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Characterization of sunflower testing environments in Serbia

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Abstract: A sunflower testing network that included 25 commercial hybrids and 26 sites in Serbia was analyzed by the sites regression biplot based on grain yield data in 2006 and 2007. The scientific aims of our study were to determine the representativeness and discriminating ability of the test sites and to identify good test sites for selecting generally and specifically adapted sunflower hybrids. Correlations among test sites, revealed by biplot and with Spearman's nonparametric rank correlation coefficients for each pair of test sites, were compared. Discriminating but nonrepresentative test sites in our study were represented by Aleksa Šantić (18.8 °C average temperature, 72.0 mm precipitation, and 269.2 h of sunshine) and Rimski Šančevi (18.4 °C average temperature, 79.2 mm precipitation, and 252.1 h of sunshine), based on a biplot analysis of the 2006 testing network. Sombor (20.1 °C average temperature, 52.5 mm precipitation, and 304.7 h of sunshine) was also a discriminating but nonrepresentative test site, based on a biplot analysis of the 2007 testing network. A test site that was both discriminating and representative was Kikinda (20.2 °C average temperature, 63.3 mm precipitation, and 313.7 h of sunshine), based on a 2007 biplot analysis. Sombor and Kikinda could be suitable test sites for selecting specifically and generally adapted hybrids of sunflower, respectively, for dry and hot areas and seasons, since 2007 had less precipitation and a higher mean temperature in comparison to 2006. The presence of close association between test sites Rimski Šančevi and Kikinda, based on the 2006, 2007, and combined data, and on biplot and Spearman's correlations, suggested that the same information about the genotypes could be obtained from either of these 2 test sites, and consequently testing costs could be reduced. The relationships among test sites revealed by biplot did not always coincide with Spearman's rank correlation coefficients for site pairs.

Key words: Biplot analysis, discriminating ability, representativeness, Spearman's rank correlation, sunflower testing network

Introduction

Sunflower (*Helianthus annuus* L.) is the fourth most important oilseed crop in the world in terms of total yearly production, after soybean, rapeseed, and groundnut. In 2009, approximately 32 million t of sunflower were harvested from 23.8 million ha worldwide, with an average grain yield of 1.3 t ha^{-1} (FAO 2009). It represents the most important crop for edible oil production in Serbia, with harvesting areas of 154,793 to 187,822 ha with production of 294,502 to 454,282 t and an average grain yield of 1.9 to 2.4 t ha^{-1} for the 2006-2009 period (FAO 2009).

The phenomenon of genotype × environment interaction (GEI) is characteristic of multi-

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environment trials and is of permanent interest for breeders and biometricians along with practical and theoretical aspects (Yan and Kang 2003). Grain yield is a quantitative trait that routinely exhibits GEI, and as it represents an agronomically and economically important trait in sunflower, different genotypes should be evaluated across multiple environments in the advanced stages of selection. GEI indicates the importance of environments and their variable factors on adaptability and stability, and it is a favorable phenomenon only if it is correlated with above-average yield (Yan and Hunt 2002). One important goal of plant breeding efforts is to decrease GEI and error variance related to phenotype values (Moreno-Gonzales et al. 2003). Multi-environment trials are organized as a part of breeding program efforts to select superior genotypes for the target region in order to make recommendations to producers, to identify sites that are representative of the target region and have good discriminating ability for genotype selection, and to investigate the target region and eventually divide it into different mega-environments.

One approach to unfavorable crossover interaction (COI) is to characterize the environments in terms of the way they influence the performance of the genotypes and to identify environment groups with negligible COI (Goyal et al. 2011). The shifted multiplicative model (Seyedsadr and Cornelius 1992) and the sites regression model (SREG) (Crossa and Cornelius 1997) are suitable models for grouping sites within which there is negligible genotypic rank change (Crossa et al. 2002). Yan et al. (2000) referred to biplots based on singular value decomposition of environment-centered or within-environment standardized genotype by environment (GE) data as a "GGE biplot"; this term emphasizes that the understanding of both genotype (G) and GE is relevant to genotype evaluation and must be considered simultaneously for appropriate genotype and test environment evaluation (Gauch and Zobel 1996).

It is considered a rule that cultivars that have wide or general adaptation show yield stability over a great range of environmental conditions and different environments. However, they have lower mean performance in comparison to specifically or narrowly adapted cultivars that possess genetic potential for high yield and achieve high yields in favorable environments and lower yields in less favorable environments (Annicchiarico 2002). Breeding programs in the second half of the 20th century were focused on yield potential increase, by using optimal environments for selection, and the concept of plant idiotype in ideal agroecological conditions. Today, breeding strategies for specific adaptation are becoming equally legitimate as the International Center for Agricultural Research in the Dry Areas conducts barley breeding for dry areas (Ceccarelli 1996), the International Rice Research Institute breeds rice for different ecosystems, and the International Maize and Wheat Improvement Center breeds wheat for 12 different mega-environments of world wheat cultivation areas (Braun et al. 1996).

The objectives of this study were to examine the representativeness and discriminating ability of the test sites included in the sunflower testing network, determine good test sites for selecting generally and specifically adapted sunflower hybrids, and compare correlations among test sites as revealed by the biplot and Spearman's nonparametric rank correlation between each pair of test sites.

Materials and methods

Sunflower hybrids and experimental design of the testing network

The genetic material used in this research was represented by 25 commercial sunflower hybrids from the collection of the Oil Crops Department of the Institute of Field and Vegetable Crops, Novi Sad, Serbia (Table 1). Sunflower hybrids were tested in multi-site trials over 26 sites evenly distributed in the sunflower-growing region of Serbia (Table 2). Variety trials were organized by the Oil Crops Department of the Institute of Field and Vegetable Crops during the 2 years of 2006 and 2007 in Serbia. The sunflower testing network included 20 hybrids and 19 test sites in 2006, and 20 hybrids and 16 test sites in 2007. There were 15 common hybrids and 9 common test sites for both years, and they were analyzed as a balanced set of data in the combined analysis.

Experimental data were mean grain yields (t ha^{-1}) of tested hybrids over the tested sites. The

Table 1. The names, codes, and types of sunflower hybrids used in the 2006 and 2007 testing network in Serbia.

Hybrid name	Type of hybrid	Code for 2006	Code for 2007	Code for 2006-2007
NS-H-111	Standard	1	5	1
Velja	Standard	2	6	2
Krajišnik	Standard	3	7	3
Olivko	Highly oleic	4	15	4
NS-H-45	Standard	5	1	5
Baća	Standard broomrape-resistant	6	10	6
Vranac	Protein	8	2	7
Pobednik	Standard	9	9	8
Sremac	Standard downy mildew-resistant	10	11	9
Somborac	Standard	11	12	10
Šumadinac	Standard broomrape-resistant	12	13	11
Kazanova	Standard	13	14	12
Rimi	Herbicide-tolerant	16	3	13
Bačvanin	Standard broomrape-resistant	17	4	14
Perun	Standard broomrape-resistant	20	8	15
Cepko	Protein	7	-	-
Stig	Medium early oil	14	-	-
Vitalko	Herbicide-tolerant	15	-	-
Dukat	For stubble-crop sowing	18	-	-
Banaćanin	Medium early oil	19	-	-
Plamen	Standard downy mildew-resistant	-	16	-
Duško	Standard downy mildew-resistant	-	17	-
Branko	Standard broomrape-resistant	-	18	-
Novosađanin	Standard broomrape-resistant	-	19	-
Oliva	Highly oleic	-	20	-

experimental design was a randomized complete block design with 4 replications, and the plot size was 28 m^2. The middle 2 rows of 4 were used for analysis, and border plants were excluded. The elementary plot size was 13.3 m^2 (0.7 m × 19 m). The parcel chosen for the experiment implementation was a parcel on which sunflower had not been cultivated for the previous 4 consecutive years, soybean and rapeseed had not been cultivated for 3 years, and maize, as the preceding crop, had not been treated with atrazine-based herbicides. Winter plowing was done to a 30-cm soil depth. Fertilization included the application of mineral fertilizers with 50 kg ha^{-1} of nitrogen, 80-90 kg ha^{-1} of phosphorus oxide (P_2O_5), and 60 kg ha^{-1} of potassium oxide (K_2O) before seeding. Sowing was done mechanically during April. Grain yield evaluation was performed by the measurement of grain mass for each elementary plot, and a grain yield (t ha^{-1}) with an 11% moisture basis was calculated.

Table 2. Test sites involved in the sunflower network yield trials in 2006 and 2007, with average grain yield, and climatic variables. Average values are from the April-September 2006 and 2007 meteorological series.

Test site	Code	Year	Coordinates	Altitude (m)	RH¶ (%)	SH* (h)	Pp# (mm)	Tmax† (°C)	Tmin‡ (°C)	Tmean§ (°C)	GY ($t\ ha^{-1}$)
Zaječar	ZA	2006	43°54′15″N	137	69.0	241.4	67.7	25.4	11.0	18.3	4.208
		2007	22°17′05″E		60.6	282.1	45.0	28.3	11.5	19.9	1.938
Kula Vitovnica	KV	2006	44°32′00″N	220	75.0	236.7	59.9	25.5	11.2	18.1	2.064
		2007	21°24′00″E		68.0	293.1	50.3	28.2	11.4	19.7	2.343
Kragujevac	KG	2006	44°00′51″N	173	68.8	232.4	72.9	24.7	12.2	18.6	1.754
		2007	20°54′42″E		60.6	294.4	48.06	27.6	12.5	20.3	2.098
Rimski Šančevi	RS	2006	45°19′51″N	84	72.4	252.1	79.2	24.1	12.9	18.4	3.316
		2007	19°50′59″E		64.6	308.7	57.8	27.1	13.02	20.0	3.880
Bačka Topola	BT	2006	45°48′32″N	110	68.2	248.3	84.9	23.7	12.1	18.0	3.070
		2007	19°38′06″E		58.7	300.6	56.3	26.3	12.4	19.3	3.910
Sombor	SO	2006	45°46′27″N	89	66.2	250.9	80.4	24.6	12.6	18.5	3.100
		2007	19°06′44″E		55.6	304.7	52.5	27.3	12.9	20.1	3.113
Aleksa Šantić	AS	2006	45°55′31″N	120	79.8	269.2	72.0	25.1	12.4	18.8	2.736
		2007	19°19′28″E		72.6	310.4	48.7	27.5	12.1	20.8	2.332
Kikinda	KI	2006	45°49′28″N	73	69.4	255.1	59.3	24.3	13.2	18.7	3.030
		2007	20°27′33″E		61.2	313.7	63.3	26.8	13.7	20.2	3.409
Vršac	VS	2006	45°06′60″N	84	67.4	251.7	81.4	24.8	12.8	18.7	2.550
		2007	21°18′08″E		57.8	315.9	39.2	27.3	12.7	20.5	2.406
Bačka Palanka	BP	2006	45°15′02″N	80	75.0	250.8	71.7	24.7	13.1	18.9	2.512
		-	19°23′19″E		-	-	-	-	-	-	-
Bečej	BC	2006	45°37′05″N	84	65.8	249.8	69.3	24.6	13.2	19.1	3.168
		-	20°02′06″E		-	-	-	-	-	-	-
Subotica	SU	2006	46°05′53″N	114	68.8	245.0	92.5	23.9	13.5	18.6	3.294
		-	19°40′16″E		-	-	-	-	-	-	-
Aradac	AR	2006	45°22′35″N	86	72.5	245.2	65.0	24.6	13.3	18.8	2.107
		-	20°18′03″E		-	-	-	-	-	-	-
Lazarevo	LA	2006	45°23′18″N	80	72.8	245.2	65.6	24.5	13.2	18.7	2.506
		-	20°32′20″E		-	-	-	-	-	-	-
Srpski Itebej	SI	2006	45°34′12″N	83	73.7	245.2	67.6	24.3	12.1	18.4	2.656
		-	20°42′49″E		-	-	-	-	-	-	-
Pančevo	PA	2006	44°51′49″N	72	64.6	245.2	84.2	24.5	14.8	19.4	2.537
		-	20°39′33″E		-	-	-	-	-	-	-
Kovin	KO	2006	44°44′31″N	79	75.2	256.0	64.5	24.5	12.9	18.3	2.440
		-	20°58′20″E		-	-	-	-	-	-	-
Beška	BE	2006	45°07′28″N	122	75.0	236.5	76.6	24.6	12.4	18.1	3.051
		-	20°03′35″E		-	-	-	-	-	-	-
Požarevac	PO	2006	44°36′55″N	97	72.4	238.2	77.8	25.0	12.5	18.3	1.836
		-	21°10′57″E		-	-	-	-	-	-	-
Kula	KU	-	45°36′19″N	84	-	-	-	-	-	-	-
		2007	19°31′21″E		69.4	253.3	74.2	23.7	13.1	19.0	2.962
Bačko Gradište	BG	-	45°31′35″N	81	-	-	-	-	-	-	-
		2007	20°01′25″E		66.1	256.3	70.2	24.5	13.4	19.3	3.629
Đurđin	DU	-	45°57′07″N	115	-	-	-	-	-	-	-
		2007	19°29′14″E		81.2	307.2	58.0	28.8	14.4	20.8	2.500
Zrenjanin	ZR	2007	45°22′00″N	80	-	-	-	-	-	-	-
			20°23′00″E		64.8	307.5	48.8	27.3	13.6	20.4	2.421
Neuzina	NZ	-	45°20′39″N	81	-	-	-	-	-	-	-
		2007	20°42′44″E		66.5	307.5	50.8	27.3	13.5	20.2	2.633
Neštin	NS	-	45°14′00″N	76	-	-	-	-	-	-	-
		2007	19°27′00″E		72.0	307.1	54.6	27.7	12.4	20.3	3.706
Negotin	NE	-	44°13′21″N	80	-	-	-	-	-	-	-
		2007	22°31′31″E		55.0	302.9	36.3	28.4	14.6	21.8	1.143

† Tmax, maximum temperature; ‡ Tmin, minimum temperature; § Tmean, average temperature; # Pp, precipitation; ¶ RH, relative humidity; * SH, sunshine hours; GY, grain yield.

Additional information on climatic variables during the April-September sunflower vegetation period was provided by the Hydrometeorological Service of Serbia. Average values for maximum temperature, minimum temperature, mean temperature, relative humidity, sunshine hours, and precipitation are given in Table 2.

Statistical analysis

The mean yield of hybrid *i* in site *j* is described by a general linear model:

$$Y_{ij} = \mu + \alpha_i + \beta_j + \phi_{ij} + \varepsilon_{ij} \qquad (1)$$

where μ is the grand mean, α_i is the main effect of the *i*th hybrid, β_j is the main effect of the jth site, is the interaction between hybrid *i* and site *j*, and ε_{ij} is the random error. In order to evaluate test sites for their representativeness and discriminating ability, both hybrid (H) and hybrid by site interaction (HS) effects must be considered simultaneously, so we used the SREG model (Crossa and Cornelius 1997) to obtain the HHS biplot.

Nonparametric correlations between test sites represented by Spearman's rank correlation coefficients were computed and displayed as heat-map diagrams. All data analysis was done within the R computing environment (R Development Core Team 2010).

Results

Discriminating ability and representativeness of the test sites

With regard to the use of single-year results for the analyses, the HHE biplot is referred to as the HHS biplot (environment = site × year combination) for the 2006 and 2007 data sets, and as the HHE for combined data.

The biplots of the first 2 principal components (PCs) showed 59.1% of total H + HS grain yield variance for 2006 (Figure 1), 47.9% for 2007 (Figure 2), and 58.0% of total H + HE grain yield variance in the combined analysis (Figure 3). The test sites (see Table 2 for abbreviations) used in the 2006 testing network that showed the best discriminating ability were RS and BC, but ZA, AS, SO, and LA also had good discriminating ability (Figure 1). NZ and SO were the most informative of the test sites used in the 2007 testing network, but NS and KI also showed good discriminating ability (Figure 2). For the combined data set test environment, the test site with the best discriminating ability was RS-6, along with ZA-6,

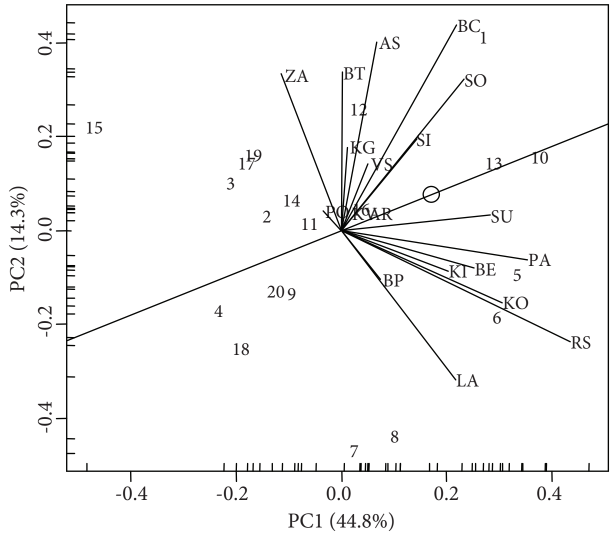

Figure 1. A sites regression biplot based on the grain yield data for the 2006 sunflower testing network. Discriminating ability, representativeness of test sites, and correlation between test sites are shown. The details and codes for the genotypes are given in Table 1. The details for the test sites are given in Table 2.

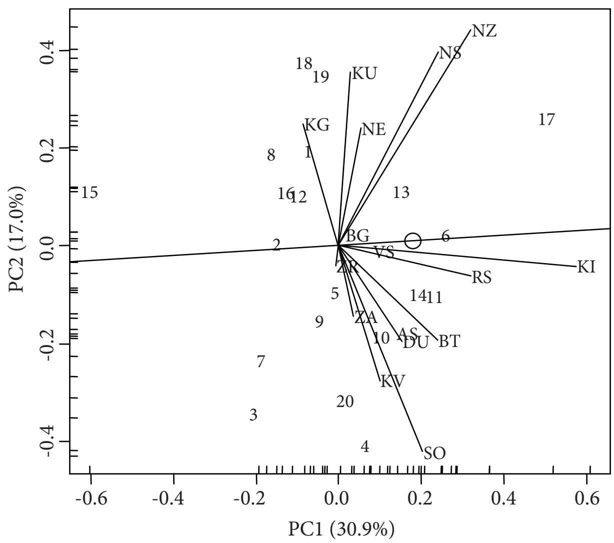

Figure 2. A sites regression biplot based on the grain yield data for the 2007 sunflower testing network. Discriminating ability, representativeness of test sites, and correlation between test sites are shown. The details and codes for the genotypes are given in Table 1. The details for the test sites are given in Table 2.

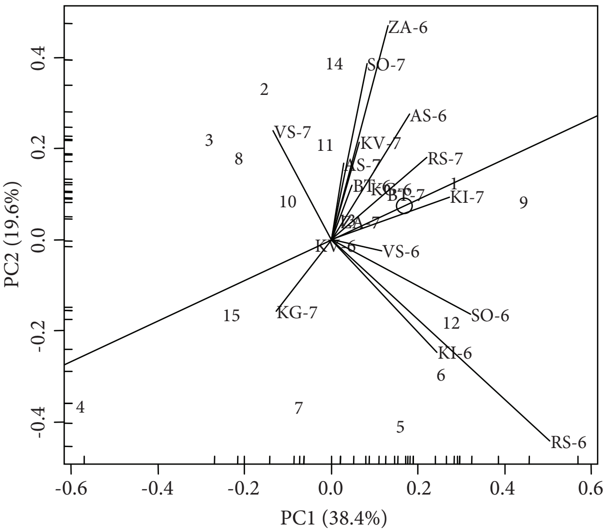

Figure 3. A sites regression biplot based on the combined grain yield data analysis. Discriminating ability, representativeness of test environments, and correlation between test environments are shown. The details and codes for the genotypes are given in Table 1. The details for the test environments are given in Table 2.

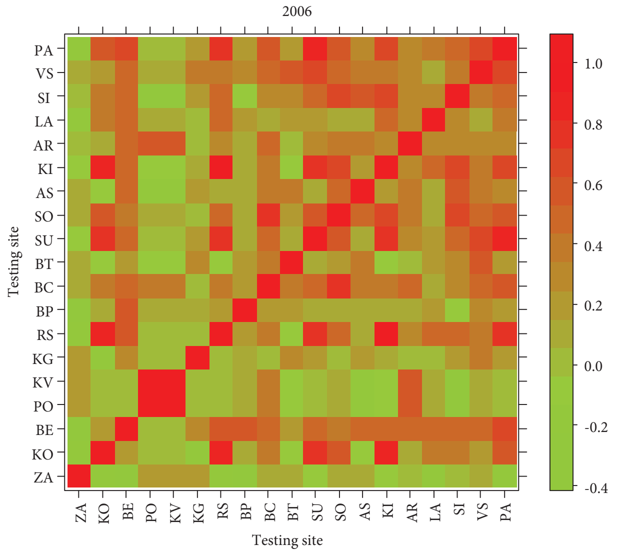

Figure 4. A heat map of the Spearman nonparametric rank correlations for grain yield among the sunflower test sites for 2006. The legend on the right side depicts the correlation color scale. The details for the test sites are given in Table 2.

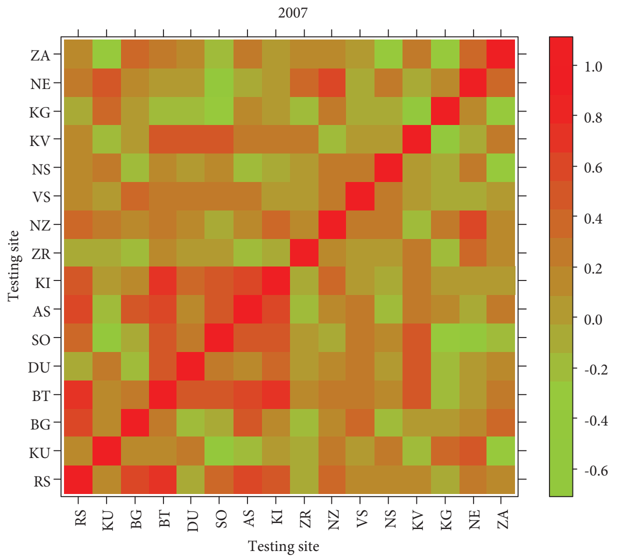

Figure 5. A heat map of the Spearman nonparametric rank correlations for grain yield among the sunflower test sites for 2007. The legend on the right side depicts the correlation color scale. The details for the test sites are given in Table 2.

SO-7, and SO-6 (Figure 3). The worst discriminating ability was shown by test sites AR, PO, KV, and VS in the 2006 sunflower testing network (Figure 1), BG and ZR in the 2007 sunflower testing network (Figure 2), and VS-6, KV-6, and ZA-7 for the combined data set (Figure 3).

The most representative sites in the 2006 testing network were AR, KV, SU, SI, and SO, whereas the least representative were ZA and LA, followed by BP and BT (Figure 1). For the sites in the 2007 testing network, the most representative sites were BG and KI, followed by RS and VS. The remaining sites can be regarded as not representative (Figure 2). Combined data set analysis showed that KI-7 was the most representative site, followed by BT-7, KG-6, and RS-7, while the least representative sites were KG-7, VS-7, KI-6, and RS-6 (Figure 3).

Spearman's nonparametric correlations and biplot relationships among test sites

The Spearman's rank correlations calculated for grain yield between each pair of sites for the 2006, 2007, and combined data are represented by colored heat maps (Figures 4-6). For the 2006 testing network, a significant ($P < 0.01$) rank correlation in the 0.8-1.0 range was demonstrated between the following pairs of sites: RS-KI, RS-KO, KI-KO, SI-SO, SU-RS, and SU-PA (Figure 4). Furthermore, a significant ($P < 0.01$) rank correlation in the 0.6-0.8 range was observed between the SU-KO, RS-PA, KI-PA, SO-BC, and SI-KI pairs of sites (Figure 4). Positive significant ($P < 0.01$) rank correlations in the 0.6-0.8 range were observed between the BT-RS, RS-KI, and KI-NZ pairs of sites for the 2007 testing network (Figure 5). Negative significant ($P < 0.01$) rank correlations in the 0.6-0.8 range were observed between the KG-KU pair of sites (Figure 5). For the combined data set, positive significant ($P < 0.01$) rank correlations in the 0.6-0.8 range were observed between RS-6 paired with KI-6, VS-6, and VS-7; VS-7 paired with SO-6, KI-6, RS-7, and BT-7; VS-6 paired with RS-7 and BT-7; KV-7 paired with AS-6, ZA-6, and SO-7; KG-6 paired with ZA-7 and KI-7; KI-6 paired with SO-6; and SO-7 paired with AS-6 (Figure 6).

The site pairs SI-SO, VS-BC, and LA-BP in the 2006 testing network were correlated well, but not identically, in their ability to discriminate among hybrids for their yield performance, because BC, SO, and LA, having longer vectors, were more discriminative (Figure 1). Similarly, AS and DU in the 2007 testing network were almost similar; they overlapped each other (with no angle between their vectors) and they also discriminated hybrids in a similar fashion (Figure 2). Site pairs BT-7 and RS-7, KV-7 and ZA-6, AS-7 and SO-7, and KG-6 and AS-6 in the combined data set were well correlated, but

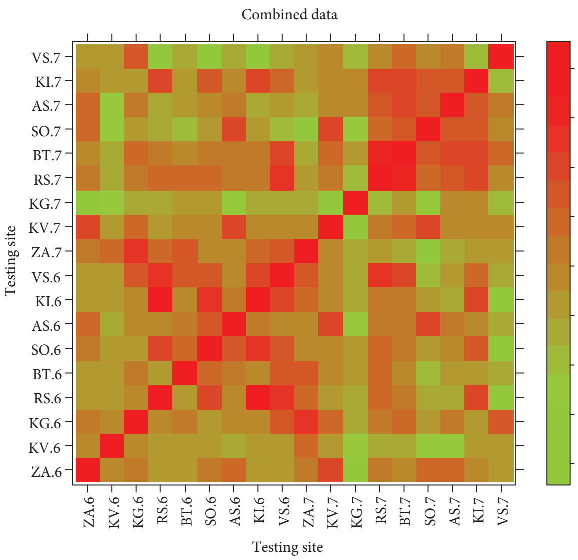

Figure 6. A heat map of the Spearman nonparametric rank correlations for grain yield among the combined sunflower test environment data. The legend on the right side depicts the correlation color scale. The details for the test environments are given in Table 2.

weaker discriminating ability was exhibited by BT-7, AS-7, KG-6, and KV-7 (Figure 3). Sites KO, RS, and KI in the 2006 testing network were closely correlated based on the small angle between their vectors, but RS was the most informative of the 3 sites (Figure 1). The following site groups were closely correlated in the 2007 testing network: VS, KI, and RS; NS and NZ; and KV, ZA, and SO (Figure 2). In the combined data set, KG-7 was poorly correlated with all other sites in the network (i.e. its vector made an obtuse angle with the other vectors), suggesting that this site tended to be distinctly independent (Figure 3).

Discussion

Plant breeders and agronomists have found SREG biplot analysis to be useful for test site evaluation of representativeness and discriminating ability, simultaneous evaluation of genotype performance and stability, and mega-environment investigation (Butron et al. 2004; Kang et al. 2005; Dardanelli et al. 2006; Navabi et al. 2006; Fan et al. 2007; Akash et al. 2009; Mohammadi et al. 2010; Goyal et al. 2011). In our investigation, the site regression biplot proved its effectiveness in explaining all aspects of the sunflower testing network.

The results of the biplot analyses were compared within single years and across combined data, considering producers' hybrid choices among a great number of commercial hybrids of different types and different quality traits. Moreover, by excluding some sites and adding other sites, more reliable conclusions about the target region and hybrid site relation could be made.

Discriminating ability refers to the site's ability to maximize the variance among genotypes in a study (Blanche and Myers 2006); it is approximated by the length of the site vectors. Biplots with an average-environment axis (AEA) (Yan et al. 2001) aid in the determination of test site representativeness; a test site that has a smaller angle with the AEA is more representative of the other test sites (Yan and Tinker 2006). "Test environments that are both discriminating and representative … are good test environments for selecting generally adapted genotypes. Discriminating but non-representative test environments … are useful for selecting specifically adapted genotypes *if* the target environments can be divided into mega-environments" (Yan and Tinker 2006, p. 630). Figures 1-3 show the discriminating ability and the representativeness of the test sites (environments), as well as the relationships between them.

One test site that was both discriminating and representative based on the 2007 testing network grain yield results was KI, so it would be a good test site for selecting generally adapted hybrids of sunflower for dry and hot areas and seasons, due to the fact that 2007 had less precipitation and higher mean temperatures in comparison to 2006 (Table 2). Discriminating but nonrepresentative sites are useful for selecting specifically adapted hybrids, and in our study these were represented by AS and RS based on the biplot analysis of the 2006 testing network, which had more precipitation and lower insolation rates than 2007 (Table 2, Figures 1 and 3). In addition, another discriminating but nonrepresentative test site, based on the biplot analysis of the 2007 testing network, was SO (Figures 2 and 3).

There were no test sites in our investigation that were both nondiscriminating in consecutive years and across both years and that thus needed to be dropped as redundant from the testing, according to Yan and Tinker (2006). For example, KV was the least informative in 2006, but that changed in 2007 (Figure 3).

The vector view of the SREG biplot shows the interrelationships between sites (Yan et al. 2000). The cosine of the angle between the vectors of 2 sites approximates the correlation between them (Kang et al. 2005). "If two test environments are closely correlated consistently across years, one of them can be dropped without loss of much information about the genotypes" (Yan and Tinker 2006, p. 630).

Biplot relationships among test environments have been investigated by many authors for several species (Kang et al. 2005; Dehgani et al. 2006; Akash et al. 2009; Goyal et al. 2011). The angle between the environmental vectors indicates the correlation coefficient between test sites (environments) in our experiment (Figures 1-3). The Spearman's correlation coefficients between test sites for grain yield are presented with colored heat maps in Figures 4-6. Biplot relationships among test sites did not always match the Spearman's rank correlation coefficients for site pairs. The site pairs SI-SO, VS-BC, and LA-BP in the 2006 testing network were highly correlated according to the biplot view (Figure 1), which was confirmed with the Spearman's rank correlation for the first 2 pairs of sites but not for LA-BP (Figure 4). In addition, the biplot describes the interrelationships among all sites on the basis of the overall pattern of the data, whereas correlation coefficients only describe the relationships between 2 sites. For the 2007 testing network, the AS-DU and ZA-KV pairs showed the highest correlation, but this was not confirmed by the Spearman's rank correlation (Figures 2 and 5). Similarly, the pairs of RS-7 and BT-7, and KV-7 and ZA-6, in the combined data showed a close relationship in the biplot view, which was confirmed with the Spearman's rank correlation (Figures 3 and 6), but in the case of the AS-7 and SO-7 pair, the biplot correlation was not the same as the Spearman's rank correlation for the same pair of test sites (Figures 3 and 6).

The presence of close associations between test sites RS and KI, based on the 2006 data, 2007 data, combined data, biplot analysis, and Spearman's rank correlation, suggests that the same information about the genotypes could be obtained from either of these 2 test sites and consequently could reduce testing costs.

For breeders interested in applying SREG biplot methodology, we can recommend the discriminating ability and the representativeness biplot view, which proved to be an effective tool for test site evaluation in our investigation and which can lead to the identification of a set of discriminating and representative/nonrepresentative test sites for different purposes under diverse meteorological conditions.

The presented results have several implications for future breeding, hybrid evaluation, and recommendation of promising sunflower hybrids in Serbia. SREG biplot techniques offered us the opportunity to identify and utilize test sites suitable for selecting generally and specifically adapted sunflower hybrids for the diverse environmental conditions of the sunflower-growing region in Serbia, and also to discard test sites closely correlated across years, which was already being done in commercial practice.

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