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Original scientific paper

STABILITY OF SOYBEAN SEED COMPOSITION

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Stability of protein and oil content of 13 soybean varieties were examined using linear model across seven locations and during six years. Due to heterogeneity of environments all year/locations was distributed in to two groups, based on achieved yield. Stability of protein content differed in the low and high yielding environments, while average values show only minor differences. In contrast, oil content stability was slightly changed in the low and high yielding environments, while the average oil content were significantly higher in the low yielding environments. Environmental factors influenced the correlation between oil and protein content in soybeans. Negative correlation between protein and oil content was observed only in the high yielding environments, while varieties in low yielding environments lack this well known inverse relation.

Key words: protein content, oil content, soybean, stability, yield

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INTRODUCTION

The chemical composition of soybean seed is one of the most important factor for processing industry (ŽILIĆ *et al*., 2009). Protein and oil content in soybean seed are determinate by genetic and environmental factors. In the past, breeding programs have primarily been focused on increasing the yield of the crop grown under regional climatic conditions (USTUN *et al*., 2001). However, considering the demands of the processors in the recent times, the soybean breeding has been focused on increasing the protein content, and improving oil quality.

Protein composition and quality are variety-dependent and can be significantly affected by environmental conditions (MILADINOVIĆ *et al*., 1996a; BALEŠEVIĆ-TUBIĆ *et al*., 2009; ĐUKIĆ *et al.,* 2010). Although genetics are generally considered the main determinant of composition, environmental variation in protein or oil concentration may determine years, or locations where deficits in crude soybean oil or protein meal yield occur. The differences between varieties represent 50% from the total variation in the soybean seed composition in one district (BRUMM and HURBURGH, 2002).

To predict how environmental conditions ultimately affect the final protein and oil concentrations, therefore, it is necessary first to understand how the accumulation of each individual seed component responds to environmental conditions during seed filling (ROTUNDO and WESTGATE, 2009). During soybean seed development the four main stages can be observed: morphogenesis and cell division, cell enlargement, seed maturation, and ultimately the release of moisture, and period of seed dormancy. Synthesis of proteins and oils takes place during the growth phase of seed cells (BLANUŠA *et al*., 2000). Therefore, the growing conditions at this stage were significantly correlated with protein and oil content in soybean seed (ĐORĐEVIĆ *et al*., 2010). Numerous estimations, however, confound both genotypic and environmental effects, which makes it difficult to separate the relative importance of these two factors (PIPER and BOOTE, 1999; YAKLICH *et al*., 2002; DARDANELLI *et al.,* 2006).

The aim of this study was to determine the stability of the chemical composition of soybean genotypes under conditions where high yields were achieved and under those conditions where the yields were bellow average. Another aim was to determine how the chemical composition and its stability were affected by the change in environmental conditions.

MATERIALS AND METHODS

Thirteen varieties different maturity groups were chosen for evaluation of the stability of the chemical composition of soybean genotypes. Early varieties from 0 maturity group (Afrodita, Valjevka, Bečejka, Alisa), mid varieties from I maturity group Balkan, Sava, Zvezda, Tea, Ravnica, Ana and late varieties from II maturity group (Vojvođanka, Venera, Mima) were included in the study. Researh was done during six years (2003 – 2008) at seven locations in Vojvodina (Fig. 1.), near meteorological stations (Subotica, Sombor, Zrenjanin, Kikinda, Novi Sad, Sremska Mitrovica, Pančevo).

Figure 1. Trial location in Vojvodina province

During that period different environmental conditions prevailed, but there were some favorable (2004-2006), and some unfavorable years (2003, 2007, 2008). Accordingly, the studies of the soybean chemical composition stability were divided into two groups: the group of trials where the achieved yield was above the average, and those with the yield below the average.

The protein and oil content in grain was determined by DA 7000 spectrophotometer using the principle of NIR technique, based on absolute dry matter (BALEŠEVIĆ-TUBIĆ *et al.* 2008). For evaluation of the genotype stability the slope of linear regression of the given genotype was used in relation to the environmental average.

Varietals stability was estimate by linear model $y = a + bx$ and plotted against varietals mean (FINLAY and WILKINSON, 1963). Evaluation of the slope of linear regression of the protein and oil content in the soybeans (*b* coefficient) was done separately both for the low, and the high yielding environments, and then for the entire six-year period. The combination locality/year was observed as a single environment.

RESULTS AND DISCUSSION

Chemical composition depends on genetic background of variety, but it is also significantly determined and influenced by environmental factors. Yield stability even under unfavorable growing conditions is very important for farmers, while seed processing industry require better grain quality, ie. increased protein and oil content (VIDIĆ *et al.*, 2003).

The interpretation of the *b* coefficient in respect to evaluation of genotype stability was based on the tendency that the value of *b* coefficient is close to 1.0 (FINLAY *and* WILKINSON, 1963). Since it represents the slope of linear regression of the genotype value on the environment index, this coefficient can also be explained as the genotype response to environmental changes, as environmental conditions become more favorable, the response of a given genotype becomes less or more intense. Genotypes with $b > 1.0$ had better response to improved environmental conditions, ie. increase of the mean genotype value was greater than the increment of the mean value of other varieties. Such genotypes have the ability to better use even the smallest improvements under growing conditions. Unlike them, those genotypes with b coefficient < 1.0, had less intense reaction to improved environmental conditions and were characterized by a lower ability to adapt to changing environmental conditions.

Partition of environments by other criteria, the high and low yielding is justified if we consider the fact that this research involved experiments from six years and that the yield varied. Due to environmental heterogeneity, partition to the low and high yielding environments made it possible to observe changes in the chemical composition, and draw the more precise conclusions on the stability of the chemical composition of soybean genotypes. The final composition of the seed is known to vary by genotype and in response to environmental conditions during seed development (FEHR *et al*., 2003).

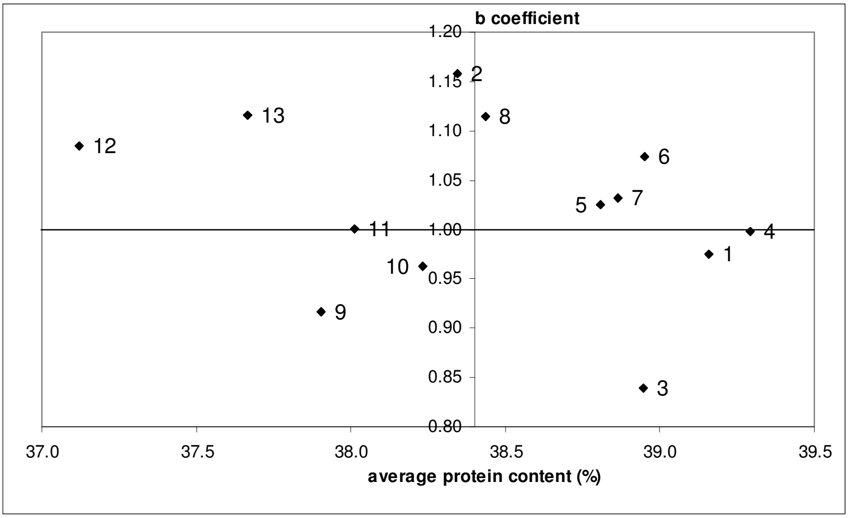

Figure 2. Average protein content and b coefficient of 13 soybean genotypes (joined for six years 2003-2008). Genotypes: 1. Afrodita, 2. Valjevka, 3. Bečejka, 4. Alisa, 5. Balkan, 6.Sava, 7. Zvezda, 8. Tea, 9. Ravnica, 10. Ana, 11. Vojvođanka, 12. Venera, 13. Mima.

By observing the entire period, it could be noticed that the protein content of Afrodita and Alisa varieties was above the average, and b coefficient was close to 1.0, which indicated that these varieties were well adapted to all environments (Fig. 2.).

Varieties Valjevka and Tea had the average protein content, and above average stability, which pointed out to their adaptability to favorable environments, while Bečejka was suitable for unfavorable environments due to its low stability.

Varieties Balkan, Sava and Zvezda had average stability and their protein content was above average, but they were inferior in comparison to Afrodita and Alisa varieties. Protein composition and quality are variety-dependent and can be significantly affected by environmental conditions (HURBURGH, 2000). While seed composition is primarily genetically determined, environmental conditions during seed development also affect seed component accumulation, and can result in protein deficit for processing (ROTUNDO and WESTGATE, 2009).

Based on analysis of average values of genotypes and *b* coefficients, divided into high and low yielding environments, some differences were observed in comparison with results obtained by analyzing the entire testing period (Fig. 3.), where the Alisa variety occupied the position of the high-protein content, which has been adapted to all environments. However, the division of the environments indicated that this genotype reached its high protein content in the low yielding environment, while it can be recommended for unfavorable environments by the lower values of *b* coefficient. Varieties Balkan, Sava and Zvezda showed small differences in the mean values of protein content and *b* coefficient in the high and low yielding environments, which pointed out to their good adaptability to all environments.

Afrodita variety, which proved its good adaptability in all environments over the period of the six years, had a very low *b* coefficient in the low yielding environment ie. the response of this genotype was very weak under stress conditions.

For the entire observed period, varieties Valjevka and Tea occupied the position of those well adapted to favorable environments, with the values of protein content close to the average value. Division of the environments increased the protein content in Valjevka by 1% in unfavorable environments in relation to favorable environments, and the lower value of *b* coefficient was also observed.

The best results were obtained for this genotype in the low yielding environments. Tea variety had almost identical values in both, the low and the high yielding environments, but its stability was pronounced in the low yielding environments. Over the period of the six years, as well as the environment division, Bečejka variety showed adaptability to adverse environments. Ravnica differed from other tested genotypes. The values of *b* coefficient in the low and high yielding environments were almost identical, while the mean protein content was approximately 1% higher in the low yielding environments. It can be concluded that this variety had the same adaptability under all conditions, but it had higher mean protein content in the low yielding environments. Number of investigations attempts to distinguish the response of soybean seed components to specific environment conditions across genetic backgrounds and stages of development (MILADINOVIĆ *et al.*, 1996b; WILCOX and SHIBLES, 2001; MAHMOUD *et al.*, 2006).

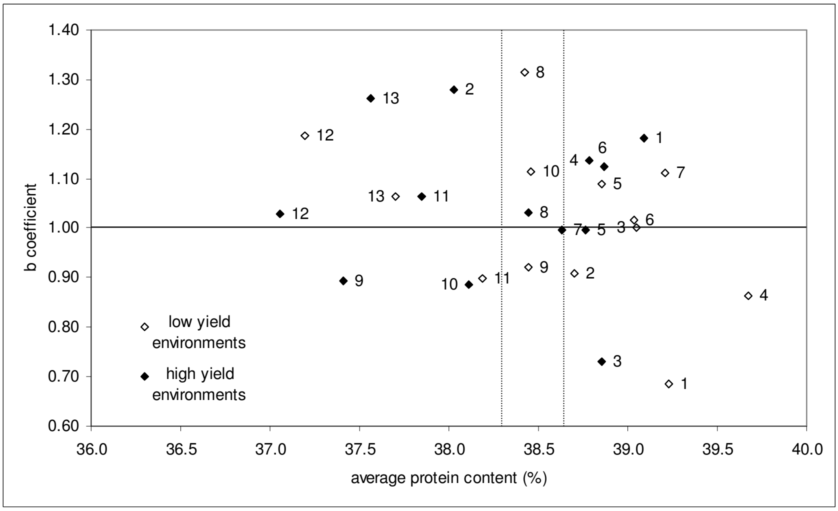

Figure 3. Average protein content and *b* coefficient in high and low yielding environments. Dash lines represent average protein content in high yield environments (38.3 %) and low yielding environments (38.6%). Genotypes: 1. Afrodita, 2. Valjevka, 3. Bečejka, 4. Alisa, 5. Balkan, 6.Sava, 7. Zvezda, 8. Tea, 9. Ravnica, 10. Ana, 11. Vojvođanka, 12. Venera, 13. Mima

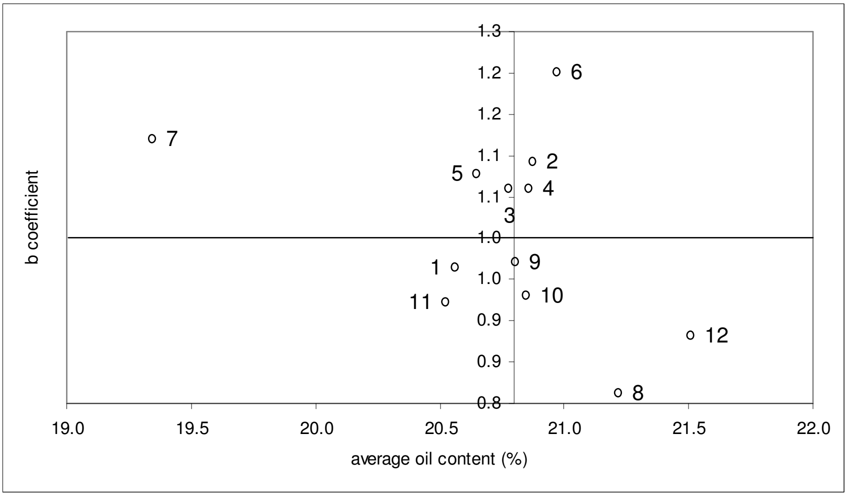

Figure 4. Average oil content and b coefficient of 13 soybean genotypes (join for six years 2003-2008). Genotypes: 1. Afrodita, 2. Valjevka, 3. Bečejka, 4. Alisa, 5. Balkan, 6. Sava, 7. Zvezda, 8. Tea, 9. Ravnica, 10. Ana, 11. Vojvođanka, 12. Venera, 13. Mima.

The oil content of the majority of tested genotypes was at the level of the mean trial value (Fig. 4.). Varieties Mima, Venera and Tea, with the oil content above the average, and good adaptibility in unfavorable enviroments can be spoted. Variety Sava have a good adaptibility in favorable enviroments and the oil content above the average. Oil content in soybean grain varied from 12 to 24% depending on variety and growing conditions (MILADINOVIĆ *et al.*, 2008).

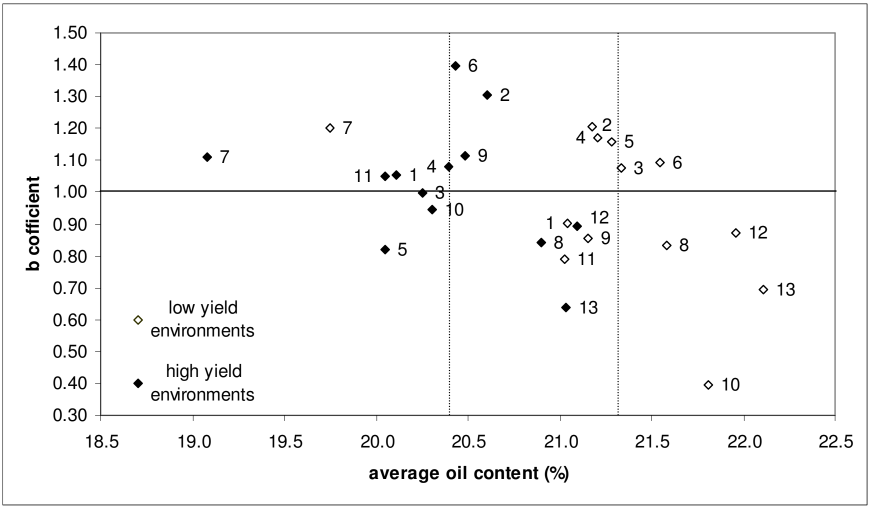

Figure 5. Average oil content and b coefficient in high and low yielding environments. Dash lines represent average oil content in high yield environments (20.4 %) and low yielding environments (21.3%). Genotypes: 1. Afrodita, 2. Valjevka, 3. Bečejka, 4. Alisa, 5. Balkan, 6. Sava, 7. Zvezda, 8. Tea, 9. Ravnica, 10. Ana, 11. Vojvođanka, 12. Venera, 13. Mima.

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Genotypes under investigation had higher oil content in low yielding environments (Fig. 5). Varieties Tea, Venera and Mima were adapted to unfavorable environments, both in the high and the low yielding environments. These three genotypes are recommended for growing in all environments, and may achieve above average oil content in unfavorable environments. Varieties Sava and Valjevka had average oil content in bout types of environments, but in high yielding environments showed better adaptability in favorable environments. Big differences were observed in Ana variety both in high and low yielding environments. This variety had the oil content above the average in low yielding environments, and low value of *b* coefficient, which pointed out to insignificant variations in this type of environments.

In general, small differences were observed in genotype adaptability in both types of environments, the high and low yielding environments, ie. small differences in *b* coefficient values. Differences between above mentioned type of environments were observed for the oil content, indicating that synthesis and accumulation of oil was increased in unfavorable environments. YAKLICH and VINYARD (2004a, 2004b) found that the oil content was higher under unfavorable conditions at higher temperatures during soybean seed filling.

Distribution of environment based on yield in analysis of soybean chemical composition stability was only a partial success. Specifically, the protein content, where there were large differences in the stability of genotypes between high and low yielding environments, such an analysis revealed a specific genotype responses that were not visible in the analysis of the entire six-year period. On the contrary, for oil content where differences between high and low yielding environments were reflected first of all in the changes of the average oil content, and *b* coefficient showed small variations, such analysis provided results very similar to the analysis of all six years joined together. Such approach to the analysis of genotype stability allowed a more precise recommendation of varieties for specific growing regions, which is significant both for farmers and for the processing industry.

The attempt to separate genotype that has the best average values of the chemical composition in most of the environments is a difficult task. Sava variety is according to the results of this research nearest to a "universal"genotype, adaptable to a wide range of growing area. This genotype achieved average and above average values for protein and oil content, both in the low and high yielding environments, while *b* coefficient values were greater than 1.0 indicating the good response of this genotype to improved, favorable environmental conditions. Processing industry may find interest in growing this genotype on larger production areas, for above average oil and protein contents, and the overall stability of the grain chemical composition.

The inverse proportional relation of oil and protein content is well known and genetic and ecological factors influence the negative correlation of these two soybean seed constituents. When correlation between protein and oil contents in tested genotypes was observed, it could be noticed that, besides the influence of genotypes, significant influence was also exerted by environmental factors.

In low yielding environments, only Tea variety had significantly negative correlation between oil and protein content, while in other tested genotypes this well known relationship was not statistically significant On the contrary, negative correlation between oil and protein content was determined in all tested genotypes in high yielding environments. PIPER and BOOTE (1999) had analyzed the influence of temperature on soybeans chemical composition and had concluded that negative correlation between oil and protein content was decreased by the elevated temperature during grain-filling period. Average mean daily temperature (during Jun – August) in low yielding environments was 22,9 ^{o}C, while in high yielding environments it was 20,7 ^{o}C. This confirms previous allegations that the mean daily temperature during soybean seed filling is one of important ecological factors influencing the correlation between oil and protein content.

Table 1. Corrleation between protein and oil content in high and low yielding environments

Genotype	low yielding environments	high yielding environments
Afrodita	-0.06 ^{ns}	-0.56 *
Valjevka	-0.13 ^{ns}	-0.89 **
Bečejka	-0.23 ^{ns}	-0.77 **
Alisa	-0.05 ^{ns}	-0.86 **
Balkan	-0.32 ^{ns}	-0.75 **
Sava	-0.17 ^{ns}	-0.76 **
Zvezda	-0.35 ^{ns}	-0.73 **
Tea	-0.51 *	-0.70 **
Ravnica	0.09 ^{ns}	-0.75 **
Ana	-0.12 ^{ns}	-0.60 **
Vojvođanka	-0.29 ^{ns}	-0.64 **
Venera	-0.25 ^{ns}	-0.68 **
Mima	0.03 ^{ns}	-0.64 **

ns - not significant; * and ** - significant at $p<0.05$ and $p<0.01$

CONCLUSION

Distributions of environments according to additional criteria, ie. yield revealed specific responses of genotypes and allowed better observation of genotype responses to variable environmental conditions.

Stability of protein content in tested genotypes differed both in the low and high yielding environments, while average values only differed slightly.

The results showed that the oil content stability was slightly changed in the low and high yielding environments, while the average oil content values were higher in the low yielding environments.

Environmental factors influenced the correlation between oil and protein content in soybeans. Negative relationship between protein and oil content was pronounced in the high yielding environments.

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STABILNOST HEMIJSKOG SASTAVA SEMENA SOJE

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I z v o d

Ispitivanja stabilnosti hemijskog sastava zrna soje sprovedena su na 13 genotipova soje, šest lokaliteta, tokom šest godina, korišćenjem linearnog modela. Usled heterogenosti uslova uspevanja, svi lokaliteti/godine podeljeni su u dve grupe, u zavisnosti od prinosa. Stabilnost sadržaja proteina u semenu razlikovala se u zavisnosti od visine prinosa, dok kod prosečnih vrednosti nisu zabeležene veće razlike. Nasuprot tome, stabilnost sadržaja ulja u semenu nije se značajnije razlikovala u zavisnosti od prinosa, dok je prosečan sadržaj ulja bio veći na lokalitetima/godinama kada su zabeleženi niži prinosi soje. Uslovi spoljašnje sredine utiču na korelaciju između sadržaja ulja i proteina. Negativna korelacija između sadržaja ulja i proteina uočena je samo pri visokim prinosima, dok pri niskim prinosima ova negativna veza nije dobijena.

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