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Soybean [*Glycine max* (L.) Merr.] Seed Yield and Seed Oil Content as Influenced by Different Environmental Conditions and Genotypes

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ABSTRACT

Soybean yield potential is strongly impacted by environmental conditions. Soybean yield variability could be explained by climatic variables. Choice of tolerant varieties adapted to different limited environmental conditions could be used as adaptive strategies to sustain the development of soybean areas. Three soybean varieties with high seed and oil content (Balkan, Novosađanka and Vojvođanka) were analyzed in three localities of Vojvodina Province in Serbia: Novi Sad (45°20′00″ S; 19°51′00″), Pančevo (44°52′15″ S; 20°38′51″) and Laćarak (44°59′45″ S; 19°34′03″). The highest yield of the three examined soybean varieties was shown by Vojvođanka (3365.0 kg ha^{-1}), whereas the statistically highest yield was in 2010 (4301.1 kg ha^{-1}) in the investigated period (2006-2011). All three varieties gave the lowest seed yield at the Pančevo locality, due to the deficit of precipitation and lower content of humus in the soil. The oil content in the seeds was also influenced by all three examined factors. The soybean varieties Vojvođanka and Balkan had statistically higher oil content than Novosađanka. The agroecological and soil conditions of Novi Sad were the most suitable for the synthesis of oil in the seeds of all genotypes. Oil content was statistically highest in 2010 (22.31%) compared to all tested years. The analysis has shown that Vojvođanka was the most promising of all soybean's varieties.

Keywords: soybean, abiotic stress, variety, quantity and quality parameters, weather conditions.

INTRODUCTION

Soybean is one of the most common seed crops worldwide, representing an important oil source. According to data published by FAO (www.fao.org/faostat/en, accessed on 1 July 2023), it currently occupies the largest cropping area in the world (over 126 million hectares) and the total global production of soybeans reached 368 million tons in 2021. In Europe, soybean still plays a minor role since annual production in 2021 was 11.5 million tons according to FAO, while soybean production in Serbia accounted for only 4.7% of European production. Soybean oil is high in unsaturated fatty acids (Boerma and Specht, 2004) and concentrations of oil in soybean seeds are important factors determining the quality of soybean meal and its competitiveness in international markets (Rotundo et al., 2011). Soybean provides 28% of the world's oilseed production for edible oil (Kim et al., 2015).

Soybean is a thermophilic short-day plant which favours areas with hot and humid summers, but without sudden temperature changes. However, it is cultivated mainly in southern and continental parts, where droughts and heat waves are expected (Allen et al., 2018; Rojas et al., 2019). Soybean diversifies significantly during maturity (Jia et al., 2014). Maturity traits not only include total growth duration but also the vegetative and reproductive phases, and their relative ratios (Egli, 2011). Categorizing soybeans into different maturity groups (MG) is convenient for breeding practices (Boerma and Specht, 2004). As a reference to classify local soybeans into different MG, we used soybeans from very early (MG 000 and 00), early (0), medium (I) to late (II and III), with a growing period of 105 to 160 days.

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Soybean yield potential is strongly impacted by environmental conditions. Climatic variables explain soybean yield variability (Bacigaluppo et al., 2011; Di Mauro et al., 2018). Water stress is the main abiotic factor that limits soybean biomass, seed yield and, consequently, seed-quality and tends to increase under climate change. Moderate water reduction (low root length and root surface area contributed to a water-saving mechanism) can improve soybean seed-quality and by selecting drought-resistant varieties we can increase the yield of soybean grown in intercropping systems (Iqbal et al., 2018; Gao et al., 2020). Choice of tolerant varieties adapted to limited water conditions could be used as adaptive strategies to sustain the development of soybean areas.

Developing varieties high in seed yield is a difficult task because the traits have an inverse relationship (Brzostowski et al., 2017; Petcu et al., 2024). A negative correlation between yield and protein concentration is strong, but it is weaker than that between protein and oil (Chung et al., 2003; Nichols et al., 2006; Vaughn et al., 2014). Progress has been hindered by negative correlations with yield and oil concentration (Wilcox and Guodong, 1997; Wilcox and Shibles, 2001). Environmental conditions influence the quality of seeds throughout the growing periods (Pádua et al., 2009; Petcu et al., 2021; Staniak et al., 2021; Šarčević et al., 2022).

The environmental variables during seed development directly affects seed maturation process and may lead to changes in chemical composition and influence the final seed quality (Weerasekara et al., 2021). In addition to environmental conditions, seed development is also influenced and determined by genetics factors, as well as their interactions (Abdelghany et al., 2021; Szczerba et al. 2021; Liu et al., 2023). This, therefore, creates the need for soybean varieties for different environments (Sritongtae et al., 2021).

Very little is known about the potential for soybean in semi-continental conditions such as Voivodina Province. Its production and produced seed quality are challenged by the increasingly reported drought waves because of its relative susceptibility to drought stress conditions.

The aims of this study were (i) to identify climatic variables that explain soybean yield and its quality components variation and (ii) to determine the genotype magnitude through the environment interaction (G×E) of soybean breeding lines identifying widely and/or specifically adapted genotypes under the three typical environmental conditions of Vojvodina Province, Serbia from 2006 to 2011.

MATERIAL AND METHODS

Three soybean varieties with high seed and oil content (Balkan, Novosađanka and Vojvođanka), created at the Institute of Field and Vegetable Crops in Novi Sad, Serbia were used as the experimental material. Balkan and Novosađanka belong to the first (I) maturity group, whereas Vojvođanka belongs to the second maturity group (II).

Field trials were conducted in six consecutive growing seasons (2006-2011) under temperate conditions in three localities of Vojvodina Province, Serbia, with following localities: Novi Sad (45°20′00″ S; 19°51′00″), Pančevo (44°52′15″ S; 20°38′51″) and Laćarak (44°59′45″ S; 19°34′03″). The experimental fields belong to the institutes (Institute of Field and Vegetable Crops - experimental field Rimski Šančevi, Novi Sad, Serbia; Institute Petar Drezgić, Agriculture Extension Service Province of Vojvodina - experimental field Laćarak, Sremska Mitrovica, Serbia; Institute Tamiš, Agriculture Extension Service Province of Vojvodina - experimental field Tamiš, Pančevo, Serbia. The trials were set up according to a randomized complete block design in four replications on low-carbonaceous chernozem (Laćarak and Novi Sad) and carbonaceous chernozem (Pančevo) (IUSS Working Group WRB, 2022). The size of the experimental plot in each trial was 15 m^2 (6 rows, inter-row spacing 50 cm, 5 m length).

In the study period, soybeans were grown in a wheat-corn-soy triple field. Just before sowing, the soybean seeds were inoculated with the microbiological preparation NS Nitragin (a biostimulator produced at the

Institute of Field and Vegetable Crops, Novi Sad, Serbia). Sowing was performed on April 8th in 2006 and 2010; April 10th in 2007, 2008 and 2011 and April 12th in 2009, at all three localities in all years at plant density 450 000 plants ha^{-1} for the I maturity group with a row spacing of 4.5 cm and 400 000 plants ha^{-1} for the II maturity group with a row spacing of 5 cm. The row distance was 50 cm. Agrotechnical operations were carried out as follows: crop rotation, spatial isolation, basic tillage, genotype selection, pre-sowing soil preparation, sowing time and density, plant nutrition, irrigation, care measures, cleaning of atypical plants, harvesting, final processing, storage and preservation of seeds. With the basic cultivation (at the beginning of autumn, to a depth of 30 cm), mineral fertilization was applied at each locality on the basis of chemical analysis of the soil. In order to compare the obtained results, fertilization was carried out with the same amount of fertilizer in all localities, and the soybean pre-crop was wheat in all years and in all localities. Basic fertilization was done with NPK mineral fertilizer (60 kg ha^{-1} nitrogen, 90 kg ha^{-1} phosphorus and 60 kg ha^{-1} potassium). Due to the short distance between the plots on which the five-year experiments were conducted, the soils have similar agrochemical properties. The analyses were carried out in the laboratory of the Institute Tamiš, Pančevo, Serbia, and showed that these soils differ very little in natural fertility. For these reasons, average values for five years of research were used for the analysis (Table 1).

Table 1. Agrochemical soil analysis, Srem, Banat and Bačka District in Vojvodina, in Serbia

Depth (cm)	pH		Humus%	$CaCO_3$%	P_2O_5	K_2O
	in H_2O	in KCl			mg $100g^{-1}$	
Novi Sad, Banat District in the autonomous province of Vojvodina, Serbia						
0-30	7.3	7.6	4.4	7.3	20.5	17.0
30-60	7.4	7.5	3.9	10.7	15.2	13.8
60-90	7.5	7.6	2.7	18.7	7.8	11.5
Laćarak, Srem District in the autonomous province of Vojvodina, Serbia						
0-30	8.3	7.6	2.6	6.0	18.7	17.9
30-60	8.2	7.6	2.3	9.6	17.1	13.4
60-90	8.3	7.7	1.8	15.1	8.7	10.0
Pančevo, South Banat District in the autonomous province of Vojvodina, Serbia						
0-30	7.7	7.3	2.5	4.4	25.4	22.2
30-60	7.8	7.5	2.4	11.6	17.1	18.4
60-90	7.9	7.7	1.1	24.1	2.7	7.0

Due to such a large amount of lime in the deeper parts of the profile of this type of soil, pseudomycelia are a regular occurrence. The pH value in KCl is lower in the humus horizon and ranges from 7.6% in Banat, to 7.6% in Srem, and 7.3% in Bačka, while it is higher in the transitional part (AC) and parent substrate (C). The percentage share of humus in the arable part of the profile ranges from 4.4% (Banat) to 2.6% (Srem) and 2.5% (Bačka). With increasing depth, the amount of humus decreases. Natural supplies of readily available phosphorus range from 18.7 mg in 100 g of soil (Srem), to 20.5 (Banat) and 25.4 mg in 100 g of soil (Bačka). A higher level of easily accessible phosphorus in soil in a layer of up to 30 cm is a consequence of the introduction of larger amounts of phosphorus nutrients in an earlier period. Quantity of easily accessible potassium is within the limits of less fluctuation compared to easily accessible phosphorus. The supply of this element in the arable layer ranges from 17.0 mg (Banat) to 17.9 mg (Srem) and 22.2 (Bačka) mg in 100 g land that corresponds to well-supplied soil. In the arable part of the A horizon, $CaCO_3$

content was 12.3% in Banat, 6% in Srem and 4.4% in Banat, while it increased with depth and in the 60-90 cm layer it was 18.7%, 15.1% and 24.1%, respectively (Table 1).

Basic fertilization was done with NPK mineral fertilizer (60 kg ha^{-1} nitrogen, 90 kg ha^{-1} phosphorus and 60 kg ha^{-1} potassium). Pre-sowing soil preparation was performed twice (in early spring and immediately before sowing). As a measure to control weeds, the trials were treated in the phase of 2 to 3 well-developed leaf blades with two herbicides. Glyphosate was applied to the crop before emergence in the amount of 4 l ha^{-1} (2006-2011) and Pulsar 40 1 l ha^{-1} + Harmony 8 g ha^{-1} in 2006-2009, and Acetogal 1.8 l ha^{-1} + Mistral 0.35 kg ha^{-1} in 2010 and 2011. In order to prevent negative effects of weeds, inter-row cultivation was carried out on two occasions (at the sprouting stage and when the plants were about 20-30 cm high), as well. The first inter-row cultivation was two weeks after crop emergence, and the second inter-row cultivation was three weeks after the first inter-row cultivation, namely after 5 weeks from soybean emergence. The harvest was carried out at the stage of technological maturity, when the moisture content of the grain fell below 14%. Soybeans were harvested mechanically with a combine in the middle and second half of September.

Three main productivity parameters were analyzed: seed yield (kg ha^{-1}) and expressed at 14% moisture content, oil content (%) and oil yield (kg ha^{-1}). Seed oil contents were determined by nuclear magnetic resonance apparatus (NMR, model Oxford-4000, Bruker, Billericay, Massachusetts, USA), approximately 10 g samples of seeds according to the procedure described by Granlund and Zimmerman (1975) in three measurements for each replication. Oil yield was calculated as the product of seed yield and oil content.

Meteorological data (2006-2011) were gathered from the three localities at the Agrometeorological Experimental Stations which are located in the immediate vicinity of the experimental fields (Republic Hydrometeorological Service of Serbia). Primary agroecological conditions were analyzed (amounts and distribution of precipitation, distribution of heat and heat sums for the vegetation period of the soybean seed crop).

The data were statistically analyzed by three-factorial analysis of variance (ANOVA) by InfoStat software Version 2016e (UNC, Argentina). The first factor was the production year, second factor was the genotype, whereas the third was locality followed by the comparison of mean values based on Tukey's multiple means comparison tests with a 95% confidence level. All measurement were done in quadruplicate. Multivariate analysis of principal components was used for the retrieval of underlying interdependences of seed yield, oil content, oil yield, and soybean genotypes produced in different years at different localities by using XLSTAT-Pro, demo version, Version 5.03, 2014 software (Addinsoft, Paris, France).

RESULTS AND DISCUSSION

Mid-daily air temperatures and the amount of precipitation per month, as well as the multi-year average (2006-2011) by locality are shown in Figures 1, 2 and 3.

The studied years differed significantly from each other, both in terms of total amounts of precipitation, as well as in terms of their distribution by month. In general, during the six-year study at all three localities, the mean monthly air temperature had a uniform increase from April to July, and then a decrease during the autumn months.

On the locality Novi Sad during 2006-2011 period, the average temperature was recorded at the level of 19.08°C. The critical period was determined in June, July and August in all examined years. The years 2009 and 2011 were dry. On average, in the growing season of 2009 precipitation was 27.32%, while in 2011 was 43.49% less than the six-year average. The highest amount of precipitation on the locality Novi Sad was recorded in 2010, which was 83.20% more than the average for the examined period (Figure 1).

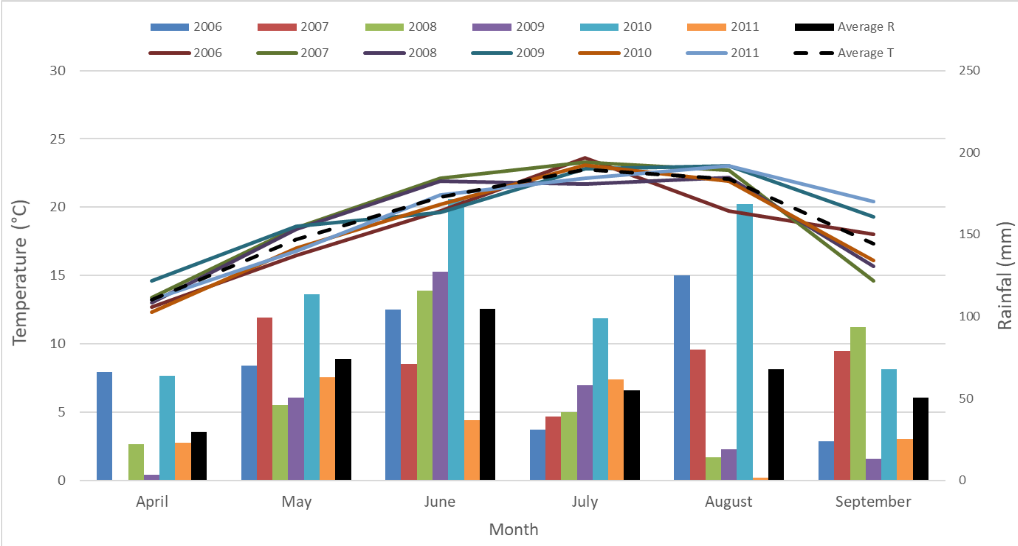

Figure 1. The average monthly temperatures (°C, lines) and precipitation (mm, columns), Novi Sad

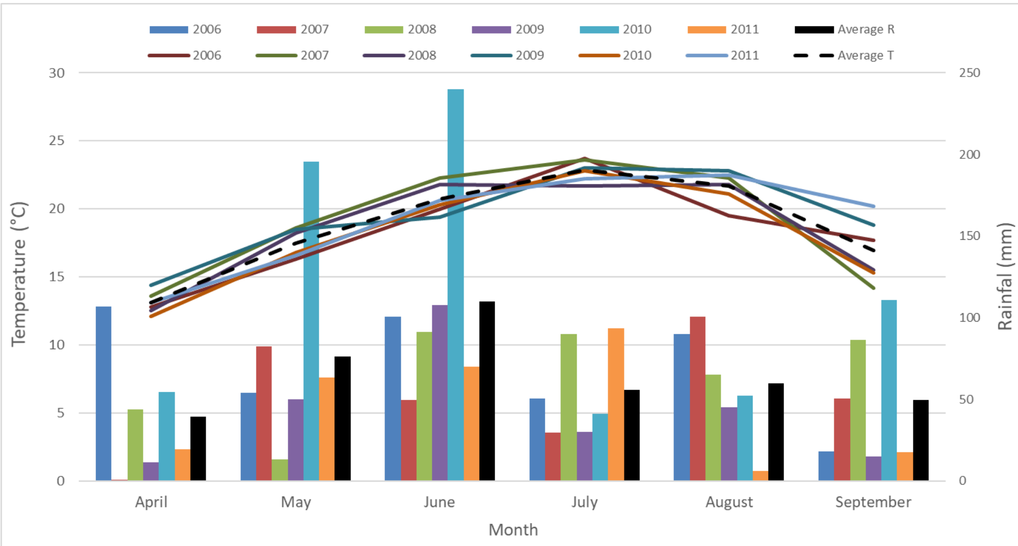

Figure 2. The average monthly temperatures (°C, lines) and precipitation (mm, columns), Laćarak

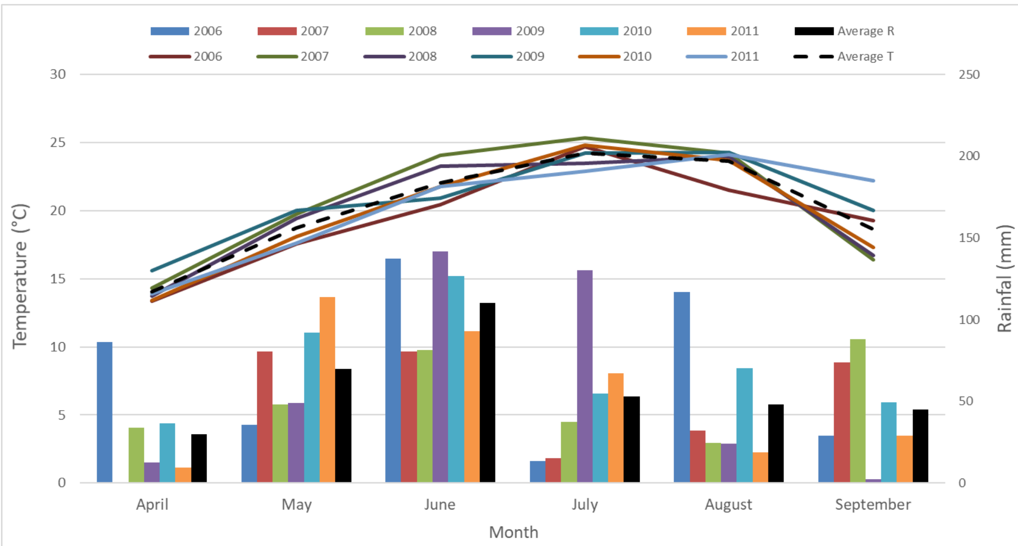

Figure 3. The average monthly temperatures (°C, lines) and precipitation (mm, columns), Pančevo

The average temperature was 18.9°C in 2006-2011 period on the Laćarak locality. Temperatures in 2007 were recorded at the average level for the investigated period. The temperatures in 2009 and in 2010 were significantly higher compared to the six-year average. The critical period in 2011 was determined in July and August. The years 2009 and 2011 were extremely dry, one year was extremely wet (2010) and two years were at the six-year average (Figure 2).

On the Pančevo locality, the average temperature was recorded at the level of 20.37°C. Precipitation was 343.34 mm on average over six years. The lowest amount of precipitation was recorded in 2007 (Figure 3). On the locality Pančevo, a higher amount of precipitation was determined compared to the locality Laćarak and a slightly lower amount of precipitation compared to the locality Novi Sad. In 2009 and 2011, there was significantly more precipitation in the Pančevo locality than in the Novi Sad and Laćarak localities.

Table 2 shows average results of seed yield, content and oil yield of the soybean genotypes Vojvođanka, Novosađanka and Balkan. The lowest seed yield was obtained by Balkan genotype, slightly higher was achieved by Novosađanka, whereas Vojvođanka showed statistically higher yield than Balkan. Novosađanka showed the lowest average oil content. Balkan and Vojvođanka possessed the oil content on the same level. The highest average yield of oil was in Vojvođanka, which was statistically higher than the average oil yield of Balkan and Novosađanka. Generally, the variety Vojvođanka (II maturity group) had higher grain yield, higher oil content and yield than the medium varieties (Balkan and Vojvođanka).

Table 2. Production parameters of the genotypes Vojvođanka, Novosađanka and Balkan

Genotype	Seed yield (kg ha^{-1})	Oil content (%)	Oil yield (kg ha^{-1})
Vojvođanka	3365.2 ± 76.5 ^{A}	21.14 ± 0.14 ^{A}	716.4 ± 19.6 ^{A}
Novosađanka	3332.8 ± 68.8 ^{AB}	20.85 ± 0.15 ^{B}	699.8 ± 18.5 ^{B}
Balkan	3300.5 ± 68.5 ^{B}	21.08 ± 0.11 ^{A}	697.7 ± 16.3 ^{B}

Mean values of parameters labelled by the same letter were not statistically significant ($p<0.05$).

There was a significant influence of the locality on the achieved result in soybean production (Table 3). Namely, the seed yield was the statistically highest at Novi Sad locality. Seed yield at Laćarak locality was statistically higher than Pančevo locality, which proves that the locality has a significant impact on the seed yield of soybeans. The lower values of yield, oil yield and oil content at the Pančevo locality can be attributed to the lower humus content in the soil. The same trend was observed for oil yield parameters, whereas in case of oil content parameter Novi Sad locality was statistically higher than other two localities.

Table 3. Soybean production parameters of the localities Novi Sad, Laćarak and Pančevo

Locality	Seed yield (kg ha^{-1})	Oil content (%)	Oil yield (kg ha^{-1})
Novi Sad	3505.0 ± 73.6 ^{A}	21.50 ± 0.11 ^{A}	756.8 ± 18.6 ^{A}
Laćarak	3314.2 ± 83.1 ^{B}	20.79 ± 0.16 ^{B}	694.5 ± 21.1 ^{B}
Pančevo	3179.3 ± 90.0 ^{C}	20.78 ± 0.10 ^{B}	662.6 ± 20.1 ^{C}

Mean values of parameters labelled by the same letter were not statistically significant ($p<0.05$).

The observed and established significance of the influence of years on seed yield is shown in Table 4. The highest average yield of soybean was in 2010 and it was statistically higher than in 2011 and 2006. On the other hand, the statistically lowest average was in 2008 and 2009, whereas average yield of soybean in 2007 was statistically higher than in these two years. The same trend was observed for oil yield parameters with some exceptions. Namely, oil yield in 2011 was statistically higher than in 2006 and average yield of 2007 and 2009 was not statistically different. The highest oil content characterized 2010 together with the highest yield of soybeans and was statistically higher than in 2008 and 2011. The statistically lowest oil content was observed in 2007, whereas yield of soybean in 2009 was statistically higher than in 2007. Medium level of all examined years was observed in 2006. Climatic conditions (year), locality, interaction of years and genotypes, interaction of years and locality have a statistically significant influence on soybean seed yield, while other effects do not show statistical significance (Table 4).

Climatic conditions (year), locality, interaction of years and cultivars, interaction of years and locality have a statistically significant influence on soybean seed yield, while other effects do not show statistical significance (Table 4). Almost two thirds seed yield (CY) variation (66.58) was under year (Y) effect, while the influence of year by locality (Y × L) interaction explained 24.26% of the total variation. All observed factors had a significant ($P<0.01$) effect on oil content. More than half of the variation in oil content was explained by the influence of Y, followed by the influence of Y × L interaction, Locality (L) and year (Y) × cultivar (C) interaction. Variations in oil yield were mostly related to differences among year and were followed by the influence of the year Y × L interaction.

Table 4. Soybean production parameters in the analyzed period (2006-2011)

Year	Seed yield (kg ha^{-1})	Oil content (%)	Oil yield (kg ha^{-1})
2011	3429.1 ± 28.7 ^{B}	21.41 ± 0.07 ^{B}	734.3 ± 6.7 ^{B}
2010	4301.1 ± 37.8 ^{A}	22.31 ± 0.14 ^{A}	960.2 ± 11.8 ^{A}
2009	2918.0 ± 68.0 ^{D}	20.45 ± 0.15 ^{D}	599.3 ± 17.6 ^{E}
2008	2885.6 ± 105.8 ^{D}	21.54 ± 0.12 ^{B}	623.9 ± 24.7 ^{D}
2007	3043.3 ± 25.8 ^{C}	19.81 ± 0.19 ^{E}	603.4 ± 9.1 ^{E}
2006	3420.0 ± 55.2 ^{B}	20.64 ± 0.08 ^{C}	706.5 ± 12.9 ^{C}

Mean values of parameters labelled by the same letter were not statistically significant ($p<0.05$).

In order to understand how the examined parameters affect soybean genotype produced in different years and localities, the results were subjected to a robust PCA composition. The first principal component (PC1) accounted nearly 85% of the variability, while the second principal component (PC2) explained about 15% of the variability (Figure 4).

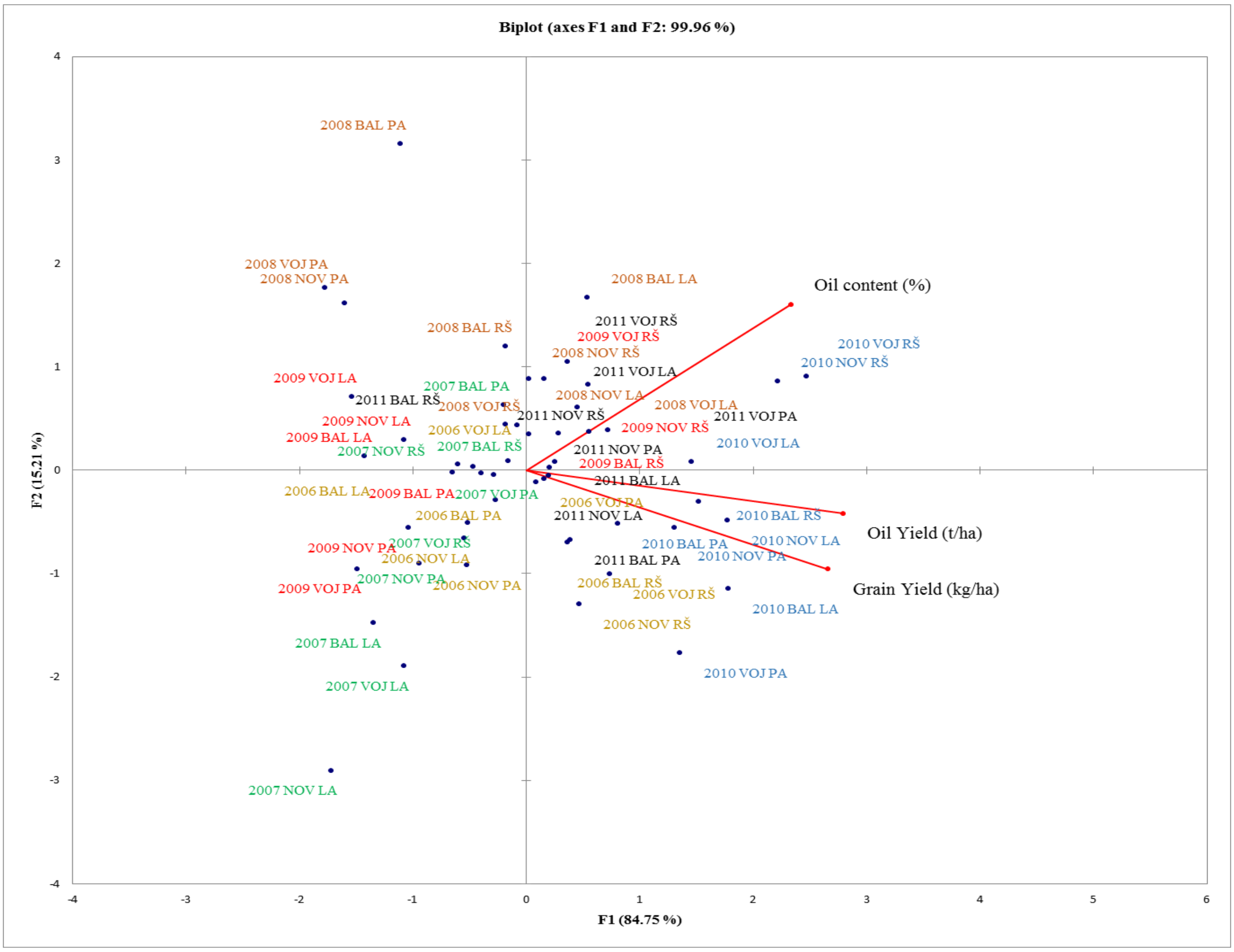

Figure 4. PCA biplot of the seed yield, oil content and oil yield where abbreviation NOV, VOJ and BAL present Novosađanka, Vojvođanka and Balkan soybean genotypes, respectively; NS, PA and LA present Novi Sad, Pančevo and Laćarak locality, respectively, and ♦ marks the 2006 year, ♦ marks the 2007 year, ♦ marks the 2008 year, ♦ marks the 2009 year, ♦ marks the 2010 year and ♦ marks the 2011 year.

The content of seed yield exhibited a positive correlation with the oil yield, while it was unrelated to oil content. Four soybean samples produced in 2006 Balkan, Vojvođanka and Novosađanka from Novi Sad locality and Vojvođanka from Pančevo locality, soybean cultivar produced in Laćarak locality in 2011 year and six soybean samples from 2010 year (Balkan, Vojvođanka and Novosađanka from Pančevo locality, Balkan and Novosađanka from Laćarak locality and Balkan from Novi Sad locality) were closely associated with seed yield and oil yield. On the other hand, all three examined soybean cultivars produced in Pančevo in 2007 and Laćarak in 2009 were negatively correlated with these two parameters. Four soybean samples produced in 2008 (Balkan and Novosađanka from Laćarak and Vojvođanka and Novosađanka from Novi Sad), all three examined soybean cultivars produced in Novi Sad locality in 2010, three soybean samples produced in 2010 (Vojvođanka and Novosađanka from Novi Sad locality and Vojvođanka from Laćarak locality) and four soybean samples produced in 2011 (Vojvođanka and Novosađanka from Novi Sad locality, Vojvođanka from Pančevo and Laćarak localities) were closely associated with oil content. On the other hand, four soybean samples produced in 2006 (Balkan and Novosađanka from Laćarak and Pančevo localities), six soybean samples produced in 2007 (all three from Laćarak locality, Vojvođanka and Novosađanka from Pančevo locality and Vojvođanka from Novi Sad locality) and all three examined soybean cultivars produced in Pančevo locality in 2009 were negatively related with oil content. Also, all three examined soybean cultivars produced in Pančevo locality in 2008 were not related with this parameter. All this had a highly significant effect on seed yield, oil content, and ultimately on oil yield per unit area (Figure 4).

Influence of the environment × genetics × management on soybean seed yield was also investigated by other authors (Molua, 2009; Sobko et al., 2020; Madias et al., 2021; Winck et al., 2023) and they reached similar results. The effect of cultivars (C) on oil yield (Table 5) shows that all three observed C are of approximately equal genetic potential when it comes to seed and oil yield.

Table 5. Results of testing the influence of observed factors on seed yield, oil content and oil yield

Source	Seed yield	Oil content	Oil yield
Year	10153728**	29.06**	676926**
Cultivar	75369ns	1.71**	7558**
Locality	1928507**	12.37**	165176**
Year × Cultivar	119402**	2.09**	9228**
Year × Locality	1850021**	5.61**	105305**
Cultivar × Locality	51549ns	1.66**	5853**
Year × Cultivar × Locality	78773**	0.47**	4067**
% of SS			
Year	66.58	54.53	67.96
Cultivar	0.20	1.28	0.30
Locality	5.06	9.28	6.63
Year × Cultivar	1.57	7.83	1.85
Year × Locality	24.26	21.05	21.14
Cultivar × Locality	0.27	2.50	0.47
Year × Cultivar × Locality	2.07	3.52	1.63

Further analysis will show that in interaction with other factors, C have a significant impact on oil yield, which means that the genetic potential manifests itself differently depending on the growing conditions of the C.

Other authors who also investigated the interaction between the C and the studied parameters of soybean seeds came to the similar results that the seed yield depends on the cultivar and its genetic potential, the level of agricultural practice and climatic conditions (Chung et al., 2003; Battisti et al., 2017).

Abiotic environmental factors such as high or low temperatures, lack and excess of water, have a negative impact on the metabolism of seed crops and therefore on the yield and quality of soybean seeds (Faé et al., 2020; Staniak et al., 2021). Therefore, it is important to define the most relevant indicators that will serve to predict the ability of soybean to tolerate global and regional climate changes (Allard and Bradshaw, 1964). Our results show (Table 4) that there was a significant difference in the yield of soybean seeds (2008 compared to 2006 and 2010), which means that at the observed localities, climatic factors differs significantly and influence on the yield of soybean seeds throughout the observed time period. The different oil content of soybean seeds is determined by the locality where the soybean was grown, as well.

All the studied traits varied significantly depending on variety and from one year to the other. The year 2009 was significantly more favorable for oil synthesis than 2010 (Table 4). In 2009, the grain oil content of soybean was significantly higher than in 2010. On average, the highest oil content and oil yield, both in the control and foliar treatments, were recorded in the variety Tea (21.7% and 1146 kg ha^{-1}). The same variety also had significantly higher oil content than the other varieties, both in the foliar treatments and in the control (Popović et al., 2013). The obtained results indicate that the grain yield and oil content in soybean is a cultivar characteristic, but it is also strongly affected by the environment, which is consistent with the results of other researchers (Perić et al., 2009; Popović et al., 2012, 2013, 2015, 2016, 2020). The current assortment of NS soybean varieties in 2023 is: Favorite, NS Kaća, NS Olympus (000 MG), Merkur, Typhoon, NS Teona, NS Valantis (00 MG), Galina, Valjevka, NS Maximus, NS Atlas, NS Viseris, NS Adonis (0 MG), NS Apolo, NS Hogar, NS Ramonda, NS Zmaj, NS Deneris (I MG), Rubin, NS Kolos, NS Fantast, NS Validus (variety II RG). The yield potential of NS soybean varieties is very high, so in the extremely unfavorable year of 2022, high yields were achieved with many NS soybean varieties (Kolarić et al., 2023). The increase in soybean yield and quality depending on I × C can be attributed to the development of new cultivars with greater genetic potential and adaptability to the environment. It is preferable to sow varieties that are suitable for a certain locality based on the results of experiments with soybeans over several years (Popović et al., 2020).

When we look at the influence of the locality on oil yield, it is noted that the best result was achieved at the Novi Sad locality (Table 2). The lowest oil yield was achieved at locality Pančevo, where the lowest amount of precipitation and a significantly higher average daily temperature was recorded. High temperatures were accompanied by a very uneven distribution of precipitation in the critical stages of growth and development which had consequences for the yield of oil per unit area. Soybean oil yield is also statistically significantly dependent on the locality where soybeans are grown, and the same trend was noticed for seed yield. From the above it could be seen that the studied parameters of soybeans - seed yield, oil yield and oil content were significantly influenced by the locality, which could be explained by the different agroecological conditions (abiotic stress) of the environment. Namely, meteorological parameters (shown in Figure 1) indicate that the amount of precipitation was significantly higher on the experimental field Novi Sad than in the locality Laćarak and Pančevo. In the Laćarak locality, the lack of precipitation is accompanied by high mean monthly air temperatures (Figure 2), which results in a decrease in yield and quality of soybean seed crop (Table 2).

The oil content changed from year to year (Table 3), which confirms that climatic conditions in different years have a significant influence on the oil content and on the oil yield of soybeans. The highest oil content was recorded in 2010, when significantly higher amounts of precipitation and relatively high average daily air temperatures were recorded, and the lowest oil content was in extremely dry year 2007, which is explained by different climatic conditions in the mentioned years. The influence of abiotic stress on yield and seed quality of different soybean cultivars was also examined by other authors (Iqbal et al., 2018; Staniak et al., 2021; Liu et al., 2023) who found that as drought stress increased, oil content decreased linearly, at all temperatures. This could be confirmed with the research of many other authors who investigated effect of water deficit at vegetative and reproductive stages on seed yield and quality of soybean (Mertz-Henning et al., 2017; Iqbal et al., 2018; Šarčević et al. 2022).

Soybean grain yield, yield and seed oil content were influenced by environmental conditions, location and the interaction of the examined factors. The highest grain yield, content and yield of oil was at the site in Novi Sad and the lowest in Pančevo. The lowest rainfall and the lowest humus content in the soil were recorded in Pančevo, which affected the yield and oil synthesis. The highest average yield of soybean seeds was recorded with the Vojvođanka cultivar (3365.0 kg ha^{-1}), while statistically the highest yield was in 2010 (4301.1 kg ha^{-1}) compared to the examined years. The content and yield of oil in the seeds were influenced by all three examined factors. Agroecological and soil conditions in locality Novi Sad were the most suitable for the synthesis of oil in the seeds of all tested cultivars. The Vojvođanka and Balkan cultivars had a statistically higher oil content than the Novosađanka cultivar. The oil content was statistically the highest in 2010 (22.31%) compared to all the examined years. The Vojvođanka cultivar had the highest average oil yield. In order to achieve high yields, the most common limiting factor in soybean production is the lack of rainfall during the critical stages of plant growth and development. Stable yields are achieved by sowing declared seeds, correct selection of varieties and correct and timely application of cultivation technology. In addition to the correct and timely application of agrotechnical measures, it is also very important to select high-yielding varieties that will achieve the maximum yield and grain quality under certain production conditions.

CONCLUSIONS

From the results it can be concluded that the highest average yield of soybean seeds was found in the genotype “Vojvođanka”. The interaction between climatic conditions (years) and seed yield was significant in all tested genotypes. The yield of soybean seeds was statistically significantly influenced by the agro-ecological conditions of the locality. The lowest soybean yield was found in Pančevo, then in Laćarak and the highest in Novi Sad. The genotype “Novosađanka” had the lowest average oil content. The oil content was the highest in Novi Sad, while it was at approximately the same level in Pančevo and Laćarak. The yield of soybean oil is statistically significantly dependent on climatic conditions (years), locality, their interaction and their interaction with the studied genotypes. The location where soybeans are grown has a significant impact on oil yield. The lowest oil yield was achieved at the Pančevo locality. The highest average oil yield was found in the genotype “Vojvođanka”. Genotypes “Balkan” and “Novosađanka” achieved the highest yields at the Novi Sad locality. The “Vojvođanka” genotype achieved the highest yields in the localities Laćarak and Novi Sad. All three genotypes gave the lowest seed yield at the Pančevo locality. The agroecological and soil conditions of Novi Sad were the most suitable for the synthesis of oil in the seeds of all genotypes. Statistically, the best result in oil yield was determined in the locality of Novi Sad. All the investigated characteristics of soybean seeds achieve the best results in Novi Sad locality. The increase of soybean yield and quality depending on agroecology conditions x genotypes can be attributed to the development of new genotypes with greater genetic potential and adaptability to the environment, changes in the environment as a result of climate change, and/or improvements in crop management by farmers.

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