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GENOTYPE AND ENVIRONMENT EFFECTS ON YIELD AND QUALITY OF WINTER GARLIC

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Genotype response to changeable environmental factors as expressed through genotype x environment interaction offers important information to breeders and growers as end users. Bulb mass and dry matter yield per bulb are major components of garlic yield and quality. The paper analyzed G x E interaction of 18 winter garlic genotypes (13 populations and five clones) across three growing seasons. Main effects of the genotype, environment and their interaction were determined applying the AMMI model. Year was the major source of variability for bulb mass (70.7%), while G x E interaction amounted to 6.18%. Dry matter yield was most variable under the effect of genotype (46.91%) and the interaction was high, 13.45%. The first principal component was important for bulb mass and dry matter yield since it explained 77.52% and 78.39% of the G x E interactions, respectively. A biplot was constructed to graphically represent the G x E interaction.

Key words: genotype/environment interaction, AMMI, garlic

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INTRODUCTION

Use of garlic in human diet is primarily due to its health benefits which had already been recognized by ancient Egyptians and Greeks (KAZAKOVA, 1978). Current studies of garlic are focused on bioactive substances contained in allicin, the etheric oil which has specific odor and taste (KEUSGEN, 1997).

The garlic reproduces vegetatively under the local conditions. In the case of vegetatively reproducing plant species, variability among plants is considered as ecological variability because it is the result of influences of changeable environmental factors (BOROJEVIĆ, 1992).

Genotype response to environmental variations is an important piece of information for breeding. Stability of a trait during breeding depends on the intrinsic structure of the genotype and its reaction to the environment. It is desirable for a genotype to have a minimum reaction to changes of environmental factors. In the case of garlic, which reproduces vegetatively, genetic stability of its quantitative and qualitative traits is manifested as phenotypic uniformity across different environments (JANICK, 1999).

Because of differences among garlic genotypes regarding yield performance and variations in yield and quality from one year to another, it was deemed worthwhile to study the stability of these traits and their interactions with the environment. The objective of this study was to assess the reaction of winter garlic genotypes to variable environmental conditions, i.e., to assess their reaction to the weather conditions during growing season.

MATERIALS AND METHODS

Eighteen genotypes of winter garlic were tested during three growing seasons (1998/99, 1999/2000, 2000/2001). Experiments were conducted at Rimski Šančevi experiment field of Institute of Field and Vegetable Crops using random blocks design with three replications. Of the 18 genotypes analyzed, 13 were populations and three were clones (lines derived from these populations). The populations draw origin from the Vojvodina Province. Garlic yield and quality were represented as bulb mass and dry matter yield per bulb.

Additive main and multiplicative interaction (AMMI) model was used to distinguish the main effects, genotype, environment and their multiple interactions. This model is a combination of ANOVA and principal component axis (PCA) analysis. Variability sources in the interaction genotype x environment are partitioned by the analysis of principal components and they are called IPCA (interaction PCA) (GAUCH and ZOBEL, 1990):

$$\gamma_{ge} = \mu + \alpha_g + \beta_e + \sum_{n=1}^{N} \lambda_n \gamma_{gn} \delta_{en} + Q_{ge}$$

Where:

γ_{ge} is the yield of genotype g in environment e,

μ is the grand mean,

α_g are the genotype mean deviations (means minus grand mean),
β_e are the enviroment mean deviations,
N is the number of PCA axes retained in the model,
λ_n is the singular value for PCA axis n,
γ_{gn} are the genotype eigenvector values for PCA axis n,
δ_{en} are the enviroment eigenvector values for PCA axis n, and
Q_{ge} are the residuals.

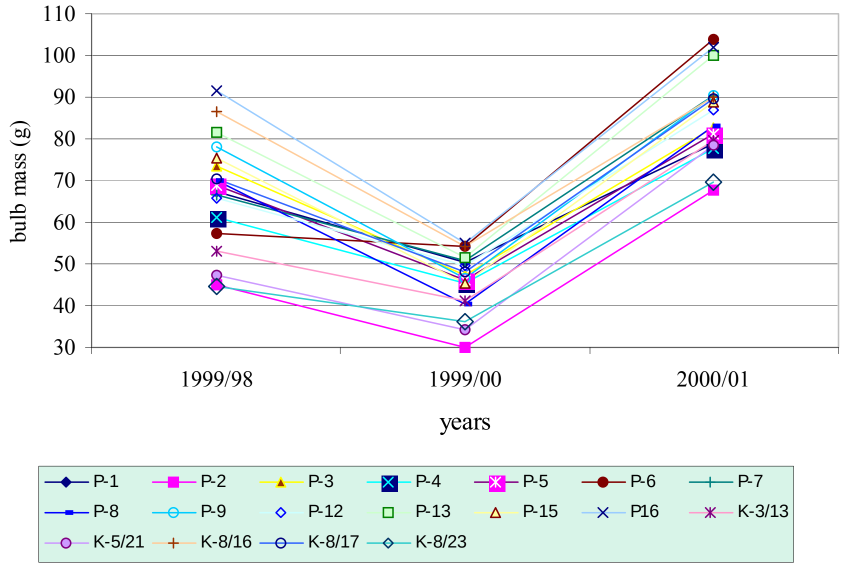
Significance of IPCA was tested by the F-test after GOLLOB (1968).

In joint biplot, the G x E interaction (via IPCA 1) was given on the vertical axis and average values of genotypes and environments on the horizontal axis.

The analytical procedure and interpretation of the results are based on GAUCH and ZOBEL (1990). AMMI analysis was done using the program Excel Biplot Macros (www.jstatsoft.org/v07/i05/biplot01.xla) of LIPKOVICH and SMITH (2002).

RESULTS

Bulb mass. - Graph 1 shows the changes of bulb mass mean values across the test years and their interactions. The graph distinguishes the types of interactions present in the analyzed genotypes (KANG, 1998).



Graf. 1. Three-year ranking of winter garlic regarding bulb mass

Most of the tested genotypes responded similarly to the changes of environmental factors across the three growing season, i.e., they decreased their bulb mass. Genotype P-6 reacted specifically - in the second year, it reduced the bulb mass by only 3 g in relation to the total average, while in the third year it produced the largest bulbs. The clone K-5/21 exhibited a similar reaction. Contrarily to these genotypes, the clone K-8/23 exhibited a decreasing reaction, but the differences among the years were small.

Table 1 shows the AMMI analysis of all sources of variability. Highly significant values were obtained for the genotype, year, interaction and only the first principal component (IPCA 1).

Table 1. Analysis of variance of main effects and multiple interactions among the analyzed traits in winter garlic

Source	Df	Bulb mass (g)			Dry matter yield (g)		
		S.S	M.S.	Explained %	S.S	M.S.	Explained %
Replication	2	590.9	295.467	0.98	68.23	34.116	2.02
Genotype (G)	17	13335.9	784.464**	22.16	1583.96	93.174**	46.91
Year (E)	2	42516.4	21258.198**	70.66	1269.86	634.929**	37.61
G*E	34	3722.2	109.477**	6.18	454.11	13.356**	13.45
IPCA 1	18	2885.51	160.306**	77.52	355.86	19.769**	78.39
IPCA 2	16	836.72	52.295	22.48	98.11	6.132	21.62
Error	106	38.6	36.506		493.97	4.66	

Table 2. Mean values of the analyzed traits for genotypes and years, PCA values calculated on the bases of the AMMI model

Genotype	Bulb mass (g)			Dry matter yield (g)		
	mean	IPCA 1	IPCA 2	mean	IPCA 1	IPCA 2
P-1	65.4	0.30	-1.88	22.3	0.25	-1.15
P-2	47.6	-0.70	-0.41	16.2	0.35	0.3
P-3	67.8	1.13	-0.64	23.0	1.02	-0.47
P-4	61.4	-0.13	-1.28	20.8	0.10	-0.46
P-5	65.3	0.61	-0.73	21.5	0.31	-0.26
P-6	71.8	-3.41	1.38	24.0	-1.90	0.29
P-7	69.3	-0.74	-0.06	23.1	-0.43	-0.33
P-8	64.6	1.01	0.62	21.2	0.82	0.35
P-9	71.7	1.21	0.85	23.8	0.66	0.21
P-12	67.5	-0.54	-0.44	22.7	-0.47	-0.47
P-13	77.6	0.60	1.55	26.9	0.43	0.84
P-15	70.0	1.02	0.74	23.6	0.88	0.59
P-16	82.8	1.71	1.39	28.6	0.69	0.91
K-3/13	57.9	-1.23	-0.34	19.5	-0.92	-0.05
K-5/21	53.4	-1.56	0.64	18.2	-1.08	0.90
K-8/16	76.8	1.96	-0.51	26.0	0.66	-0.51
K-8/17	69.3	0.05	0.33	23.1	0.07	0.15
K-8/23	50.2	-1.30	-1.20	17.1	-0.72	-0.58
Year/ mean	61.13			22.33		
1998/99	66.9	4.54	0.22	23.0	2.65	0.35
1999/00	45.9	-2.00	-2.99	18.6	-0.90	-1.84
2000/01	85.6	-2.53	2.77	25.4	-1.75	1.49

P-population; K-clon

The year had the highest influence on bulb mass, as much as 70.66%, genotype explained 22.16 %, while G x E interaction explained 6.18% of the total variation. Although the effect of G x E interaction was small percentagewise, IPCA 1 was highly significant. The first principal component explained 77.52% of G x E interaction, i.e., 4.79% of the total variability for bulb mass. Individual results of AMMI analysis for the genotypes and years are presented in a table (Table 2.) and graphically (Fig. 1.).

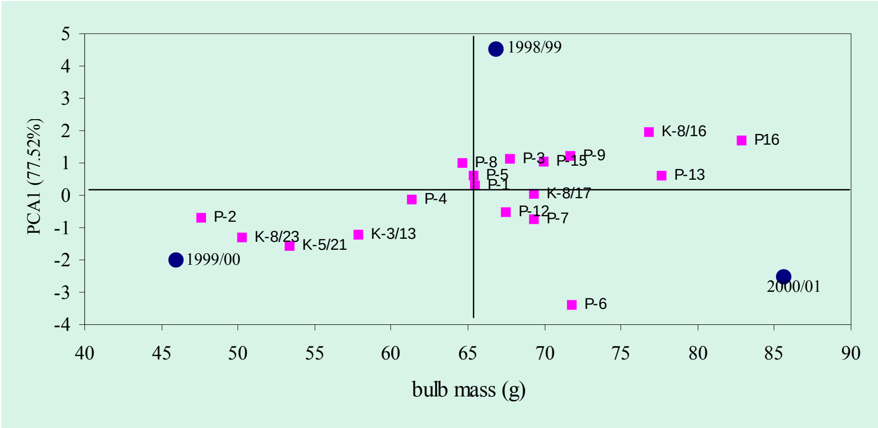
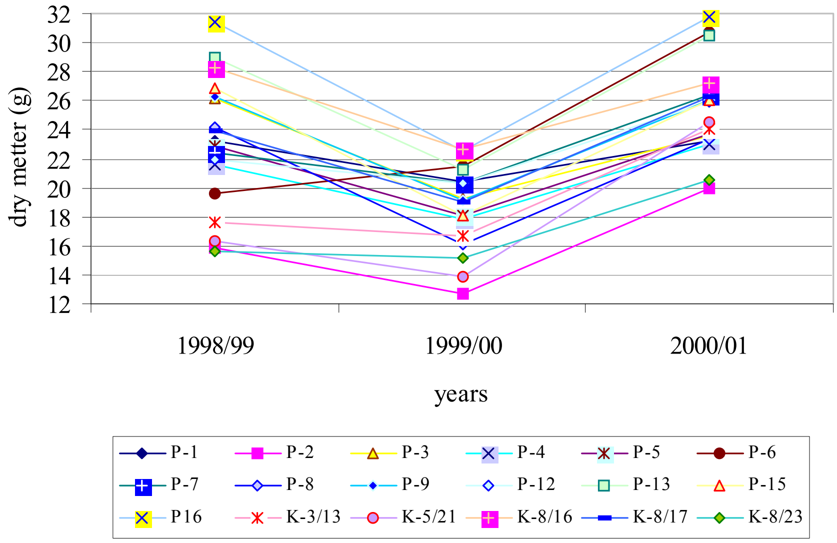


Fig. 1. AMMI model biplot for bulb mass in winter garlic

The graph shows that genotypes K-8/16, P-13 and P-16, as well as the first test year, had very high mean values and high and positive IPCA 1 values. The largest bulb mass (85.6 g) was obtained in the third year. That year, as well as the genotype P-6, had the highest negative values of IPCA 1, -2.53 and -3.41, respectively. The lowest average bulb mass (45.9 g) was obtained in the second year. That year had a negative IPCA 1 value, and so did the genotypes P-2, K-8/23, K-5/21 and K-3/13. The genotypes grouped around the coordinate zero (P-8, P-1, P-5), which had the average bulb mass close to the general average and very low IPCA 1 values, also had a low response to the environmental factors.

Dry matter yield. - Graph 2 ranks the genotypes regarding their yields of dry matter across the years. It can be seen that a reduction in dry matter yield occurred in the second year, in response to the change in the environmental factors. Reductions were registered for all genotypes except P-6. In the third year, P-6 increased its dry matter yield even more, 11.2 g per bulb more than in the first year. The genotype K-8/23 had the lowest response to the change of environmental factors during growing season.

The genotype, year and G x E interaction explained 46.91%, 37.61% and 13.45% of the total variation, respectively (Table 1). All three main effects were statistically highly significant. The sum of squares of IPCA 1 was 78.39% and it was statistically highly significant. The biplot (Figure 2) clearly distinguished the three years and the genotypes suitable for all environments.



Graf. 2. Three-year ranking of winter garlic regarding dry matter yield

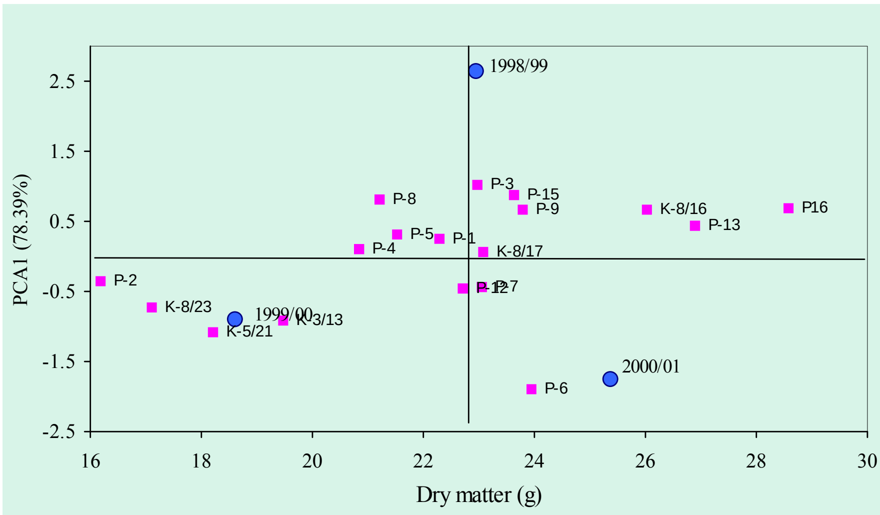


Fig. 2. AMMI model biplot for dry matter yield in winter garlic

The first year had a high IPCA 1 value. The IPCA 1 values in the genotypes P-3, P-15 and P-9 were above the average. Maximum IPCA 1 values, which were positive, were found in the genotypes K-8/16, P-13 and P-16. On the other side were the genotypes whose dry matter yields were below the average and whose IPCA 1 values were negative (P-2, K-8/23, K-3/13, k-5/21 as well as the second year). The genotype P-6 and the third year had high negative IPCA 1 values for dry matter yield but still these values were above the total average. The genotypes K-8/17, P-12 and P-7 exhibited the smallest changes of this trait in the course of the three years.

DISCUSION

G x E interaction is a category coming from quantitative genetics and it is used in plant breeding. It reflects genotype adaptability and stability. Variation of the genotype in different environments is manifested as a change in phenotype (KANG, 2002). Changes in the phenotypic values result from the reaction of the genotype to the prevailing environmental conditions. The genotype has certain phenotypic expression which is called reaction type. Therefrom are the genotype and environment the two main factors determining the phenotype (KANG, 1998).

The tested genotypes had different reaction types in the course of the three years but it may be said generally that a considerably lower bulb mass was obtained in the second year while the highest G x E interaction was registered in the third year. When considered individually, the garlic genotypes exhibited an array of different reactions to the environmental variations. They had an increased or decreased bulb mass in relation to the average value for the year. For example, the genotype P-6 had the bulb mass lower by 3 g in the second year and the largest increase of bulb mass in the third year. Conversely, the genotypes P-1, P-8 and K-8/17 exhibited the smallest reactions to the environment during the three years. The analysis of the main effects and multiple interaction confirmed that the three years were quite different, resulting in the variations in bulb mass. The analysis of the main effects and the multiple interactions showed that the three years were mutually quite different and that they caused largest variations in bulb mass, larger than the genotype. This was an indication that climatic factors (temperature and amount of rainfall) played a key role in bulb formation. Water shortage combined with high temperatures during the critical stages of garlic development tends to cause yield reduction (KAZAKOVA, 1978). In this study, this happened in the second year, when high temperatures occurred at the stages of leaf and bulb forming. Bulb mass is highly correlated with environmental factors (SHINDE *et al.*, 1999). Genotype x year interaction explained 6.2% of the total sum of squares in the AMMI analysis and it was statistically highly significant. Low percentage of statistically highly significant G x E interaction indicates a high degree of adaptation of garlic genotypes (YAN *et al.*, 1998), while the significance of interaction indicated their stability, i.e., the differential genotypic reaction to given environmental conditions. The high adaptation of the garlic genotypes observed in this study is the result of a long period of their cultivation in this agroclimatic region. Genotypic stability represents the reaction to changeable environmental factors which frequently are an unforeseeable source of variation (KANG, 2002). The joint biplot showed a pair of genotypes grouped near the coordinate zero (P-1, P-5). They were stable for bulb mass as indicated by the low values of IPCA 1. Another group included the genotypes P-16 and K-8/16 which had a high average bulb mass, a high positive interaction with the first year and negative interactions with the second and third years. Genotypes positioned highest in a sector grow best in the environment represented by this sector (YAN, 2001). Opposite to this group was the population P-6, with a large bulb and negative IPCA 1 value, and the third year. Simultaneously, this genotype had the largest bulb mass in the third year, i.e., the climatic conditions of that year favored the expression of that trait in the case of this genotype. The same is true for the other genotypes in that sector, but their values were much lower. The genotype P-2 had the lowest mean value of bulb mass in the second year but also low negative interactions with the first and third years. The yields of the genotypes K-8/23, K-5/21 and K-3/13 were below the average, which was in good part due to the effect of the year. If we know the environmental factors that favor a genotype, it may help us identify the geographic origin of that genotype. The interactions of the genotype P-6 with certain environmental conditions indicated that this genotype originated from a region abounding in rainfall. Obviously, this genotype could receive more intensive cultural practices when grown under the local conditions, i.e., it could be grown in irrigation, which is not common practice in our country.

Quality of garlic, i.e., yield of dry matter, is important for its utilization rate during processing. The tested genotypes had the lowest average yield of dry matter in the second year; however, the rates of dry mater reduction differed among the individual genotypes. The genotypes K-8/17 and P-1 had the lowest reaction to environmental changes, the genotype P-6 had the highest reaction. The sum of squares (SS) of the genotype explained the largest part of the total variability for yield of dry matter, followed by year and interaction. The portion of the genotype in the total variability was much higher than it was the case with bulb mass. This is due to the complexity of the trait which encompasses within itself a quantitative part (bulb mass) and a qualitative part (dry matter). Variability of qualitative traits across different environments is minimal (PRITTS and LUBY, 1990). Conversely, POOLER and SIMON (1993) found that the phenotypic variability of bulb traits (bulb mass, number and size of cloves) is due to the reaction to environmental factors, which in its turn is the consequence of the vegetative mode of reproduction. The analyzed genotypes differed regarding the yield of dry matter (GVOZDANOVIĆ-VARGA, 1997). The high PCA 1 value and the low PCA 2 value for the first year indicate that the genotypes responded positively to the favorable environment. There was a low negative correlation between the genotypes and the second year. All genotypes produced small bulbs, resulting in low total yield in spite of the high dry matter contents. The high negative IPCA 1 value for the third year indicates that the genotypes increased the yield of dry mater in response to a favorable environment, the major contributor to the increase being bulb mass. The genotype P-6 had the highest bulb mass in the third year. Three of the analyzed clones, which had been selected for high dry matter content, had a low interaction with the second year and negative IPCA 1 values for the first and third years because their dry matter contents were poorly corelated with bulb mass (GVOZDANOVIĆ-VARGA *et al.*, 1994). The group of genotypes with very high yields included a clone which had been selected for high yield performance and two populations. Their positive interactions with the first year indicate that this growing season provided optimum conditions for maximum realization of this complex trait, i.e., for the development of large bulbs with a high dry matter content (KUMAR *et al*., 1994; SHINDE *et al.*, 1996; GVOZDANOVIĆ-VARGA *et al.*, 2002).

Stability of dry matter content in a genotype may be assessed on the basis of its distance from the coordinate zero (YAN, 2002). In our study, only one clone was stable for this trait. Stability was also exhibited by the populations P-1, P-3, P-15 and P-9 which in addition had above-average yields. This is an indication that these populations can be used in breeding for high dry matter content. As this group of genotypes was genetically heterogeneous, the year had a lesser effect on this trait.

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UTICAJ GENOTIPA I SPOLJNE SREDINE NA PRINOS I KVALITET JESENJEG BELOG LUKA

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Izvod

Značajnu informaciju o genotipu za oplemenjivače i proizvođače kao krajnje korisnike, predstavlja njegov odgovor na promenljive faktore sredine, koji je izražen preko interakcije genotipa sa spoljnom sredinom. Prinos i kvalitet belog luka predstavljeni su masom lukovice i prinosom suve materije po lukovice. U radu je analizirana G x E interakcija 18 genotipova (13 populacija i 5 klonova) jesenjeg belog luka tokom tri vegetacione sezone. Primenom AMMI modela ustanovljeni su glavni efekti genotipova za ispitivane osobine preko glavnog efekta sredine za genotipove i njihove interakcije. Najveći izvor varijabilnosti za masu lukovice imale su godine (70,7%) dok je interakcija iznosila 6,18%. Prinos suve materije je najviše varirao pod uticajem genonotipa (46,91%) i visok udeo interakcije 13,45 %. Za masu lukovice i prinos suve materije je značajna prva glavna komponenta, kojom je objašnjeno 77,52% odnosno 78,39% G x E interakcije. Korišćen je biplot da bi se grafički predstavila G x E interakcija.

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