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ORIGINAL ARTICLE

Evaluation of plasticity and yield stability in white lupin and soybean varieties

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The research was conducted in 2016–2020 at the National Research Center "Institute of Agriculture of the National Academy of Agrarian Sciences of Ukraine". The experimental plots were placed on the fields of selection crop rotation located in the Kyiv-Sviatoshynskyi district of the Kyiv region; the soils of the fields belong to the sod-medium-podzolic sandy loam. The years of research on the temperature regime generally exceeded the value of the average long-term norm, and the amount of precipitation was characterized as arid. According to the generally accepted technology for lupin and soybeans, experiments to determine the plasticity and stability of varieties were carried out on a single agronomic background. The area of the experimental plots was 20.0 m2, repeated four times. Twelve varieties and selection numbers of white lupin and 15 soybean varieties of selection "NSC Institute of Agriculture of National Academy of Agrarian Sciences of Ukraine" were analyzed according to the manifestation of seed yield. Field, measuring, weighing, and laboratory research methods were used to evaluate the material. The analysis of varieties and selection numbers of white lupin allowed dividing them into groups according to the level of yield and plasticity and determining the reaction to changes in environmental conditions, which must be taken into account when determining the location and cultivation technologies. It is established that precocious soybean varieties provide the highest and stable seed yields. Due to the short growing season, ultra-early varieties do not have time to provide high enough yields but are characterized by stable productivity, which allows them to be sown later as an insurance crop and used as a precursor for winter cereals. Medium-ripe varieties of soybeans often suffer from drought in the second half of summer, so high yields can be formed only with sufficient moisture during this period

Keywords: white lupin, soybean, variety, regression coefficient, standard deviation, year conditions index, yield.

Introduction

Now the climate change on a global scale is recognized by the world scientific community as an indisputable fact (Pachauri, Reisinger, 2008). In agriculture, crop production is most dependent on the weather. This is influenced by deviations from the average rainfall and average daily air temperature and the variability of climatic conditions within years, increasing manifestations of extreme weather events in critical periods of ontogenesis, which causes stress in plants and, as a result, changes in intensity and direction. Physiological processes on which the formation of the final productivity of culture depends (Managing the risks, 2012; Crop Production, 2021). Pyatygin (2008) defines stress as a complex protective reaction of the body to the influence of various factors, which is accompanied by a physiological and biochemical restructuring of the body in a critical situation. According to Pyatygin (2008), due to the impossibility of changing their location, plants are forced to perceive the effects of various stresses, not avoiding them but relying solely on their internal reserves.

Because of this, technologies aimed at maximizing the protective reactions of the plant organism to adverse environmental conditions are of particular importance in crop production. Such technologies have high flexibility to environmental conditions due to the variation of the set of technological operations that are most appropriate in the specific conditions of the growing season. The defining element in such technologies is the variety because of its biological, morphological, and genetic features, the strategy of choice of the predecessor, tillage, fertilizer, sowing, care of crops, and harvesting is built.

Therefore, the creation of high-yielding varieties has always been the highest priority among the tasks of selection. Genetic control of yield is carried out through physiological and biochemical processes in plants and is manifested in the whole system of traits, the phenotypic manifestation of which is also the result of interaction with the environment. In white lupin, the seed yield formation largely depends on growing conditions. If lupin is a culture relatively undemanding to the type and fertility of soils, then other factors significantly affect the growth and development of its plants. Thus, it should be noted its demanding moisture, especially in critical periods of initial development and formation of generative organs. Soybean productivity also

largely depends on the provision of moisture during the formation and filling of beans. In general, soybeans are a thermophilic crop, but high temperatures and air drought during this period significantly reduce yields due to abortion of beans and weight loss of 1000 seeds.
Different genotypes of plants differ in the rate of response to changes in growing conditions. Of great importance are the potential productivity of varieties and their ecological resistance to adverse environmental conditions. When a variety is genetically unadapted to a wide range of soil and climatic conditions, it cannot withstand the effects of various biotic and abiotic factors. Therefore, the value of varieties is determined by their plasticity and stability, or the ability to form a certain yield level in different environmental conditions (Grogan et al., 2016; Sapega, 2017; Starichenko, Guba, 2018). The reaction of varieties to changes in conditions must be taken into account when choosing the place and technology of cultivation, which will promote the best manifestation of their genetic potential. Breeders' efforts aim to create varieties that will give high and stable yields in different environmental conditions (Detsyna et al., 2019; Mameev, 2017; Peltonen-Sainio et al., 2011; Rolando, Torres, 2018).
The research aimed to identify the peculiarities of yield formation of varieties and selection numbers of white and soybean lupin under different weather conditions and establish their plasticity and stability to determine varieties with maximum adaptive capacity to ensure the appropriate level of grain productivity.

Materials and methods

The research was conducted in 2016–2020 at the National Research Center "Institute of Agriculture of the National Academy of Agrarian Sciences of Ukraine". The experimental plots were placed on the fields of selection crop rotation located in the Kyiv-Sviatoshynskyi district of the Kyiv region; the soils of the fields belong to the sod-medium-podzolic sandy loam. The years of research on the temperature regime generally exceeded the value of the average long-term norm, and the amount of precipitation was characterized as arid. According to the generally accepted technology for lupin and soybeans, experiments to determine the plasticity and stability of varieties were carried out on a single agronomic background. The area of the experimental plots was 20.0 m2, repeated four times. Twelve varieties and selection numbers of white lupin (*Lupinus albus*) and 15 soybeans (*Glycine max*) varieties of selection "NSC Institute of Agriculture of NAAS" were analyzed according to the manifestation of seed yield. Field, measuring, weighing, and laboratory research methods were used to evaluate the material. The computer program StatSoft Statistica v. 8.0 was used for mathematical and statistical analysis. According to Eberhart S. A. and Russel W. A. (1966), plasticity and stability were calculated.

Results and discussions

Weather conditions of the research years differed in temperature and precipitation, which affected the yield of white lupin. Thus, the conditions of 2016 contributed to the formation of relatively good yields of varieties and breeding numbers, which averaged 3.23 t ha^{-1} and ranged from 2.72 t ha^{-1} in the variety September to 3.47 t ha^{-1} in number 825/10. This year's conditions index was 0.74. The hot and dry weather during the lupin growing season in 2017, and especially during flowering and bean tying, led to a significant reduction in yields. The value of the index of conditions of the year decreased to -0.95. Seed yield averaged 1.54 t ha^{-1} with variability ranging from 1.16 (September variety) to 2.15 t ha^{-1} (number 825/10). Sufficient moisture supply and optimal temperature in June and July 2018 contributed to the excellent development of lupin plants and the formation of high seed yields. This year, the highest annual index was 1.22, and the best seed yield was 3.71 t ha^{-1} and ranged from 3.35 (September variety) to 3.98 t ha^{-1} (Barvynok variety). In 2019, high temperatures and insufficient moisture supply, which fell during critical periods for the formation of productivity of lupin - flowering, tying and pouring beans led to accelerated ripening and reduced seed yields. This year's index of conditions was -0.02, and the average seed yield was 2.47 t ha-1 with variability ranges from 2.13 (September variety) to 2.67 t ha^{-1} (number 770/78). Excessive rainfall in April and May and severe drought during the flowering and filling of beans in 2020 harmed the growth and development of lupin and caused a significant reduction in seed yield. This year, the lowest yield was obtained, which averaged 1.52 t ha^{-1} and ranged from 1.14 t ha^{-1} in the variety September to 2.21 t ha^{-1} in number 105/4. This year's conditions index was -0.97. Such contrasting weather conditions of the years of research allowed to assess the varieties and breeding numbers for the level of plasticity and stability of seed yield (Table 1).
The primary indicator of the plasticity of varieties in terms of yield and other valuable economic characteristics is the regression coefficient (bi), which reflects their response to changes in environmental conditions and allows to predict the manifestation of the studied characteristics when grown in different conditions. The standard deviation characterizes the stability of the variety, i.e., how reliably the variety corresponds to the plasticity indicated by the regression coefficient (Kirchev, Georgieva, 2017; Prysyazhnyuk et al., 2020; Shcherbina et al., 2020).
According to the indicators of plasticity and stability, the 11 best varieties of seed lupins and selection numbers of white lupin from the competitive variety test and the September standard variety were evaluated. According to the level of yield and plasticity, the studied material was divided into three groups. The first group included the variety Barvynok and numbers 825/10, 105/4, 778/15 with the highest yield (2.65-2.81 t ha^{-1}), which had a regression coefficient from 0.730 to 0.920. Variety Snigur and numbers 770/78, 765/18, which were included in the second group, were characterized by a lower level of yield (2.45-2.50 t ha^{-1}) and more remarkable plasticity (bi = 1.143-1.219), i.e., they reacted more strongly to changeable environmental conditions. The least productive were numbers 247/6, 824/34, 122/6, and the variety Chabansky from the third group (2.33-2.43 t ha-1), which had reasonably high plasticity (bi = 1.027-1.092). All studied varieties and numbers had low standard deviation values (0.005-0.064), which indicates their high stability.

Table 1. Plasticity and stability of seed yield of white lupin varieties

Variety, selection voucher	Yield, t/ha						Plasticity, b_i	Stability, S_i^2
	2016	2017	2018	2019	2020	Average		
September standard	2.72	1.16	3.35	2.13	1.14	2.10	0.980	0,005
825/10	3.47	2.15	3.74	2.46	2.21	2.81	0.730	0,047
Barvynok	3.28	1.94	3.98	2.65	1.81	2.73	0.920	0,015
105/4	3.27	1.97	3.71	2.50	2.12	2.71	0.750	0,022
778/15	3.22	1.75	3.76	2.52	1.98	2.65	0.845	0,018
Snigur	3.22	1.39	3.95	2.56	1.38	2.50	1.143	0,009
770/78	3.20	1.22	3.87	2.67	1.43	2.48	1.143	0,031
765/18	3.42	1.29	3.85	2.47	1.20	2.45	1.219	0,006
247/6	3.10	1.32	3.78	2.58	1.39	2.43	1.081	0,018
824/34	3.43	1.52	3.40	2.36	1.19	2.38	1.027	0,064
Chabanskiy	3.18	1.34	3.54	2.44	1.18	2.34	1.070	0,015
122/6	3.23	1.37	3.60	2.28	1.18	2.33	1.092	0,009
Average	3.23	1.54	3.71	2.47	1.52	2.49		
Annual conditions index, I_j	0.74	-0.95	1.22	-0.02	-0.97	–	–	

Figure 1 shows the regression lines of the yield of Snigur variety and selection numbers 105/4 and 247/6, characterized by different indicators of plasticity and stability. Number 105/4 has the highest among them the average seed yield over the years of research (2.71 t ha^{-1}), but the lowest value of the regression coefficient (0.750), so when the conditions of the year improve, it is inferior to the yield of Snigur and number 247/6, which react more strongly to changes in growing conditions. In turn, the Bullfinch variety is more stable compared to the number 247/6.

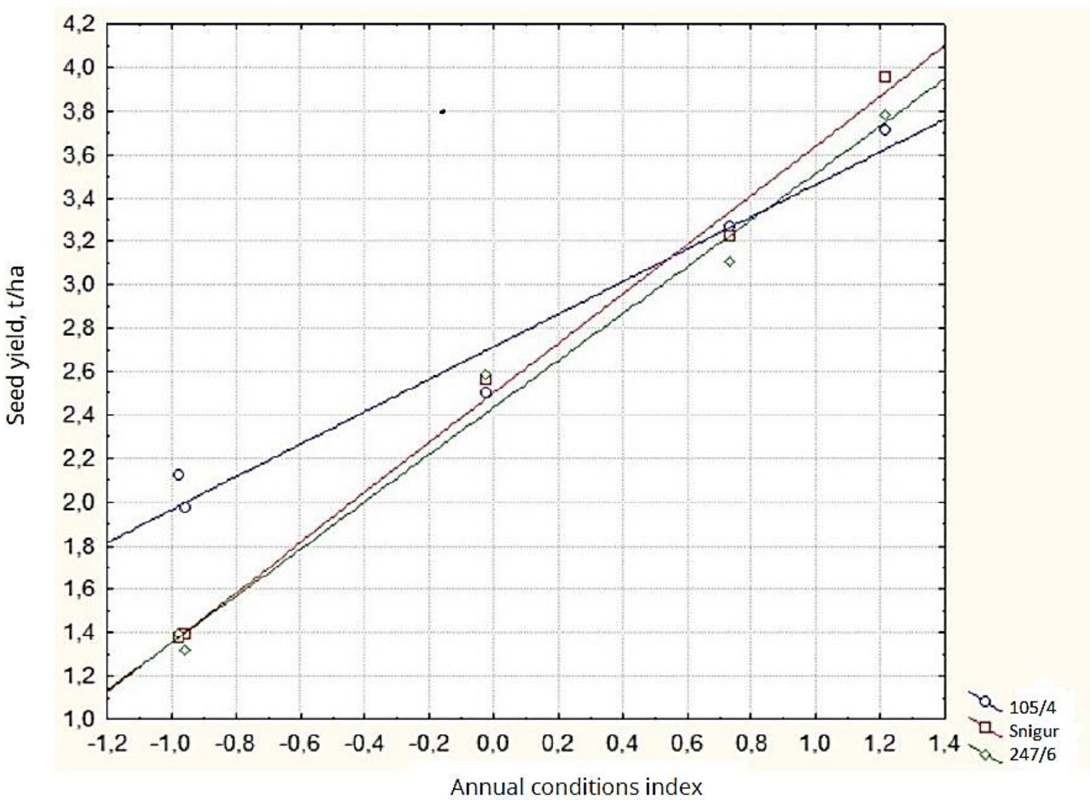

Fig. 1. Regression of white lupin seed yield vs. annual conditions indices

Evaluation of varieties for the manifestation of valuable economic characteristics in different environments should be done to determine the suitability of the variety for implementation in certain growing regions. Therefore, studies to study the plasticity of varieties of cereals, legumes, oilseeds, cereals, and other crops are widely carried out by scientists from different countries (Sapega, 2017; Peltonen-Sainio et al., 2011; Prysyazhnyuk et al., 2020; Delchev, 2018; Diordiieva et al., 2018). The study of the reaction of white lupin varieties, including those originating from Ukraine, to changes in growing conditions, was carried out at the Institute of Forage Crops (Bulgaria). Varieties with different levels of plasticity and stability in grain yield and the manifestation of individual elements of the productivity structure were selected (Georgieva, Kosev, 2018; Kosev et al., 2019; Kosev, Vasileva, 2019; 2020; according to the research conducted at the Research Institute of Lupin (Russian Federation), the level of plasticity and response to changes in weather conditions of white lupin varieties with different types of branching, as well as the manifestation and variability of elements of seed productivity (Zakharova et al., 2014). According to the results of our previous research, the ecological plasticity and stability of collecting samples of white lupin of different geographical origins were determined. The selection value of the genotype was determined for simultaneous selection for general adaptive ability and stability. Samples with the most significant effects of total adaptive capacity were characterized by maximum seed productivity for all media sets (Levchenko, Baidyuk, 2016).

Due to the later sowing period, the stages of the ontogenesis of soybean plants occurred in periods with other weather conditions. Therefore, soybean varieties observed a different reaction to the manifestation of seed yield to the conditions of growing years. Thus, the deficit of precipitation in July-September 2016 led to a decrease in the productivity of soybean plants. The year 2017 was also unfavorable for the growth and development of soybeans because during its active growth and flowering, rains fell unevenly and in insufficient quantities, and rains at the end of the growing season caused the lodging of medium-ripe varieties. Weather conditions in 2018 were the most favorable for soybean crops, which ensured the formation of high seed yields. The high daytime temperatures of the second and third decades of June 2019, when soybeans were in bloom, negatively affected the tying of beans and seeds. Conditions in 2020 due to lower night temperatures led to the delayed emergence of seedlings, which led to an increase in the length of the growing season and ripening. Thus, the weather conditions of the years of research in different ways affected the manifestation of yield in soybean varieties.

The studied varieties of soybeans belong to different groups of maturity: Yug-30, Legend, Arnica, Siverka - ultra-early (duration of the growing season 85-100 days); Vorskla, Khvylia, Jacqueline, Ustya, Elena, Vilshanka, Vyshivanka, Muza - precocious (101-115 days); Kyivska 98, Vasylkivska, Suzir'ya - medium ripe (115-130 days). The manifestation of seed yield in these varieties, depending on the year of cultivation, was different. Thus, the value of the regression coefficient (bi) in ultra-early varieties varied from 1.652 in the cultivar Yug-30 to -0.395 in the cultivar Legenda (Table 2).

Table 2. Plasticity and stability of soybean varieties seed yield.

Varieties	Yield, t/ha						Plasticity, b_i	Stability, S_i^2
	2016	2017	2018	2019	2020	Average		
Ultra-early ripening varieties								
Siverka	2.50	2.37	2.62	2.41	2.81	2.54	0.597	0.026
Yug-30	2.01	2.31	3.21	2.13	2.41	2.41	1.652	0.201
Arnika	2.50	2.01	2.24	2.15	2.30	2.24	-0.030	0.000
Legenda	2.20	1.77	2.02	2.08	1.54	1.92	-0.395	0.011
Early ripening varieties								
Muza	3.21	3.24	4.42	3.51	3.02	3.48	3.632	0.970
Jacqueline	3.01	3.35	3.52	3.61	3.23	3.34	2.040	0.306
Vyshivanka	3.12	2.99	3.45	3.69	3.33	3.32	1.937	0.276
Ustya	2.96	3.01	3.52	3.24	2.21	2.99	2.084	0.319
Khvylia	2.30	3.07	3.54	3.58	2.25	2.95	2.096	0.323
Elena	2.95	3.54	2.61	2.31	2.03	2.69	0.504	0.019
Vilshanka	2.10	2.57	3.89	1.77	2.33	2.53	2.847	0.596
Vorskla	2.65	1.98	2.74	2.20	2.18	2.35	0.846	0.053
Mid-season varieties								
Suzir'ya	2.76	2.65	2.56	2.7	3.31	2.80	0.456	0.015
Vasylkivska	1.96	2.83	3.63	2.89	2.01	2.66	2.310	0.392
Kiyvska 98	2.63	2.81	2.56	2.27	2.25	2.50	0.469	0,016
Average	2.59	2.70	3.10	2.70	2.48	2.72	–	
Annual conditions index, I_j	-0.13	-0.02	0.39	-0.01	-0.24	–		

The year conditions had the least effect on the yield of the Arnica variety (bi = -0.030, S_i^2 = 0.000). A similar reaction was also observed in the cultivar Legenda (bi = -0.395; S_i^2 = 0.011). The regression lines of these varieties were almost parallel to the abscissa axis, which confirms their high stability, although the slope of the regression line of the Legend variety was opposite to that of all other varieties (Fig. 2). This can be explained by the fact that in ultra-early varieties of soybeans, the stages of ontogenesis occur faster than in later ones, so even minor changes in growing conditions can greatly affect the formation of productivity. Varieties Yug-30 and Siverka in reaction to growing conditions were close to precocious varieties and generally had a slightly higher yield than the two aforementioned varieties.

The highest seed yields on average in five years were provided by the precocious varieties Muza (3.48 t ha^{-1}) and Jacqueline (3.34 t ha^{-1}); they were also the most plastic (bi = 3.632 and 2.040, respectively). The Jacqueline variety was inferior to the Muza variety in terms of yield, but it was more stable. In the graph, the regression line of this variety has a smaller slope than the Muza variety. In terms of yield (3.32 t ha^{-1}), it was almost equal to the Vyshivanka variety, and by the plasticity and stability (bi = 1.937; S2 = 0.276) it was more similar to the Jacqueline variety.
Medium-ripe varieties Suzir'ya, Vasylkivska, and Kyivska 98 showed lower yields than early-ripening varieties: 2.80, 2.66, and 2.50 t ha^{-1}, respectively. This can be explained by the fact that the beans were tied later and often coincided with the period of drought and high temperatures in early August. The most plastic among them was the Vasylkivska variety (bi = 2.310), and the regression line of this variety on the graph runs almost parallel to the line of the Muza variety.

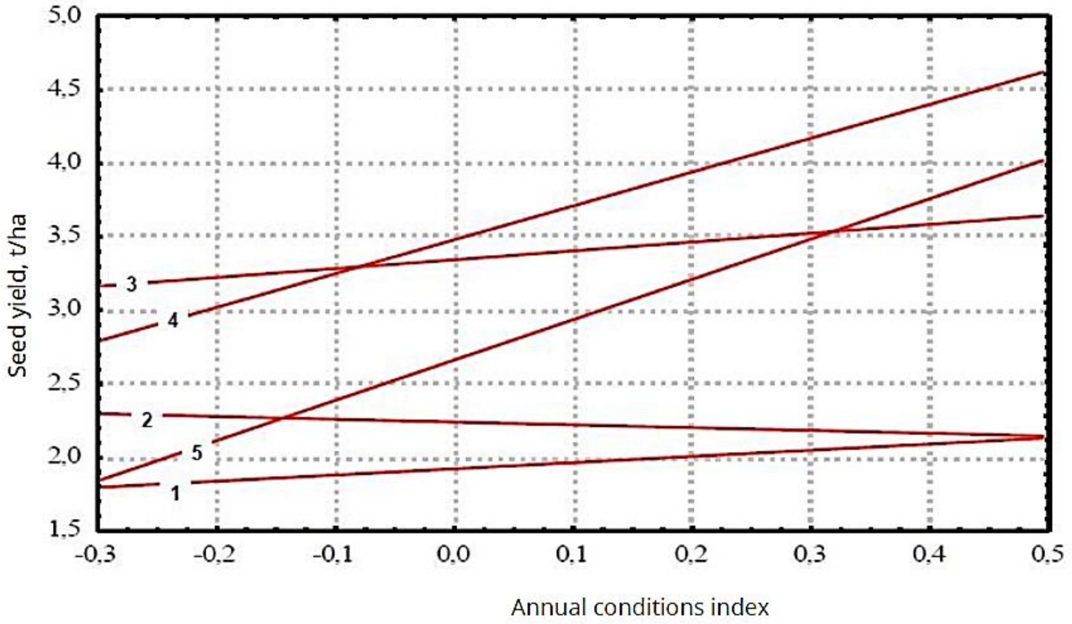

Fig. 2. Soybean seed yield and year conditions indices regression. Soybean varieties: 1 - Legend; 2 - Arnica, 3 - Jacqueline; 4 - Muza, 5 - Vasylkivska

Studies of soybean varieties in terms of stability and plasticity are widely used to determine the suitability of various regions' variety. Thus, the Institute of Oilseeds of NAAS assessed soybean varieties of different ecological and geographical origins and identified the most stable economic manifestations (Zinchenko et al., 2018). Similar studies were conducted at the Institute of Feed and Agriculture of Podillya NAAS to determine the response to changes in growing conditions and selection value of soybean varieties (Ivanuyk et al., 2017). At the Institute of Plant Breeding. V.Ya. Yuryev NAAS in the conditions of the eastern Forest-Steppe of Ukraine studied soybean varieties of their selection according to the stability and plasticity of yield and protein and oil content in seeds (Chernyshenko, 2014). In the conditions of the southern steppe of Ukraine in the Breeding and Genetic Institute of NAAS based on studying varieties of different ecological and geographical origin, valuable varieties for selection in terms of stability were selected (Mursakaev et al., 2018). In Poltava State Agrarian Academy, Bilyavska and Rybalchenko (2018) studied the collecting samples of soybeans of different maturity groups to identify valuable source material for creating varieties with stable yield.

Conclusions

The analysis of varieties and selection numbers of white lupin allowed us to divide them into groups according to the level of yield and plasticity and determine the reaction to environmental conditions, which must be taken into account when determining the location cultivation technologies.
It is established that precocious soybean varieties provide the highest and stable seed yields. Due to the short growing season, ultra-early varieties do not have time to provide high enough yields but are characterized by stable productivity, which allows them to be sown later as an insurance crop and used as a precursor for winter cereals. Medium-ripe varieties of soybeans often suffer from drought in the second half of summer, so high yields can be formed only with sufficient moisture during this period.

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