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DETERMINING GENETIC POTENTIAL AND QUALITY COMPONENTS OF NS SOYBEAN CULTIVARS UNDER DIFFERENT AGROECOLOGICAL CONDITIONS

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ABSTRACT

This paper aims at determining the genotype x environment interactions of seed yield and quality components of NS soybean cultivars under different agroecological conditions. Field trials were conducted in Serbia, during three years (2009-2011). Six soybean genotypes, belonging to different maturity groups were used (MG): Valjevka, Galina, Afrodita (0 MG), Sava, Victoria (I MG) and Trijumf (II MG). The effect of genotype (G), environment (E) and GxE interactions on yield, protein content and oil content were found to be significant (P<0.05, P<0.01).

During 2010 and 2011, significantly higher grain yield per area unit were achieved as compared to 2009. The highest stability of protein content in the whole tested period was found in genotype Galina. The highest seed yield and oil content were obtained by genotype Valjevka. Genotype Galina showed high stability and good performance in all years for seed yield and protein content.

Soybean yield was positively significantly correlated with precipitation (r=0.48*) and negatively significantly correlated with temperatures (r=0.52*). Oil content was negatively highly significantly correlated with precipitation (r=0.83) and positively highly significantly correlated with temperatures (r=0.81**).**

This study can represent the basis for further soybean breeding.

Key words: *Glycine max*, genotype, yield, quality components, correlations, G x E interaction.

INTRODUCTION

Importance of soybean [*Glycine max.* (L.) Merr.] stems first and foremost from the chemical composition of its grain, which is about 40% protein and around 20% oil. This adds up to soybean having over 60% of different nutrients that can be used for various purposes (Popovic et al., 2012a).

Based on dry weight, mature soybean seed regularly contains around 40% protein, 20% oil, 17% cellulose, 7% sugar, 5% fiber and around 6% ash. Depending on varieties and environmental conditions, seed protein content varies from 30% to 53%, while commercial varieties most often contain 39% to 42%. Based on the sedimentation constant, reserve proteins of soybean seeds are divided into three large groups: 2S (α-conglycinin) comprising mostly protease inhibitors, 7S (β-conglycinin) and 11S (glycinin) (Clarke and Wiseman, 2000). Depending on variety and environmental conditions, seed oil content varies from 12% to 24%, and in commercial varieties from 19% to 22%. The soybean plant has many varied uses and its importance is multifaceted. Because soybean can be used whole or can be processed to obtain oil and protein, the plant is used widely and extensively, not only in the food sector, but in various other industries as well. One must not forget the role of soybean in field crops production either. Being a legume, soybean has the ability to fix atmospheric nitrogen and provide itself with sufficient amounts of readily available nitrogen, thus reducing the need for nitrogen fertilizer application. The province of Vojvodina is the main soybean

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producing region in the Serbia. Soybean selection at the Institute of Field and Vegetable Crops in Novi Sad, Serbia has so far mostly focused on the increase of yield and its stability and on developing varieties adaptable to different growing conditions. An important feature of modern agriculture is the use of productive cultivars and hybrids, resistant to diseases, pests and other environmental stresses. These cultivars and hybrids have primarily been developed by plant breeding methods based on selection of desirable genotypes, genetic recombination of the selections through intermating, and then reselection. Selection techniques and intermating systems are numerous and differ depending on plant species and breeding goals. Many of the crop characteristics which are of the economic importance, such as productivity and quality, are metric traits. In general, metric traits are quantitatively inherited (i.e. polygenetic) and are influenced by environment. In plant populations, variation in the expression of a quantitative trait is due to both genetic and environmental variability and an interaction between the two. Variation due to genotype by environment interaction (G x E) that stems from differences in ranking of genotypes among environments reduces heritability and makes it difficult to obtain good estimates of genotypic breeding value. An approach to this problem is to study genotype response to environment and in so doing characterize genotypes according to their performance under a given set of environmental conditions (Miladinovic et al., 2011).

The aim of this study was to determine the productivity as well as G x E interaction in Serbian NS soybean varieties.

MATERIAL AND METHODS

Yield and chemical composition of soybean grain were analyzed in a three-year trial (2009-2011) in Serbia, in Sremska Mitrovica, in the village of Kukujevci in 2009 and in the village of Lacarak in 2010 and 2011. The trials were set up as randomized block design in three replicates with six NS soybean cultivars of different maturity groups (MG): Galina, Valjevka and Afrodita (0 MG), cultivars Victoria (Popovic et al., 2012b, 2014, 2015) and Sava (I MG) and Trijumf (II MG). The 2009 trial was carried out on meadow black soil low in humus, calcareous and moderately alkaline, moderate in P_2O_5 and rich in K_2O. The 2010 and 2011 trials were carried out on marshy black soil low in humus, highly calcareous, moderately alkaline, moderate in P_2O_5 in 2010, and highly P_2O_5 in 2011 and good in K_2O (Table 1).

Table 1. Agrochemical soil analysis
Sremska Mitrovica, Serbia, 2009-2011

Year	Humus %	pH in KCl	pH in H_2O	$CaCO_3$ %	P_2O_5 mg/100g	K_2O mg/100g
2009*	2.8	7.4	8.2	8.6	12.5	21.7
2010*	2.5	7.4	8.2	9.2	10.7	23.2
2011	2.5	7.3	8.1	9.2	16.2	24.9

* Popović et al., 2012b

Soybean was planted on 14 April 2009, 25 April 2010 and 18 April 2011 on a basic plot size of 10 m^2 with maize as the preceding crop. Plant density for 0 MG was 500,000 plants ha^{-1}, for I MG 450,000 plants ha^{-1}, and for II MG 400,000 plants ha^{-1}. Before planting, soybean seeds were inoculated with microbiological preparation NS Nitragin, which is produced by Institute of Field and Vegetable Crops, Novi Sad. NS Nitragin contains mixture of symbiotic bacterium strains *Bradyrhizobium japonicum*. During growing period, standard soybean cultivation practices were applied. In order to prevent negative effects of weeds (Popović et al., 2012b), the trials were treated in the phase of 2-3 well-developed leaf blades with herbicides: Pulsar 40 1 l/ha + Harmony 8 g/ha in 2009, and Acetogal 1.8 l/ha + Mistral 0.35 kg/ha in 2010 and Abastate 0.75 l/ha in 2011. Crops were harvested mechanically on 4 September 2009, 24 September 2010 and 10 September 2011.

Yield was measured after harvest and average samples were taken from each trial replicate to determine oil and protein content in grain. Total oil and protein content in grain was determined by infrared spectroscopy technique on the apparatus PERTEN DA 7000, (NIR/VIS Spectrophotometer) employing non-destructive method. Experimental data were processed using descriptive and analytical statistics of STATISTICA 10 software (StatSoft, Inc., Tulsa, OK, USA). Significance of differences between the calculated mean values of the analyzed factors (year and genotype) was tested by two-factor analysis of variance:

$$y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk},$$

i=1, 2, j=1, 2, ..., 5, k=3

Significance assessment was calculated based on LSD test for probability levels 0.05% and 0.01%. Relative dependence was defined by method of correlation analysis, and the coefficients were t-tested for probability levels 0.05% and 0.01%. Stability of tested traits was determined by the coefficients of variation (%). The results are presented in tables.

Meteorological conditions

Meteorological data were taken from the Meteorological station in Sremska Mitrovica, Serbia. During growing period in 2009 mean monthly temperature was 19.52°C which exceeded average in 2010 by 0.84°C and in 2011 by 0.32°C as well as long-term average by 1.03°C for Sremska Mitrovica (18.48°C), as shown in Table 2. Mean monthly temperature in 2010 was 18.64°C, and in 2011 it was 19,20°C. Meteorological data in years are different (Bran et al., 2008; Popovic et al., 2012b, 2013a).

Table 2. Precipitation sum (mm) and average monthly temperatures (°C)
Sremska Mitrovica, Serbia, 2009-2011

Parameter	IV	V	VI	VII	VIII	IX	Average
Precipitation, 2009	12.0	43.7	79.8	10.4	42.8	5.8	194.5
Precipitation, 2010	46.1	158.0	78.1	76.8	73.1	77.4	509.5
Precipitation, 2011	19.5	63.2	70.1	93.4	6.1	17.6	269.9
Precipitation long term	45.5	56.1	84.6	46.2	62.4	54.6	349.4
Temperature, 2009	13.9	18.8	20.6	22.5	22.3	19	19.52
Temperature, 2010	19.0	17.06	22.22	22.67	21.71	16.16	18.64
Temperature, 2011	13.12	16.58	20.61	22.2	22.47	20.22	19.20
Temperature long term	12.3	17.9	20.6	22.0	21.9	16.2	18.48

Precipitation quantity during soybean growing period in 2009 was 194.5 mm, which is by 154 mm less than long-term average for Sremska Mitrovica, 315 mm than in 2010 and 75.4 mm than in 2011 (Table 2).

In the humid year 2010, precipitation quantity was 509.5 mm, which exceeded long-term average by 160 mm for Sremska Mitrovica, and 239.6 mm than in 2011 (Table 2).

RESULTS AND DISCUSSION

Grain yield

Considering the average yields value in 2009, 2010 and 2011, it was evident that the yields were highly significantly different between the years (P<0.01). On average, significantly higher yield (5,023 kg ha^{-1}) was recorded in 2010 compared to 2009 (3,970 kg ha^{-1}) and 2011 (4,871 kg ha^{-1}). Soybean yields varied considerably in the period 2009-2011 according to precipitation quantity and distribution during the vegetation period (Table 3).

Average yield of all tested cultivars obtained in 2009 was lower by 1,052 kg ha^{-1} (26.49%) than in 2010 and by 900 kg ha^{-1} (22.62%) than in 2011. The highest yields in 2010 were achieved by cultivars Galina and Valjevka (5,290 kg ha^{-1} and 5,230 kg ha^{-1}, respectively). During the unfavorable year of 2009 cultivar Trijumf had the lowest yield of 3,447 kg ha^{-1} (Table 3).

The genotypes belonging to 0 MG had the highest grain yield of 4,735 kg ha^{-1} in the analyzed period (Table 3).

The tested genotypes produced very high yields. Average yield of NS soybean cultivars in the research period was 4,622 kg ha^{-1}. Stability of average seed soybean is evident with some oscillation and varied from 8.96% of Valjevka to 21.88% of Trijumf. The highest average yield in the period 2009-2011 was achieved by cultivars Valjevka and Galina of 0 MG (5,064 kg ha^{-1} and 4,667 kg ha^{-1}) and cultivar Trijumf of II MG (4,607 kg ha^{-1}).

The yield of the cultivar Valjevka (5,064 kg ha^{-1}) was significantly higher than of cultivars Sava and Victoria of I MG (4,355 kg ha^{-1}, 4,562 kg ha^{-1}) and Afrodita of 0 MG (4,473 kg ha^{-1}), ($P<0.05$) (Table 3).

Table 3. Soybean grain yield (kg ha^{-1}) and stability of yield (CV, %)
Serbia, 2009-2011

No.	Genotype (A)	Yield, kg ha^{-1}				Stability, %
		Year (B)			Average	CV
		2009	2010	2011		
1.	Galina	4240	5290	4472	4667	11.82
2.	Valjevka	4551	5230	5412	5064	8.96
3.	Afrodita	3740	4360	5320	4473	17.79
4.	Sava	3909	5040	4117	4355	13.82
5.	Victoria	3936	5110	4640	4562	12.95
6.	Trijumf	3447	5110	5266	4607	21.88
Average		3971	5023	4871	4622	12.30

Indicator	LSD-test	A	B	A x B
Yield	0.05 0.01	531.729 713.770	375.987 504.711	920.976 1236.286

Interactions between the analysed factors (year x genotype) had statistically significant effect on yield ($P<0.01$). In their research Aremu and Ojo (2005), Akande et al. (2009), Popovic (2010) and Kolaric et al. (2014) stated that temperatures and precipitation amount and distribution during the soybean growing season had the largest impact on high yields and grain quality.

Protein content

The protein content differed significantly between the cultivars and years ($P<0.01$) (Table 4).

Table 4. Protein content (%) in NS soybean and its stability (CV, %)
Serbia, 2009-2011

No.	Genotype (A)	Protein content, %				Stability, %
		Year (B)			Average	CV
		2009	2010	2011		
1.	Galina	38.01	37.71	38.15	37.96	0.59
2.	Valjevka	37.03	37.26	38.12	37.47	1.53
3.	Afrodita	38.01	37.71	38.38	38.03	0.88
4.	Sava	36.67	37.42	39.05	37.71	3.22
5.	Victoria	36.89	37.04	38.44	37.46	2.28
6.	Trijumf	38.07	36.71	38.01	37.60	2.04
Average		37.45	37.31	38.36	37.70	1.51

Indicator	LSD-test	A	B	A x B
Protein content	0.05 0.01	0.5309 0.7127	0.3754 0.5040	0.9197 1.2345

The protein content on average was significantly higher in 2011 than in 2009 and 2010 for all the tested cultivars (Table 4).

Afrodita and Galina (0 MG) had the highest protein content in the analyzed period and Sava (39.05%) in 2011. Cultivar Sava had significantly higher protein content in 2011 than other tested genotypes (Table 4).

The genotypes of 0 MG had the highest protein content in the analyzed period. Stability of average seed soybean is evident, based on the coefficient of variation. The highest stability of protein content in all tested period was found in cultivar Galina (Table 4).

Interactions between the analyzed factors (year x genotype) had statistically significant effect on protein content (P<0.01).

Our results are consistent with the results of Poysa et al. (2006) and Popovic et al. (2012c, 2013a, 2014), who stated that the protein content in soybean is genotype characteristic, but strongly influenced by the environment.

Oil content

The oil content in soybean grain differed significantly between the cultivars and years (P<0.01). In 2009 and 2011 oil content was significantly higher (21.79% and 21.58%) compared to 2010 (20.38%). The genotypes 0 MG had the highest oil content in the analyzed period.

During 2009 significantly higher oil content was achieved compared to 2010. Cultivar Afrodita had significantly higher oil content (21.91%) in 2011 and Valjevka (22.56%) in 2009 than other tested cultivars (Table 5).

Table 5. Oil content (%) of NS soybean and its stability (CV, %)
Serbia, 2009-2011

No.	Genotype (A)	Oil content, %				Stability, %
		Year (B)			Average	CV
		2009	2010	2011		
1.	Valjevka	22.56	20.29	21.54	21.46	5.29
2.	Galina	21.73	20.29	21.41	21.14	3.57
3.	Afrodita	21.54	20.65	21.91	21.37	3.03
4.	Sava	21.81	20.58	21.27	21.22	2.90
5.	Victoria	21.53	20.44	21.71	21.23	3.23
6.	Trijumf	21.57	20.05	21.65	21.09	4.27
Average		21.79	20.38	21.58	21.25	3.58

Indicator	LSD-test	A	B	A x B
Oil content	0.05 0.01	0.3741 0.5021	0.2645 0.3551	0.6479 0.8697

Interactions between the analyzed factors (year x genotype) had statistically significant effect on oil content (P<0.01).

Temperature and precipitation have a significant effect on the change in oil content of soybean grain. Favorable year for oils synthesis was semi-arid 2009 for all analyzed cultivars.

The total protein and oil content for all analyzed cultivars for the period 2009-2011, was 58.95%. Cultivar Afrodita of 0 MG had the highest total protein and oil content (59.40%), than other tested cultivars, Table 4 and 5.

The chemical composition of soybean seed indicated that both genotype and environment factors were important for the formation of the characteristic. Our results are consistent with the results of Hurburgh (2000).

Correlations between the analyzed traits

Correlations between the analyzed traits, in the period 2009-2011, are shown in Table 6. Soybean yield was positively significantly correlated with precipitation (r=0.48*) and positively not statistically significant correlated with oil content (r=0.22). Yield was negatively statistically significant correlated with temperatures (r=-0.52*) and negatively not statistically significant correlated with protein content (r=-0.19). Oil content was negatively highly statistically significant correlated with precipitation (r=-0.83**) and positively highly significant correlated with temperatures (r=0.81**). Protein content was negatively not statistically significant correlated with oil content (r=-0.09) and precipitation (r=-0.24), as shown in Table 6.

Table 6. Correlations between tested traits in soybean grain, during 2009-2011

Parameter	Yield	Protein content	Oil content	Temperature	Precipitation
Yield	1.00	-0.19^{ns}	0.22^{ns}	-0.52*	0.48^{ns}
Protein content	-0.19^{ns}	1.00	-0.09^{ns}	0.16^{ns}	-0.24^{ns}
Oil content	0.22^{ns}	-0.09^{ns}	1.00	0.81**	-0.83**
^{ns}- not significant; * and ** significant at 0.05 and 0.01.					

Correlations between the analyzed traits in 2009 and 2011 were statistically significant. Soybean yield was positively significantly correlated with oil content (r=0.55*, r=0.49*). Yield was negatively correlated with protein content (r=-0.45) in 2009 and negatively significantly correlated with protein content in 2011 (r=-0.55*). Protein content was negatively significantly correlated with oil content (r=-0.48*) in 2009 and negatively correlated in 2011 (r=-0.43) as shown in Tables 7 and 9.

Table 7. Correlations between tested traits in soybean grain, in 2009

Parameter	Yield	Protein content	Oil content
Yield	1.00	-0.45^{ns}	0.55*
Protein content	0.55**	1.00	-0.48*
^{ns}- not significant; *- significant at 0.05;			

In the humid year 2010 correlations between the analyzed traits in the period 2009-2011 were not statistically significant. Yield was negatively correlated with protein content and positively correlated with oil content (Table 8).

Table 8. Correlations between tested traits in soybean grain, in 2010

Parameter	Yield	Protein content	Oil content
Yield	1.00	-0.33^{ns}	0.41^{ns}
Protein content	-0.33^{ns}	1.00	0.33^{ns}
^{ns}- not significant;			

Table 9. Correlations between tested traits in soybean grain, in 2011

Parameter	Yield	Protein content	Oil content
Yield	1.00	-0.55*	-0.49*
Protein content	-0.55*	1.00	-0.43^{ns}
^{ns}- not significant; *- significant at 0.05.			

Negative correlation between protein and oil content was observed only in arid years (2009 and 2011), while humid environment (2010) did not establish this relationship.

The results of positive correlations between yield and oil content and negative correlations between yield and protein content, as well as between protein content and oil content confirm the results of other authors (Chung et al., 2003; Popovic et al., 2012c, 2013b).

CONCLUSIONS

The studied characteristics varied significantly depending on genotype and year. Considering the average yields value, protein and oil content in 2009, 2010 and 2011, it was evident that the tested traits were highly significantly different between the years (P<0.01). Interaction between the analyzed factors (year x genotype) showed statistically significant effect on yield, protein content and oil content in soybean grain, which showed that the analyzed factors jointly increase their impact (P<0.05). In humid 2010 average yield was significantly higher, while in 2011 protein content and oil content in 2009 was significantly higher. The genotypes of 0 MG had the highest yield, protein and oil content in the analyzed period.

Analysis of cultivar performance is a basis for further breeding of soybeans with increased yield potential and seed yield, as well as chemical characteristics. Negative correlation between protein and oil content was observed only in arid years (2009 and 2011), while humid environment (2010) did not establish this relationship.

Soybean yield was positively significantly correlated with precipitation (r=0.48*) and negatively significantly correlated with temperatures (r=-0.52*). Oil content was negatively highly significantly correlated with precipitation (r=-0.83**) and positively highly significantly correlated with temperatures (r=0.81**).

Investigations on G x E interaction present the basis for further refinement of soybean zoning. Environmental factors influenced the correlations between yield, oil and protein content in soybean.

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