field and Vegetable Crops, Novi Sad (Sikora & Berenji, 2010), Hungarian were developed at Gabonatermesztesi Kutato Intezet Szeged and the American cultivar was obtained from Oklahoma State University. Contemporary Serbian and Hungarian cultivars in this study represented actual European broomcorn assortment.

Experimental site, field trial design and agro-meteorological data: Multi-year field trials were setup at the site Bački Petrovac (φN 45° 20'; λE 19° 40'; altitude 82 m), on mollisol, in the seasons of 2000 (Y00), 2001 (Y01), 2002 (Y02), 2003 (Y03), 2005 (Y05), 2006 (Y06), 2009 (Y09) and 2011 (Y11). The technology recommended for commercial production of broomcorn was applied in the experiment (Berenji *et al.*, 2011). In all years, preceding crop was soybean, winter ploughing was performed to a 30 cm soil depth in November and planting was completed between 21 and 28 April. Fertilization included application of 550 kg ha^{-1} of mineral fertilizers NPK (8:16:24) along with autumn tillage and 250 kg ha^{-1} NPK (15:15:15) before seeding. The experiments were carried out under conventional tillage. The crops were kept free from weeds and insects according to best local practices. Elementary-two-row plots were 10 m long. Plant spacing was 0.7 m between rows and 0.1 m between plants within rows, and total area of each plot was 14 m^2. The experiments were conducted in a complete randomized block design with three replications. From each plot, five single, randomly chosen plants were selected for analysis. Manual harvest was carried out at physiological stage of ripe grain, in period between 15 August and 10 September. Meteorological records included average maximum temperature during vegetation (mx, °C), average minimum temperature during vegetation (mn, °C), temperature variations calculated as a difference between average maximum and minimum temperature during vegetation (dt, °C), sum of temperature during vegetation or growing degree days (gd, °C), average relative air humidity during vegetation (rh, %), pre-vegetation winter precipitation (wp, mm), precipitation during vegetation (vp, mm), and total amount of winter and vegetation precipitation (sp, mm). Meteorological data were obtained from official weather station of the Republic Hydro-meteorological Service of Serbia (http://www.hidmet.gov.rs) located close to the experimental field.

Measurements: Plant height components of selected plants were measured by the measuring stick. Plant height (PHG, cm) represents height from the ground to the tip of the main panicle, and stalk height (SHG, cm) from the ground to the upper node. Length of the panicle (PLG, cm) was calculated as difference between PHG and SHG and included length between upper node and base of fibre or peduncle length (PDL, cm) and length of the fibre from the base to top or fibre length (FLG, cm). Length of the top leaf sheath (LSL, cm) was also measured. Panicles with peduncles of 15 cm were separated by hand and dried in a dryer. After drying of individual panicles, the yield components weight of unthreshed (UTP, g) and threshed (TRP, g) panicle after threshing grain were measured in the laboratory with the technical scale. Grain weight per panicle (GWG, g) was calculated as difference between UTP and TRP. Threshed panicle ratio (TPR, %) was calculated as the ratio of threshed panicle to the grain per panicle multiplied by 100. Broomcorn panicle quality parameters include the number of fibres per panicle (FNO), determined by counting. The coefficient of fibre fineness (FFI, g m^{-1}) was expressed as the ratio of the peduncles weights and the total peduncle length per panicle multiplied by 1000.

Statistical analysis: For the analysis of GEI a number of methods have been suggested. The special class of statistical model, capable of identifying causes of the GEI is the partial least squares regression (Vargas *et al.*, 1998). This is the type of bilinear model that allows low-dimensional approximation of basic GEI in relation to the increasing number of external climatic or genotype variables. All model terms prior the estimation of the restricted maximum likelihood (REML) variance of components and associated standard errors were regarded as random sources of variation. The importance of particular random model terms was measured as ratio between (REML) variance components and its standard error. For estimation of GEI for panicle yield a two-way matrix of double centred means was related to matrix of centred environmental variables available per experimental year through the partial least squares regression (PLSR) model. After adjusting for G and E main effects, the PLSR model relates residual GEI effects as dependent variable matrix (Y) to external climatic variable matrix (Z) into a single procedure. While Y matrix contains panicle yield, Z matrix contains climatic variables recorded during experiment. The results of the PLSR model were graphically visualized in two-dimensional biplot, which superimposed the cultivars, years and climatic variables into one graphical display. The genotype × trait biplot (Yan & Rajcan, 2002) was used for studying relationship among traits across the cultivars as well as their relationship among the environments. A genotype/environment metric preserving scaling method was used prior to constructing the biplot where the units of first and second bilinear terms are the same as the unit of original data (Yan, 2002). For the purpose of visualization of genotype mean performance, the average-treatment coordinate view of the biplot was used. All data analyses were accomplished within R computing environment (R Development Core Team).

Results and Discussion

Agro-meteorological characterization of the environments: Of all the investigated years, only Y02 was at the average level, considered by temperature parameters. Y00 and Y03 can be regarded as extremely hot, with maximum average air temperature of 29.1°C in Y00 and 28.6°C in Y03,recorded during the growing season. The highest daily variations in air temperature were also recorded in these two years, when the difference between the maximum and minimum temperatures was higher than 15°C. The sum of temperatures during the growing season in these two years exceeded 2600°C. Years Y01 and Y05, with the sum of temperatures during the growing season of about 2300°C, can be regarded as extremely cold. In these years, due to lower maximum temperatures (23.3°C and 24.3°C, respectively) daily variation in temperature during the growing season was less pronounced (Table 1).

The highest stocks of winter moisture (365 mm) were recorded in Y05. The rainfall during the Y05 growing season of 397 mm was above the average, and with a total of 762 mm, this year was extremely moist. In addition, Y01 and Y06 are marked as wet with rainfall during the growing season of 356 mm and 340 mm, respectively. Despite of the above average inventories of winter moisture, lower rainfall (67 mm) during the growing season Y00, which makes a total of 383 mm, classifies the year as extremely dry. Y03 and Y09 may be denoted as dry years with precipitation below 200 mm during growing season. The surplus humidity of 71.0% and 68.0% during the growing season was recorded for Y11 and Y09, and low humidity, below 50%, for Y00 and Y03.

Discriminating ability and representativeness of the environments: The discussed agro-meteorological data observed in the corresponding years were subjected to the regression analysis and the results are presented in a biplot form (Fig. 1). Based on these observations, the first two principal components (PCs) showed 80.9% environmental variance. The test environments fell into three apparent clusters: Y00 and Y03 formed first cluster, Y02, Y09, and Y011 formed second cluster, and remaining environments (Y01, Y05 and Y06) formed third cluster. Based on the length of their vector and the cosine of the angle between them, the environments within the clusters showed positive correlations or similarity (Yan *et al.*, 2007). The presence of obtuse angles among environments that belong to the separate clusters is an indication of between clusters crossover.

Main characteristics of the first cluster of environments (Y00 and Y03) were low seasonal precipitation and sum of precipitation, and high maximum temperature and sum of temperatures during vegetation. This cluster of environments can be considered as hot and dry. Second cluster (Y02, Y09 and Y011) is characterized by average sum of temperatures during vegetation, low sum of precipitation and high seasonal relative air humidity. Third cluster included Y01, Y05 and Y06, which can be considered as cold and extremely wet in seasonal precipitation as well as in sum of precipitation.

Therefore, the most informative test environments that showed the best discriminant ability were Y00, Y05 and Y11. The presence of wide obtuse angle among these environments is an indication of strong negative correlations or strong crossover (Yan & Tinker, 2006). Y00 was considered the best for selecting specifically adapted cultivars to hot and dry conditions, while Y05 for relatively cold and wet conditions. Worst discriminating ability (non-informative) was shown by test environments Y02, Y06 and Y09. These environments provideda little information on the genotypes, and should not be used as test environments (Yan, 2014).

Table 1. Agro-meteorological data for eight years (environments) on the site of Bački Petrovac, Serbia.

Year	mx	mn	td	gd	rh	wp	vp	sp
	°C				%	mm		
Y00	29.1	13.3	15.8	2649	44.2	316	67	383
Y01	23.3	12.3	11.0	2354	55.5	248	356	604
Y02	26.5	13.4	13.1	2551	52.5	157	240	397
Y03	28.6	13.4	15.2	2668	46.3	227	165	392
Y05	24.3	12.1	12.2	2357	52.7	365	397	762
Y06	25.0	13.0	12.0	2475	58.1	229	340	569
Y09	27.0	12.0	15.0	2599	68.0	190	188	378
Y11	27.5	14.5	13.0	2415	71.0	238	209	447
Average	26.4	13.0	13.4	2509	56.5	246	245	492

For variable abbreviations, see Materials and Methods

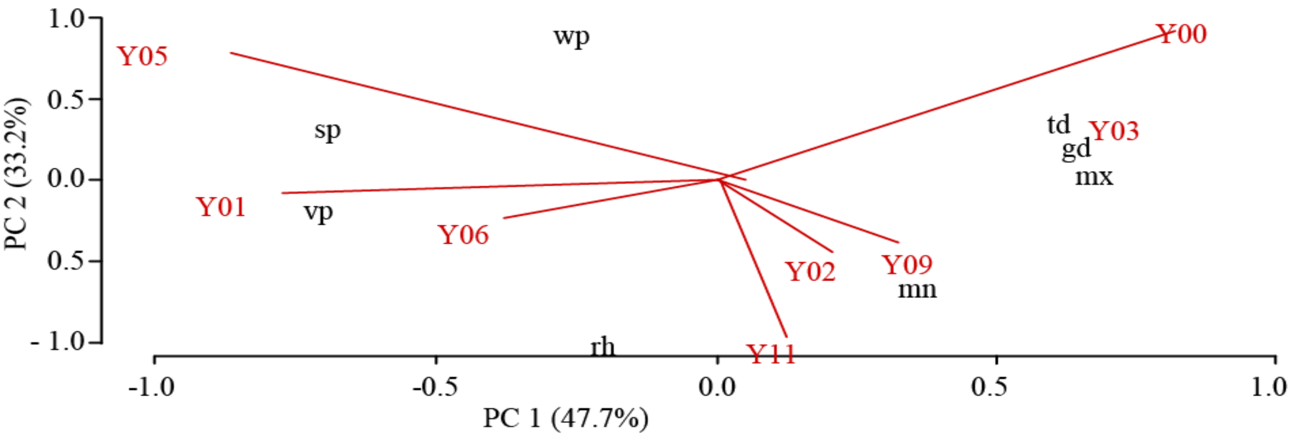

Fig. 1. Environment regression biplot based on the agro-meteorological data. For variableabbreviations, see Materials and Methods.

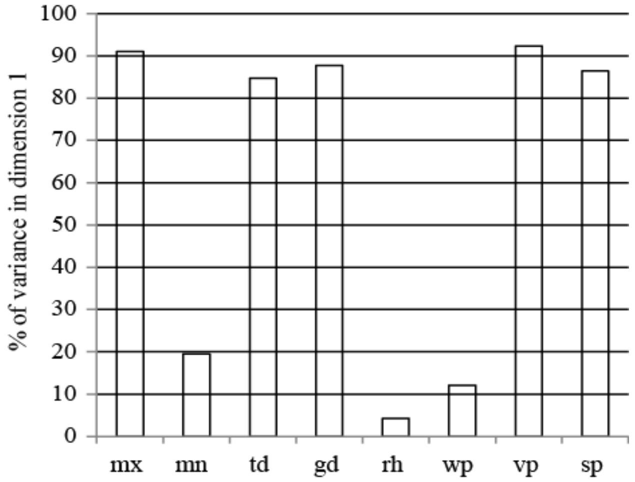

Fig. 2. Variability of environmental variables in the first dimension of PLSR model. For variable abbreviations, see Materials and Methods.

Panicle yield variation: In the reporting period, the eight-year average panicle yield variedfrom 7.86 t ha^{-1} in cultivar Sz. szlovak to 11.75 t ha^{-1} in cultivar Sava. The lowest yield (6.09 t ha^{-1}) was recorded for cultivar Sz. szlovak in Y02 and the highest (19.71 t ha^{-1}) for Sava in Y05. Between the individual years variations in average yields ranged from 7.34 t ha^{-1} in Y00 to 13.98 t ha^{-1} in Y05 (Table 2). Yield variation of individual cultivars between years indicates the existence of a strong crossover interaction. Since environmental factors such as soil quality, latitude and longitude, time of sowing, crop and plant nutrition are fixed and identical for all the tests, crossover interaction occurs due to the effect of variable to environmental factors such as temperature parameters, humidity and available moisture.

GEI effects on panicle yield: Estimation of restricted maximum likelihood (REML) variance components has the advantage of being directly comparable as they have the same scale. For panicle yield GEI variance shows greater importance (47.5%) than G main effect (30.8%) and E effect (21.7%), (Table 3). Significant GEI for *Sorghum bicolor* yield have been reported by many authors (e.g. Adugna, 2008; Ezzat *et al.*, 2010; de Almeida Filho *et al.*, 2014).

When considering the importance of individual environmental variables within the first dimension for panicle yield, the most important are precipitation in vegetation period (vp, 92.3%) and maximum air temperature in vegetation (mx, 91.0%). Thus, considering all genotypes included in the analysis, the highest panicle yields (above 10 t ha^{-1}) were recorded in the years characterized by comparatively high vp, and low mx (Tables 1, 2.). High importance within the first dimension was recorded also for difference between maximum and minimum temperature in vegetation (dt, 84.7%), growing degree days (gd, 87.7%) and sum of precipitation (sp, 86.4%), (Fig. 2). Considering the mentioned parameters; comparatively low temperature and high precipitation values were related to the highest seasonal yields, which may be explained by the fact that the cultivars included in the study were developed in and for temperate climatic conditions. Although widely recognized as stress tolerant plants (Borrell *et al.*, 2014; Schittenhelm & Schroetter, 2014), sorghums can have significant yield losses due to drought and heat, especially when exposed after flowering (Anami *et al.*, 2015).

Table 2. Panicle yield of eleven broomcorn cultivars across years (environments).

Cultivar	Panicle yield (t ha^{-1})								
	Y00	Y01	Y02	Y03	Y05	Y06	Y09	Y11	Average
Jumak	6.71	6.29	7.08	8.75	14.50	9.25	10.71	10.75	9.26
Sava	7.46	8.40	10.53	11.84	19.71	14.62	12.32	9.14	11.75
Neoplanta +	7.04	7.28	8.37	8.57	18.63	12.88	10.49	9.04	10.29
Reform	7.88	6.29	6.85	9.42	12.47	9.21	9.66	8.64	8.80
Prima	6.87	7.60	7.74	8.68	13.38	10.51	8.09	9.45	9.04
Tan Sava	8.16	7.83	7.60	11.54	16.63	13.34	10.96	7.52	10.45
Sz. szlovak	7.00	6.20	6.09	7.71	10.82	8.82	7.66	8.55	7.86
Sz. 1023	6.41	9.52	8.68	10.37	12.17	10.88	8.79	8.64	9.43
Dia	7.84	7.34	6.76	7.84	11.83	9.42	8.79	9.74	8.70
Szilard	7.80	7.42	6.68	7.80	11.03	8.89	9.76	9.13	8.56
Deer 418	7.60	7.14	6.47	8.50	12.60	10.28	7.27	7.08	8.37
Average	7.34	7.39	7.53	9.18	13.98	10.74	9.50	8.88	9.32

For variable abbreviations, see Materials and Methods

Table 3. REML variance components (± standard error of estimates) for random model of two-way genotype-by-environment table of means for panicle yield.

Estimates	Genotype (G)	Environment (E)	Interaction (GEI)
Variance	62477 ± 27892	44018 ± 22458	427050 ± 52592
Ratio	2.24	1.96	8.12
%	30.8	21.7	47.5

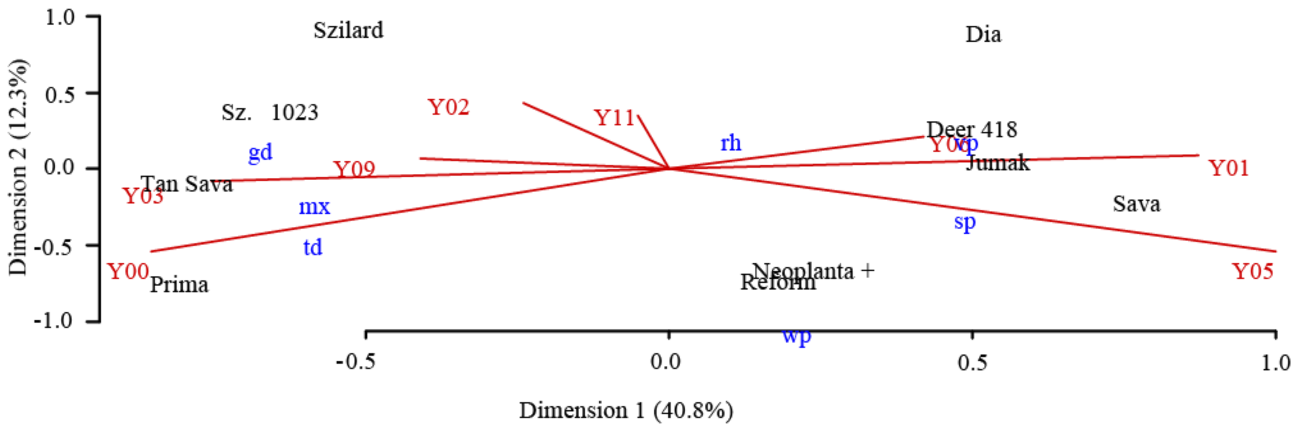

Fig 3. The PLS regression biplot for panicle yield. For variable abbreviations, see Materials and Methods.

In order to reduce the overall GEI variance into lower dimensional space while simultaneously modelling the effects of the measured external environmental factors, the PLSR model was employed. The PLSR biplot for panicle yield explained 53.1% of the interaction variance and indicated that interaction was the most important in Y00 and Y05 (extremely hot and dry, and cold and wet years, respectively); and less important in Y09 and Y11 (comparatively lower precipitation and average temperature parameters) since the position of vectors for this years was the closest to biplot origin (Fig. 3). Therefore, the interaction was in the first instance due to the genotype performance in extreme environmental conditions.

As depicted, the role of the temperature related variables was clearly separated from the precipitations by the first dimension indicating their completely independent overall interaction. However, high total precipitation (762 mm) and low gd (2357°C) in Y05 correlated to the highest average panicle yield of 13.98 t ha^{-1}. The lowest yield (7.34 t ha^{-1}) was recorded for hot (gd 2649°C) and dry (sp 383 mm) Y00.

Based on PLSR model all available variables were divided into three correlated subsets. Graphical review of applied model enables adaptation identification of certain cultivar to the specific environmental conditions (Gauch & Zobel, 1997). The first subset includes vegetation precipitation and sum of precipitation, which had relatively high values in Y01, Y05 and Y06. High amount of water affected the positive interaction of cultivars Sava, Jumak and Deer 418 within these years. Best yielding cultivar Sava achieved overall highest yield in good moisture conditions. The positive interaction of cultivars Prima, Tan Sava and Sz. szlovak with Y00, Y03 and Y09 is affected with environmental variables from second subset, which includes difference between maximum and minimum temperature, maximum average temperature and growing degree days. The third subset contains minimum average temperature in vegetation and relative humidity, and affects the positive interaction of cultivar Sz. 1023 with Y02 and Y011. The interaction performance of cultivars Reform and Neoplanta + is intermediate between Y00 and Y05 and equally affected by the environmental variables from first two subsets (Fig. 2).

Variation explained by environments indicates that environments (years) were diverse, with differences among environmental means causing the variation in broomcorn panicle yield. Total precipitation was different in Y00 and Y05 (383 and 762 mm, respective Due to expressed tolerance to high and low precipitation, Tan Sava was best yielding in Y00 with 8.16 t ha^{-1} and third best yielding in Y05, with 16.63 t ha^{-1}. In addition, minimal difference in yield score for Y00 and Y05 was found for cultivar Sava, identified in our previous work as highly stable for yield and plant height components (Sikora & Berenji, 2000). Higher GEI variance than genotypic effects indicated differences in genotypic response across environments (Asfaw *et al.*, 2009). The major source of variation for GEI is large positive IPC score of some cultivars within extremely wet environments and other cultivars having large negative values within hot and dry environments (Mohammadi *et al.*, 2007). On the other hand, high contribution of G variance can be explained by the different origin of examined cultivars.

Agro-technological traits variation: Variability of quantitative traits among the cultivars is given in Table 4. Based onplant height components (Berenji *et al.*, 2011), cultivar Deer 418 (PHG 219 cm, 148 cm SHG) belongs to American tall sorghum group. A group of European dwarf-type sorghum with SHG below 65 cm is represented by Hungarian (Szilard, Dia, Sz. szlovak and Sz. 1023) and Serbian cultivars (Jumak and Prima). The cultivars Sava, Neoplanta +, Reform and Tan Sava belong to the group of European tall sorghum. Compared to European cultivars, Deer 418 has a lower yield (15 g TRP) and short straw (FLG 48 cm) of good quality (FFI 472 g m^{-1}).

Thanks to the highest UTP (84 g) and GWG (54 g), as well as the largest FNO (67), cultivar Sava has the best yield performances. Despite the high value of the TRP (30 g), cultivar Sz. szlovak has the minimum fibre quality (FFI 553 g m^{-1}). The results are rather expected, since local cultivars were developed in and for local environmental conditions, in which the trial was conducted. The outperformance of the locally adapted sorghums has been also discussed by Mekbib (2006) and Nkongolo *et al.*, (2008).

Table 4. Agro-technological traits of broomcorn cultivars (average across eight years).

Cultivar	Traits											
	PHG	SHG	PLG	PDL	FLG	LSL	UTP	TRP	GWG	TPR	FNO	FFI
	cm	cm	cm	cm	cm	cm	g	g	g	%	-	g m^{-1}
Jumak	158	65	93	38	65	41	66	26	41	37	56	508
Sava	175	78	97	44	65	42	84	31	54	35	67	518
Neoplanta+	195	100	95	52	61	43	73	24	50	31	64	446
Reform	173	84	88	25	64	40	62	22	40	35	55	496
Prima	158	60	98	51	73	40	65	26	39	39	56	520
Tan Sava	189	90	100	28	71	42	74	26	48	35	60	488
Sz. szlovak	150	52	98	40	69	39	56	23	33	40	51	497
Sz. 1023	153	57	96	16	80	39	68	30	39	42	54	553
Dia	150	52	98	40	69	40	62	23	39	37	53	480
Szilard	143	55	89	34	65	40	62	21	41	33	52	437
Deer 418	219	148	71	24	48	42	59	15	44	24	52	472
Average	169	76	93	36	66	41	66	24	43	35	56	492

For variable abbreviations, see Materials and Methods

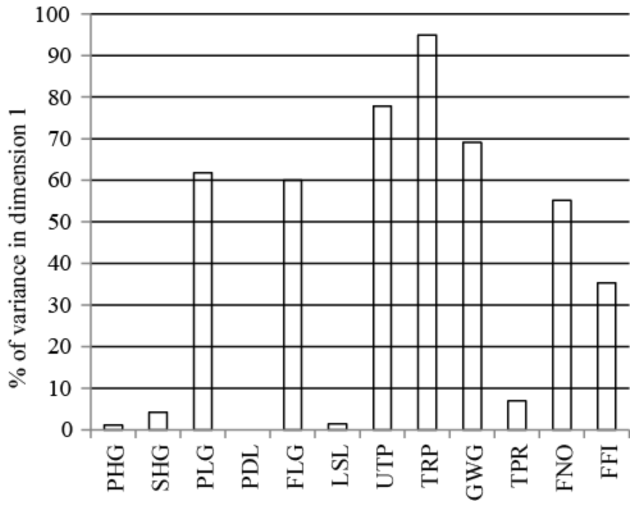

Fig. 4. Variability of agro-technological traits in the first dimension of PLSR model. For trait abbreviations, see Materials and Methods.

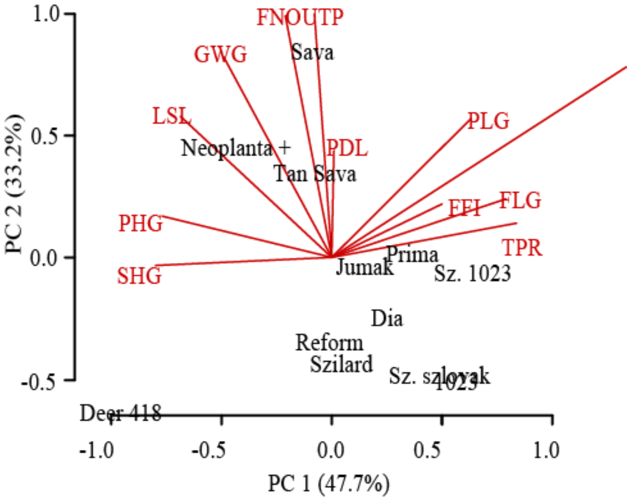

Fig. 5. Vector view of genotype-by-trait biplot showing interrelationships among traits. For variable abbreviations, see Materials and Methods.

Effects of agro-technological traits on panicle yield: When considering the importance of individual agro-technological traits within the first dimension for panicle yield, the most important are, as expected and being the important yield components, TRP (94.9%), UTP (78.0%) and GWG (70.0%). PLG, FLG and FNO, as the traits directly related to yield, were characterized with above 50% of variance in the first dimension. No importance within the first dimension was recorded for PHG (3.1%), SHG (4.2%), PDL (1.2%), LSL (1.4%) and TPR (7.0%) (Fig. 4).

To visualize the interrelationships among agro-technological traits, genotype × trait biplot is presented in Figure 5. The biplot is based on the first two principal components derived from subjecting the standardized genotype-by-trait table. The biplot explained 80.9% of the total variation of two-way table. The lowest variability was recorded for the traits with the shortest vectors (PDL and FFI). Other traits are divided into three clusters, with positive correlations between traits within the cluster. The presence of obtuse angles among the traits that belong to the cluster consisting of TRP, PLG, FLG and TPR and the cluster that included components of plant height (PHG and SHG) indicated between clusters crossover. Traits that belong to the third cluster (LSL, GWG, FNO and UTP) are correlated to the first two groups of traits, but these correlations are moderate.

The most stable cultivars with the shortest vectors and the smallest variation in traits are local cultivars Jumak and Prima. Coincidently, the two cultivars were not among the best performers, since they had average or slightly above/below average overall yields and the majority of the agro-technological traits. High stability of comparatively low-yielding varieties was reported for many agricultural plants (e.g. Karimizadeh *et al.*, 2012; Lakić *et al.*, 2015; Temesgen *et al.*, 2015). The cultivar with the best yield performances (GWG, FNO and UTP) was Sava; while on the other hand, cultivars Dia, Szilard, Sz. szlovak, Reform and Sz. 1023 performed the poorest. Cultivar Neoplanta + is correlated with LSL and Tan Sava with PDL. Due to the height of plant and stalk, American tall cultivar Deer 418 stands out on the biplot.

Therefore, the beneficial effects of the lower maximum temperatures (i.e. the absence of temperature shocks) and higher precipitation during vegetation, as well as the good overall performance of locally adapted germplasm, should be taken into account when designing the programs for breeding broomcorn attended for growing in temperate regions. Nevertheless, the field tests should be conducted in multiple diverse seasons. The weights of threshed and unthreshed panicle, and grain weight per panicle are the traits that should be analysed in every respect. Length of the panicle, fibre length and number of fibres per panicle may also be considered.

Conclusions

This long-term study revealed the greatest importance of genotype × environment interaction in broomcorn panicle yield formation, whereas genotype and year (environment) effects were less important. Discriminating ability and representativeness of the environments, genotype yield performances and stability, as well as the interrelationships among the agro-technological traits were effectively visualized and explained via the employed regression biplots.

Concerning agro-meteorological conditions, the years in which the experiment was conducted were diverse. The most informative test environments showing the best discriminant ability were Y00 (hot, dry), Y05 (cold, wet) and Y11 (average temperatures, low precipitation). On average, the highest broomcorn yields were recorded in Y05, and the lowest in Y00. The key environmental factors that contribute to the yield were precipitation in vegetation period and maximum air temperature in vegetation, followed by difference between maximum and minimum temperature in vegetation, growing degree days and sum of precipitation. Therefore, comparatively low temperature and high precipitation values were related to the highest seasonal yields of broomcorn grown in temperate region.

The highest overall broomcorn panicle yield was achieved with local cultivar Sava. When considering the importance of individual agro-technological traits within the first dimension for panicle yield, the most important are weight of threshed and unthreshed panicle, as well as grain weight per panicle. As directly related to yield; length of the panicle, fibre length and number of fibres per panicle were also important.

Broomcorn selection strategy should rely on the results of the tests performed in diverse environments, considering beneficial effects of the lower maximum temperatures (i.e. the absence of temperature shocks) and higher precipitation during vegetation, as well as the good overall performance of locally adapted germplasm. The weights of threshed and unthreshed panicle, as well as grain weight per panicle are the traits that should be analysed in every respect. In addition, length of the panicle, fibre length and number of fibres per panicle may be also considered in breeding programs.

Acknowledgment

The research was financially supported by the Ministry of Education, Science and Technological Development of Republic of Serbia (Grants TR31073 and 31005).

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(Received for publication 24 March 2017)