Variability and interrelationships of grain quantity and quality characteristics in soybean

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Variabilität und Zusammenhänge der Kornquantitäts- und Kornqualitätsmerkmale bei Sojabohnen

1. Introduction

Grain yield is the most important quantitative character in breeding of soybean (*Glycine max* (L.) Merrill), depending on both the genotypic potential and environmental conditions of soybean growing. Essentially, all of the genetic gains in soybean yield have been achieved by traditional breeding methods, involving hybridisation and phenotypic selection (CORYELL et al., 1999). Grain yield is a complex trait and consists of components of quantitative nature, whose expression is determined by genetic and environmental factors as well as their interactions. Therefore, variability of quantitative trait is caused by genetic variability, environmental variability and variability of their interaction (BURTON, 1987; BOS and CALIGARI, 1995; SOLDATI, 1995). According to BOARD et al. (1997) soybean yield is basically determined by seed size (grams per 100 seed) and seed number (number per square meter). Seed number is determined by seed per pod (number) and pod number (number per square meter) and pod number can be influenced by pod

Zusammenfassung

Das Ziel der Untersuchung war es, die Wirksamkeit und Zuverlässigkeit der Kornquantitäts- und Kornqualitätsmerkmale bei Sojabohnen (*Glycine max* (L.) Merrill), welche als Selektionskriterien eingesetzt wurden, im Laufe der Züchtung einzuschätzen. Im Osijeker Institut für Landwirtschaftswesen (Kroatien) wurden die Versuche mit 22 Sojabohnengenotypen auf einem Versuchsfeld im Zeitabschnitt von drei Jahren (1993–1995) durchgeführt. Es wurden Mittelwerte, Variationskoeffizienten, Korrelationskoeffizienten und Pfadkoeffizienten für die Ertragskomponenten, Ertrag, Protein- und Ölgehalt in Körnern bestimmt. Der Variationskoeffizient war niedrig im Falle von Öl- und Proteingehalt in Körnern, Samenertrag per Pflanze, Nodienanzahl per Pflanze und Samenanzahl per Pflanze. Phenotypische Pfadkoeffizienten wiesen hin auf einen sehr starken direkten positiven Einfluss von Samenanzahl per Pflanze und Samenertrag per Pflanze auf den Kornertrag. Anhand der Ergebnisse von biometrischen Analysen ist zu schließen, dass direkte Züchtung mit dem Ziel, eine höhere Anzahl von Samen per Pflanze und einen höheren Samenertrag per Pflanze zu erzielen, einen größeren genetischen Fortschritt für den Kornertrag als Folge haben dürfte.

Schlagworte: Sojabohnen, Ertrag, Variabilität, phenotypische Korrelation, Pfadkoeffizient.

Summary

The objective of this study was to estimate the efficiency and reliability of grain quantity and quality characteristics in soybean (*Glycine max* (L.) Merrill) as selection criteria in breeding for higher grain yield. Trials were conducted on the experimental field of the Agricultural Institute Osijek (Croatia) during a three-year period (1993–1995) and involved 22 soybean genotypes. Mean values, variation coefficients, correlation coefficients and path coefficients were estimated for grain yield components, grain yield, protein and oil content in grain. The variation coefficient was low for the following traits: oil and protein content in grain, seed yield/plant, number of nodes/plant and seeds number/plant. Phenotypic path coefficients indicated a very strong positive direct effect of seeds number/plant and seed yield/plant on grain yield. The results of biometrical analyses showed that the direct selection on higher number of seeds/plant and higher seed yield/plant would result in greater genetic advance in grain yield.

Key words: soybean, yield, variability, phenotypic correlation, path coefficient.

per reproductive node (number), reproductive node number (number per square meter), percent nodes becoming reproductive (percent) and node number (number per square meter). None of the cultivars is superior in all grain yield components. They are varied from one or few superior components on the one side to medium or inferior components on the other side. Hence, the level of grain yield is result of combinations of grain yield components, the strategies towards the increasing yield of soybean would be improved by an understanding of how yield components interact with one another in affecting yield at both the phenotypic and genotypic levels (BOARD et al., 1999). Direction and power of correlation between traits primarily depend on genetic potential of tested materials and agroecological conditions of soybean growing. For that reason, for successful selection procedure, it is necessary to possess adequate information about interrelationship among traits within selected breeding materials and environmental conditions where selection has been done. Path-coefficient analysis quantifies the direct and indirect effects of characteristics and thus allows relative weights of emphasis to be placed on characteristics to be selected or manipulated. Hence, path analyses of yield and yield components more clearly and usefully identifies yield components that can serve as effective selection criteria for higher grain yield. Therefore, the quantitative genetic analyses and statistical techniques have been used to determine the relative importance of yield components in the overall yield formation process involving genetic and environmental variables. Results of such analysis significantly contribute to formulating an effective selection program for improvement of quantity and quality of grain yield (FEHR, 1987).

The objective of this study was to estimate the reliability of grain quantity and quality characteristics in soybean as effective selection criteria (yielding indicators) in the breeding on higher grain yield throughout analysis of traits variability, phenotypic correlation and path-coefficient analysis.

2. Materials and methods

The research was conducted during a three-year period (1993–1995) at the experimental field of the Agricultural Institute Osijek (Croatia). The experimental material involved 22 soybean genotypes: 11 standard cultivars and 11 promising experimental lines. The tested genotypes originate from different hybridisations in the frame of the soybean breeding programme at the Agricultural Institute Osijek and according to the length of vegetation period, they belong to 0-I maturity group. The experiment was designed as a randomised complete block method in five replications on basic plot of 10 square meters. Trials were sown by precise planting machine Hege 95B in optimal time for soybean with plant density of 50 plants on square meter. Currently accepted levels of management and cultural practices for soybean were applied each year in trial. At maturity, 20 plants per plot were randomly selected, i.e. the sample of each genotype per experimental year amounted 100 plants. In our laboratory, the following traits were determined: plant height (cm), number of fertile nodes per plant, pods number per plant, seeds number per plant, seed yield per plant (g), above-ground mature plant weight (g). Harvest index per plant (%) was calculated from the ratio of seed yield per plant to above-ground mature plant weight. When genotypes reached the full harvest maturity, harvesting was done with combine Hege 125B. After harvesting, grain yield from each plot was weighed and converted into t/ha on standard of 13 % seed moisture content. Mass of 1000 seeds (g) and grain quality characteristics: protein and oil content in grain (percentage of absolutely dry matter of grain - % in ADM) were determined from the average sample of grain for each genotype. In order to determine protein content in grain Kjeltec Autosampler System 1035 procedure was used and for determination of oil content Nuclear Magnetic Resonance (NMR) analyzator Oxford Newport 400 was used. The summarized experimental data for grain yield, components of grain yield and grain quality characteristics were subjected to related model of ANOVA. The means were tested by the LSD test on the level of $P \leq 0.05$ and $P \leq 0.01$. Coefficient of variation (%), as a relative indicator of trait variability, was calculated for each analysed quantitative trait. If the coefficient of variation is lower, variability of traits is less, so trait is more stable. Phenotypic coefficients of correlation were calculated due to evaluation of the direction and power of interrelationship of analysed traits. Path-coefficient analysis was done according to DEWEY and LU (1959). This method enables the study of direct and indirect effects of the independent variables (x_1, x_2, ... x_n) on the depended variable (y) as well as the study of the proportion of their joint action. In this study, we determined the effects of the plant height (x_1), number of nodes/plant (x_2), pods number/plant (x_3), seeds number/plant (x_4), seed yield/plant (x_5), harvest index/plant (x_6), mass of 1000 seeds (x_7) on soybean grain yield (y). All calculations were made using computer program for quantitative genetic analyses.

The soil type at the experimental site was classified as an eutric cambisol. The chemical soil properties were: pH 7.00 in H_2O, humus 1.83 %, 30-35 mg P_2O_5/100 g of soil and 60-70 mg K_2O/100 g of soil. Meteorological data (air temperature and precipitation) for the soybean growing seasons during the period from 1993 to 1995 for Osijek are presented in Table 1.

3. Results

The mean values range of grain yield components, grain yield, protein content and oil content in grain for tested genotypes and experimental years with results of statistical analysis are presented in Table 2. The results have showed wide range of the values for all analysed traits at tested genotypes. The differences among genotypes in the average values of grain yield components, grain yield and grain quality traits were statistical highly significant, implying genetic diversity of tested materials. A wide range of the values for all analysed traits was through experimental years, too. Significant differences were among years in the average values of all studied traits.

The review of ranges of the variation coefficients at tested genotypes and experimental years as well as the overall mean of the variation coefficient for the analyzed traits is given in Table 3. According to presented coefficients of variation, obviously there were considerable differences in the relative variability among analysed traits. The lowest relative variability was observed for the grain quality characteristics: oil content 2.68 % and protein content 3.42 %. Further, the relative variability of all studied grain yield components, except plant height, were lower than the relative variability of grain yield (6.65 %). Among yield components, the lowest coefficient of variation was found in the trait seed yield/plant (3.49 %), whereas the highest coefficient of variation was found in the trait plant height (10.15 %).

The estimations of direction and power of correlation between pairs of analysed traits which were obtained in these investigations are listed in Table 4. Results of correlation analysis showed that the grain yield was in a positive relationship with all studied grain yield components, but

Table 1: Monthly mean air temperatures (°C) and monthly total precipitation (mm) per years during soybean growing seasons, 1993–1995, Osijek
Tabelle 1: Monatliche Lufttemperaturmittelwerte (°C) und monatliche Niederschlage (mm) insgesamt während der Vegetationszeit in den Untersuchungsjahren, 1993–1995, Osijek

Month	Air temperature (°C)			Precipitation (mm)		
	1993	1994	1995	1993	1994	1995
April	11.9	11.8	11.7	42.6	52.4	52.2
May	19.0	17.0	15.5	47.7	34.6	96.4
June	20.0	20.2	18.7	69.5	88.2	105.2
July	21.1	23.9	23.5	55.2	19.0	26.7
August	21.1	22.6	20.2	56.7	83.6	85.6
September	16.5	19.4	14.4	58.8	120.3	123.2
October	12.9	9.9	11.2	43.1	57.5	5.8
Total				330.5	398.1	495.1

Table 2: The range of mean values for analysed traits in soybean, 1993–1995, Osijek
Tabelle 2: Mittelwerte für die untersuchten Sojabohnenmerkmale, 1993–1995, Osijek

Characteristics	Genotypes			Years		
	Range	LSD-test		Range	LSD-test	
		0.05	0.01		0.05	0.01
Plant height (cm)	84.93–108.0	2.38	3.14	75.1–107.7	0.88	1.16
Number of nodes/plant	13.4–17.8	1.20	1.90	14.0–16.2	0.81	1.07
Pods number/plant	26.2–40.8	3.38	4.45	30.4–42.2	1.25	1.64
Seeds number/plant	77.4–105.4	3.71	4.89	80.6–94.9	1.37	1.81
Seed yield/plant (g)	10.7–17.1	0.47	0.62	11.9–15.6	0.17	0.23
Harvest index/plant (%)	34.9–46.3	1.00	1.32	35.6–45.8	0.37	0.49
Mass of 1000 seeds (g)	126.0–173.7	5.76	7.59	149.7–163.2	2.13	2.80
Grain yield (t/ha)	3.2–4.6	0.05	0.06	3.4–4.7	0.02	0.03
Protein content (% in ADM)	35.9–38.4	0.26	0.35	36.2–37.9	0.60	0.83
Oil content (% in ADM)	18.9–20.5	0.17	0.20	19.4–20.4	0.13	0.24

Table 3: Range and overall mean of coefficient of variations (%) for analysed traits in soybean,1993–1995, Osijek
Tabelle 3: Gesamtmittelwerte für den Variationskoeffizienten (%) für untersuchte Sojabohnenmerkmale, 1993–1995, Osijek

Characteristics	Genotypes	Years mean	Overall
Plant height	7.47–12.79	9.44–10.51	10.15
Number of nodes/plant	1.35– 6.80	2.60– 4.86	4.07
Pods number/plant	3.85– 9.71	4.54– 7.09	6.22
Seeds number/plant	2.39– 5.87	1.46– 6.19	4.24
Seed yield/plant	2.37– 4.41	2.53– 4.73	3.49
Harvest index/plant	2.85– 9.93	5.22– 7.32	6.21
Mass of 1000 seeds	3.45–10.14	5.24– 6.07	5.60
Grain yield	4.53– 9.37	4.95– 7.51	6.65
Protein content	2.44– 4.15	3.25– 3.65	3.42
Oil content	1.96– 3.82	2.31– 2.93	2.68

the power of these correlations varied. Thus, grain yield was rather highly positively correlated with pods number/plant (0.91**), harvest index/plant (0.86**) and seed yield/plant (0.82*). A high positive correlation was observed between grain yield and seeds number/plant (0.62*) as well as between grain yield and mass of 1000 seeds (0.60*). Morphological traits such as plant height and number of nodes/plant were less positively correlated with grain yield. Grain quality characteristics differed in their correlation with grain yield: oil content in grain was in high positive correlation (0.51*), whereas between grain yield and protein content in grain negative interdependence (-0.43) was observed.

Table 4: Phenotypic correlation coefficients among analysed traits in soybean, 1993–1995, Osijek
Tabelle 4: Phenotypische Korrelationskoeffizienten zwischen den untersuchten Sojabohnenmerkmalen, 1993–1995, Osijek

Characteristics	Plant height	Number of nodes per plant	Pods number per plant	Seeds number per plant	Seeds yield per plant	Harvest index per plant	Mass of 1000 seeds	Protein content	Oil content
Plant height (cm)	1.00								
Num. of nodes/plant	0.14	1.00							
Pods number/plant	0.27	0.22	1.00						
Seeds number/plant	0.21	0.18	0.32	1.00					
Seed yield/plant (g)	0.19	0.22	0.31	-0.17	1.00				
Harvest index/plant (%)	-0.53*	0.11	0.34	0.38	0.42	1.00			
Mass of 1000 seeds (g)	-0.29	0.13	0.12	-0.25	0.59*	0.33	1.00		
Protein content (%)	0.17	-0.12	-0.08	-0.13	-0.23	-0.25	-0.12	1.00	
Oil content (%)	-0.29	0.05	0.19	0.05	0.09	0.15	0.11	-0.21	1.00
Grain yield (t/ha)	0.10	0.39	0.91**	0.62*	0.82*	0.86**	0.60*	-0.43	0.51*

*, ** significant difference between the levels of a factor at 5 % and 1 %, respectively

Table 5: Path-coefficient analysis of grain yield, 1993–1995, Osijek
Tabelle 5: Pfadkoeffizientenanalyse des Kornertrags, 1993–1995, Osijek

Characteristics	Direct effect	Plant height	Number of nodes per plant	Pods number per plant	Seeds number per plant	Seeds yield per plant	Harvest index per plant	Mass of 1000 seeds
Plant height (cm)	0.117	–	0.010	0.142	0.190	-0.221	-0.135	-0.113
Num. of nodes/plant	0.023	0.098	–	0.240	0.201	-0.211	-0.117	-0.089
Pods number/plant	0.385	0.080	0.014	–	0.169	0.125	0.087	0.006
Seeds number/plant	0.531*	0.078	0.009	0.122	–	-0.068	0.174	-0.095
Seed yield/plant (g)	0.408*	-0.118	-0.012	0.118	-0.088	–	0.212	0.227
Harvest index/plant (%)	0.257	-0.114	-0.010	0.130	0.200	0.173	–	0.129
Mass of 1000 seeds (g)	0.386	-0.063	-0.005	0.006	-0.131	0.240	0.086	–

* significant difference between the levels of a factor at 5 %

The estimations of direct and indirect effects of grain yield components on the yield formation process, obtained in these investigations, are presented in Table 5. Among yield structure elements, seeds number/plant had the highest direct and positive effect (0.531*) on grain yield. Trait seed yield/plant had also considerably high direct positive effect (0.408*). Direct effects of other characters like plant height, pods number/plant, harvest index/plant, mass of 1000 seeds were low, so they did not appear to have influenced the grain yield substantially. Seeds number/plant that had registered maximum direct effect, also contributed to yield indirectly through mass of 1000 seeds and harvest index/plant. Other traits like pods number/plant and seeds number per plant considerably contributed via number of nodes/plant to grain yield.

4. Discussion

The summarised and analysed data for level of investigated traits indicated that phenotypic expression of quantitative traits has depended considerably on genetical potential, which has modified under impact of environment, respectively environmental growing conditions are reflected on the genotypic value. These results correspond with findings by similar investigations (KARMAKAR et al., 1993; KONIECZNY et al., 1994; AKHTER and SNELLER, 1996; VOLLMAN et al., 1996; 2000; BOUNIOLS et al., 1997; VRATARIC et al., 1998; 1999) which announced that the level of quantitative trait depends on genetic factor, environmental variables and interaction between genotype and environment.

The estimations of the relative variability of traits are one of the indicators of trait reliability as selection criterion and may contribute to more efficient selection. The obtained data about the relative variability of grain yield components in these investigations suggest that traits: seed yield/plant, number of nodes/plant and seeds number/plant would be more reliable selection criteria in the soybean breeding process on higher grain yield than other yield components due to low relative variability, and good stability, respectively.

The obtained correlation between grain yield on the one side and yield components on the other side indicates that the direct selection on higher number of pods/plant, higher harvest index/plant and higher seed yield/plant contributes to more efficiency in increasing yield potential in relation to indirect selection on higher grain yield across other yield components. Similar results were obtained by VRATARIĆ (1983), DADSON et al. (1990), PLESNIK (1991), PRABHAKAR and TIWARI (1993), VOLDENG et al. (1997).

The obtained data of path-coefficient analysis clearly indicate that seeds number/plant and seed yield/plant are the most important yield components that should be given due emphasis in selecting high yielding genotypes in soybean. Similar findings have been reported earlier by RUSSOM and OBASCOLA (1979), SIMPSON and WILCOX (1983), SKORUPSKA and KONIECZNY (1985), PLESNIK (1991). Moreover, in literature there are different results from the above mentioned. Numerous authors quote that among grain yield components the highest direct effect on grain yield formation has pods number/plant (KADLEC and VOZDA, 1983; RAJPUT et al., 1986; PRABHAKAR and TIWARI, 1993). The main reason of different evaluations of direct and indirect effect of grain yield components on grain yield are differed set of tested materials and differed set of environmental conditions of investigations. Therefore, any comments of results of quantitative analysis could be limited on tested materials and conditions were selection has been done.

On the basis of obtained results of these investigations, among grain yield components, the following traits: seed yield per plant and seeds number per plant are the most reliable yield components as selection criteria. These components have a low coefficient of variation and good stability, respectively. Further, they are in rather high positive correlation with grain yield and their direct effect on yield formation process is positive and the highest from other yield components. It suggests that single plant selection on higher seed yield per plant and higher seeds number per plant would result in greater genetic advance in grain yield.

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