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Original scientific paper

ANALYSIS OF GRAIN SIZE IN BEAN (*Phaseolus vulgaris* L.) BY LINEAR AND BILINEAR MODELS

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Bean grain size, along with grain color and shape, is a constituent of bean's market quality. In order to be able to satisfy the broad market demand, cultivars with grain of all classes (from the smallest to largest) and top agronomic qualities must be developed. This paper analyzed 24 bean genotypes. They had different grain size in terms of their specific responses to growing conditions over three growing seasons. The two-way ANOVA was used to separate the main effects responsible for the formation of grain

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of a particular size. The genotype effects were 89.9%, the year effects 2.2%, and those of genotype x year interaction 7.9%. A large portion of interaction variability was attributable to two (AMMI) or tree (SREG) highly significant (by the Gollob F-test) principal components. Most of the genotypes exhibited high stability. The various types of interactions between individual genotypes and growing conditions in a given year are shown in two types of biplot graphs (GE and GGE).t to introduce organic agriculture programs in breeding institutions.

Key words: AMMI, biplot, dry bean, grain size, interaction types, SREG

INTRODUCTION

The main objective of breeding is to develop cultivars with a high and stable genetic yield potential. Yield variations are the result of gene action and their interactions with environmental conditions (BOROJEVIĆ, 1981). When developing high-yielding cultivars, quality should not be neglected. In the case of beans, market quality should be sustained (VASIĆ *et al*., 2002). Weight of 1000 grains, as a form of expression of grain size, is a major yield component, a bean quality parameter, a distinctive market characteristics and a highly stable varietal characteristic (KELLY *et al.,* 1998; AMURRIO *et al*., 2000; VASIĆ *et al*., 2008). To meet the current market demands, it is necessary to develop bean cultivars of high agronomic quality in all commercial categories, from small- to large-seeded beans.

The earliest studies of bean variability and stability suggested that bean size depends greatly on the specific reaction of each genotype to the environmental conditions (TAVČAR, 1923) and growing conditions (ADAMS, 1967). Study of interactions between genotype and growing conditions increases the efficiency of plant breeding and it is the primary element for identification of general and specific adaptive value. Stability defines the extent of changes of a property occurring in a genotype across different environments (EBERHART and RUSSELL, 1966). Changes depend on the direct impact of the environment and the existence of genotype by environment interaction. Genotypes that show high agronomic stability over a wide range of environments are considered as having general or wide adaptability (FINLAY and WILKINSON, 1963). Genotypes that exhibit agronomic stability in the limited number of environments are considered as having a narrow or specific adaptability.

Numerous statistical methods have been proposed so far for the study of the genotype by environment interaction (LIN *et al*., 1986; KANG, 1990). All methods can be divided into two major groups: univariate (parametric and non-parametric) and multivariate. The AMMI (*additive main effect and multiplicative interaction*) analysis belongs to the latter group (GAUCH, 1988, ZOBEL *et al*., 1988). This method, which had been developed for and applied in social sciences, was subsequently used in physiological research of the impact of photoperiod and temperature on the height of bean plants (ZOBEL, 1993). It integrates two well-known statistical procedures: the analysis of variance and the principal components analysis. Considerable progress towards easier understanding of relationships between genotypes, their characteristics and environment was made by providing a visual representation of these relationships by biplot graphs (GABRIEL, 1971; YAN *et al.*, 2000). The authors of this paper have used these methods in the study of different plant species (KRALJEVIĆ-BALALIĆ *et al*., 1998; GVOZDANOVIĆ-VARGA *et al.,* 2004; VASIĆ *et al*., 2004; ZORIĆ, 2005).

The objectives of this study were to investigate the stability of grain size in the selected bean genotypes and present it graphically by two types of biplot graphs. Investigated the local white bean cultivars were compared in the study with well-known and widely used foreign cultivars.

MATERIALS AND METHODS

The study included accessions from a dry bean collection of Institute of Field and Vegetable Crops in Novi Sad. We analyzed 24 genotypes, of which 21 were white beans and three were black. The black genotypes (Sataja 425, A 55, Naya nayahit) and 5 white genotypes (Michigan, Prelom, C-20, Alubia, Robust) were foreign cultivars, 12 were of domestic origin (P-1, Biser, Medijana, Oplenac, Maksa, Panonski gradištanac, Dvadesetica, Panonski tetovac, Belko, Balkan, Galeb), and four were domestic populations (KP151, KP156, Kutjevački rani, KP175).

The trials, conducted during three growing seasons, were planted at regular dates in the spring. Weather conditions varied during the three-year study. In the first year (E_1) the rainfall was much lower than in the other two years (E_2 and E_3). The experiment was set up in a random plot design in three replications. Bean plants were planted at a spacing 50x5cm. After bean harvest, grain size was estimated via 1000-grain weight. The measurements were carried out on 30 plants per replication or a total of 90 plants per accession.

The statistical data processing started with the calculations of mean values. Then we calculated the coefficient of variation (CV), in %, for each genotype. The AMMI analysis differentiated the effects of the genotype, year and their interactions. Sources of variability in the genotype/year interaction were differentiated by the principal components analysis, PCA (GAUCH and ZOBEL, 1996). The data were also subjected to the SREG (site regression) analysis (CROSSA and CORNELIUS, 1997). Unlike the AMMI analysis, the SREG analysis adds the genotype effect to the interaction effect during the interaction matrix decomposition. IPCA significance was tested by the F-test of GOLLOB (1968). For the AMMI analysis, graphic presentation of the G x E interaction and genotype stability evaluation was done by the procedure of VARGAS and CROSSA (2000). The genotype by year stability and interaction were graphically presented by three types of biplot graphs. The GGE biplot graph was derived from the SREG analysis using the procedure of YAN *et al.* (2000).

RESULTS AND DISCUSSION

Grain size of beans is a direct yield component and the main feature when describing a genotype and market quality of a cultivar. The domestic cultivars and populations, with the grain size of about 250 g to 400 g, belonged to bean cultivars with medium-size grains (VASIĆ, 2004; Table l). Genotypes originating from foreign countries had smaller grains, with the exception of one genotype. Most genotypes had a coefficient of variation below 10%, similar to previous studies (VASIĆ, 2004).

Table 1. Thousand-grain weight (g) and coefficients of variation per genotype and year

N°	Genotype (G)	Year (E)			Mean (G)	CV (%)
		E_1	E_2	E_3		
1	Sataja 425	159.5	164.1	161.8	161.7	1.4
2	A 55	184.7	205.4	211.5	200.4	6.9
3	Naya nayahit	165.7	165.2	172.9	167.9	2.6
4	Michigan	194.8	200.5	241.7	212.3	12.1
5	Prelom	235.9	203.7	229.5	222.9	7.7
6	Kp 151	265.6	252.0	275.9	264.5	4.5
7	P-1	162.0	172.5	183.3	172.5	6.2
8	Biser	256.1	233.0	250.8	246.8	4.9
9	Medijana	254.4	214.7	219.3	229.4	9.5
10	Kp 156	225.7	210.6	231.1	222.4	4.8
11	C-20	179.3	180.2	178.0	179.1	0.6
12	Kutjevački rani	240.5	285.7	252.7	259.6	9.0
13	Oplenac	322.7	285.3	378.4	328.7	14.2
14	Kp 175	280.2	258.5	345.4	293.8	15.3
15	Maksa	352.6	310.8	359.2	340.8	7.7
16	Alubia	336.4	291.4	383.0	336.8	13.6
17	Panonski gradištanac	420.8	401.0	377.7	399.8	5.4
18	Kp 193	328.0	288.6	310.3	308.9	6.4
19	Dvadesetica	355.4	312.1	351.9	339.8	7.1
20	Panonski tetovac	423.4	395.1	365.8	394.7	7.3
21	Robust	424.9	274.4	423.8	374.3	23.1
22	Belko	309.4	278.9	302.7	297.0	5.4
23	Balkan	333.4	290.1	329.8	317.7	7.6
24	Galeb	379.0	366.7	311.0	352.2	10.3
	Mean (E)	282.9	260.0	285.1	276.0	
	CV (%)	30.3	26.2	27.3		

We found highly significant effects of the genotype, year and their interaction on the formation of grain of certain size (Table 2). GOMEZ (2004) came to a conclusion that the effect of the environment was not significant for variations in the 1000-seed weight. DE RON *et al.* (2004) reported that the effect of environment was not significant, while interactions between the environment on one side and other factors exhibited significance with most bean quality indicators. Were the previous true only for grain size as yield component, it would be an advantage for the breeder. However, grain size is also a market characteristic of a variety, which requires production stability under different conditions in order to standardize the marketable product, i.e., bean grain. It may be assumed that such a high impact on the genotype on grain size results from breeding efforts in that direction.

Table. 2. ANOVA of main effects and multiple interactions (AMMI and SREG model) for 1000-grain weight (g)

Source of variation	df	SS	SS (%)	MS
Two-way ANOVA				
Genotype (G)	23	1142261	89.9	49664**
Year (Y)	2	27866	2.2	13933**
G × Y	46	101125	7.9	2198**
Error	138	59873	-	434
AMMI model				
IPC_1	24	71491	70.7	2979**
IPC_2	22	29634	29.3	1347**
SREG model				
PC_1	24	1157082	93.1	48211**
PC_2	22	67403	5.4	3063**
PC_3	20	18901	1.5	945*

*p=0.05; **p=0.01

Complex characteristics determined by many factors are subject to methods of multivariate analysis (SEAL, 1964; KENDALL, 1980; KOVAČIĆ, 1994). The AMMI analysis produced two significant interaction principal components (Table 2). The first component (IPC_1) explained 70.7% of the interactions, the other explained the rest. The unexplained part of the variability was negligible. Unlike the AMMI analysis, the SREG analysis distinguished three statistically significant principal components, of which the first one was predominant.

The $AMMI_1$ model graph, whose x-axis shows average value of a characteristic and the y-axis the values of IPC_1, shows the values of individual genotypes and their stability (Fig. 1). The vertical line indicates the general mean for grain size (276.0 g) of all genotypes and all years. The mean values of grain size were quite similar in the three years of study, but the different IPC_1 values indicated that there existed differences in the year by genotype interactions. In the case of grain size, priority should be given neither to genotypes with large nor the genotypes with small grains because all grain sizes have their place on the fastidious bean market (AMURRIO *et al.*, 2000; TODOROVIĆ *et al.*, 2008). Most cultivars were distributed around the x axis, which indicated their stability.

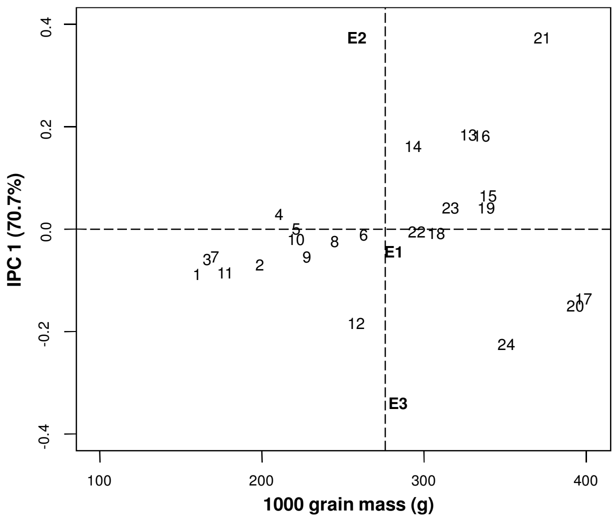

Figure 1. Genotype stability ($AMMI_1$) biplot for 1000-grain weight

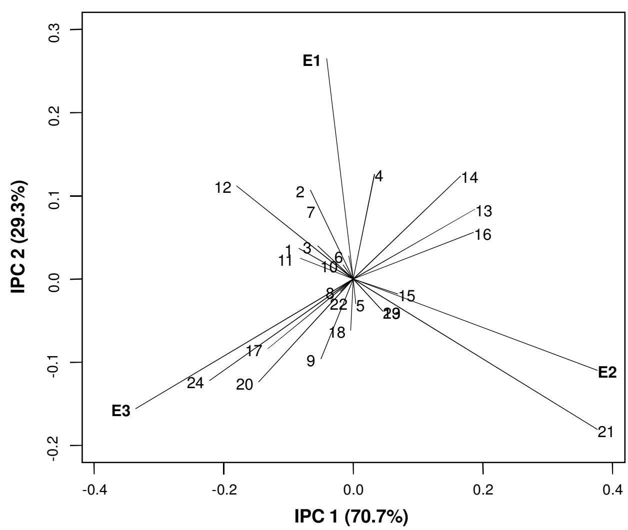

Figure 2. Genotype to environment affinity (AMMI) biplot for 1000-grain weight

The $AMMI_2$ model graph indicates the proximity or relationship between the studied genotypes (G) and the growing environment (E) and it is called the GE biplot. It indicated that each year exhibited a specific influence (Fig 2). Genotypes that depart from the coordinate origin in the same direction as a particular year establish a positive interaction with that year and their grains are larger than could be expected on the basis of the results of the additive method that relies only on the main effects of the genotype and year. If the direction of departure is opposite, the interaction is negative. Genotypes located in the center of the biplot practically do not interact with the specific conditions of study year and are very stable.

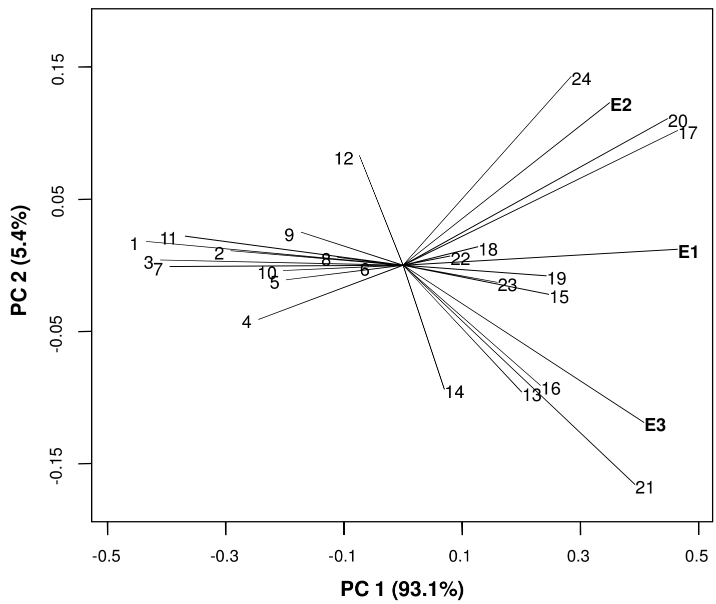

Figure 3. $SREG_2$ (GGE) biplot for 1000-grain weight

The SREG biplot model, called the GGE biplot, uses the variance of genotypes (G) and their interactions with the environment (GE) as components that valorize the expression of a studied characteristic (YAN *et al*., 2000). In that way it is possible to distinguish genotypes with a desirable primary effect, which in this case is the appropriate grain size, from genotypes with a small secondary effect, which means they are less influenced by the environment, i.e., they are more stable. The selection of such genotypes is the most common breeding objective no matter if the final aim is the development of a new variety or the choice of parental pairs for crossing. In our case, we could not rely on the stability of genotypes with large grains because their grain size varied much above the average across the study years

(Fig. 3). In this study, high stability was exhibited by the genotypes with smallest grains.

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ANALIZA KRUPNOĆE ZRNA PASULJA (*Phaseolus vulgaris* L.) PRIMENOM LINEARNO-BILINEARNIH MODELA

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I z v o d

Krupnoća zrna pasulja je, uz njegovu boju i oblik, tržišni kvalitet pasulja. Da bi se zadovoljili različiti zahtevi tržišta moraju se stvarati sorte u svim trgovačkim klasama pasulja, od sitnog do najkrupnijeg zrna visokih agronomskih kvaliteta. U radu je analizirana specifičnost reakcije 24 genotipa pasulja različite krupnoće zrna na uslove uzgajanja tokom tri vegetacione sezone. Izdvojeni su glavni efekti odgovorni za formiranje zrna odredjene krupnoće. Rezultati ipitivanja govore da su uticaj genotipa, uslova uspevanja i specifične reakcije genotipa na uslove uspevanja značajni za formiranje zrna određene mase 1000 zrna kod pasulja. Uticaj genotipa je izuzetni visok, oko 90%, uticaj godine mnogo manji, ali takođe značajan, a interakcije genotip x godina oko 8 %. Primenom AMMI za objašnjenje varijabilnosti interakcije bile su potrebne dve visoko značajne glavne komponente, a za SREG model tri. Najveći deo genotipova, uz pojedinačne specifične reakcije, ispoljio je visoku stabilnost za krupnoću zrna što potvrđuje i njihov raspored na $AMMI_1$ biplot grafikonu. Na osnovu $AMMI_2$ biplot grafikona može se zaključiti da svaka godina ispoljava karakterističan uticaj, da su pojedini genotipovi imali pozitivnu ili negativnu interakciju sa pojedinim godinama, ali i da je bilo genotipova bez specifične reakcije sa uslovima uspevanja. Pomoću GGE biplota konstruisanog primenom SREG modela zaključeno je da su od ispitivanih genotipova oni sa krupnim zrnom imali manju stabilnost od onih sa sitnim zrnom. Korišćenjem AMMI i SREG metoda multivarijacione analize, a posebno konstruisanjem GE i GGE biplot grafikona mogu se dobiti potrebni odgovori o uzrocima formiranja zrna određene krupnoće kod pasulja, o stabilnosti ispitivanih genotipova i o specifičnim reakcijama pojedinačnih genotipova sa određenim uslovima uspevanja.

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