COMPARATIVE ANALYSIS OF SOME SOYBEAN GENOTYPES BASED ON BIOMETRIC PARAMETERS

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Abstract. *The study made a comparative analysis regarding the behavior of some soybean genotypes in non-irrigated crop system. Experiments were carried out within ARDS Lovrin, on a chernozem type soil with medium fertility. The following genotypes were cultivated: 'Calma', 'Caro TD', 'Isa TD', 'Karavukovo', 'Perla', and 'Ziana TD'. Sowing was done at the optimal time, at a distance of 70 cm between rows, and the crop technology ensured favorable conditions for plant growth. At physiological maturity, plant samples were taken and determinations were made regarding: plant density (PD, plants/m^2), plant weight (PW, kg/m^2), soybean pod weight (SpW, kg/m^2), soybean grain weight (SgW, kg/m^2), soybean pods shells weight (SpsW, kg/m^2). Based on the recorded values, the yield of soybeans in relation to pods (Y, %) was calculated. PW/SpW, PW/SgW, and PsW/SgW ratios were also calculated. Very strong, positive correlation was recorded between SgW and SpW (r = 0.998), between Y (%) and SpW (r = 0.923), and between Y and SgW (r = 0.944). According to PCA, PC1 explained 74.369% of variance, and PC2 explained 14.769% of variance. The Cluster Analysis generated the dendrogram of soybean genotypes based on similarity (Coph.corr = 0.972), and a high level of similarity was recorded between 'Calma' and 'Isa TD' genotypes (SDI = 1.6926). In relation to the average value of the experiment, the 'Perla' genotype stood out for the PW parameter, the 'Ziana TD' genotype for the SpW parameter, the 'Ziana TD' genotype for the SgW parameter, and the 'Perla' genotype for yield (Y, %).*

Keywords*: Cluster Analysis, comparative analysis, PCA, productivity parameters, soybean, variability*

INTRODUCTION

Soybean is a crop of economic importance, and with a multivalent ecosystem role, a protein crop that contributes to ensuring sustainable food security (Siamabele and Moral, 2021).

The increasing demands for the use of soybean production in human food, for fodder and the biofuel industry, determined that the areas cultivated with soybean registered an increasing trend in the last decades (Bheemanahalli et al., 2022). Great attention was paid to the cultivated soybean varieties, in relation to the maturity group, the production level and the quality indices required by the market.

At the level of EU countries, soybean is of high interest for animal feed, and GMO-free forms are of interest for human consumption, as a result of the quality of soybean preparations (Rotundo et al., 2024). The high interest in soybeans has led to studies and experiments regarding the behavior of some soybean genotypes and the level of yields in favorable areas, but also in less favorable, warm, or cooler areas (Southern or Northern areas). The authors of the study also analyzed advantages regarding the reduction of CO_2 emissions, as well as in relation to the level of nitrogen fertilizers by expanding the area cultivated with soybeans. Starting from the high interest in the soybean crop in the EU, the behavior of different maturity groups of soybeans was analyzed, under conditions of an irrigated system, as a single annual crop, or as a double sequential crop, after certain winter crops (Simon-Miquel et al., 2024). The authors of the study communicated results regarding yield, as well as ecosystem advantages through symbiotic nitrogen fixation.

The interest in the production of vegetable proteins through soybean crops, associated with the ecosystem advantages, determined the testing of genotypes with different vegetation periods in areas of Northern Europe (Coleman et al., 2021). The authors recorded variable yields, in relation to the genotype and the location of the study, and estimated favorable prospects for the soybean crops in relation to the trend of climate change.

The increased interest in soybean crops has led to studies on the behavior of different soybean genotypes in relation to environmental and technological factors. Soybean crop productivity was studied in relation to different input factors, under the conditions of a representative sample of farmers, with random stratified sampling (Kristanti et al., 2018). The authors of the study communicated values of productivity and yield in relation to different input factors, over a period of eight years of study. Wang et al. (2023) reported results regarding the behavior of some soybean varieties in relation to low temperatures through simulation analysis, and identified varieties with a resistance to the study conditions.

The agronomic attributes of soybean varieties have been studied in relation to the selection and reproduction processes, in order to explain the increased yields of the last decades (Umburanas et al., 2022). The authors of the study analyzed yield and quality aspects of soybean production in a collection of 26 varieties. The authors recorded different yield trends in relation to seed quality indices (oil content, proteins) and estimated

certain prospects for increasing yields for the next period.

Wang et al. (2020) analyzed the photosynthetic capacity and pod formation in soybean under intercropping conditions. The authors of the study identified the response of several soybean varieties tested and recorded better yields in intercropping conditions as a result of the survival of several reproductive structures in the outcrops, in key positions (R5, according to the authors).

Associated with climate changes, and the interest in vegetable protein production, soybean crop has been the subject of studies in West African conditions (MacCarthy et al., 2022). The authors of the study used different modules and modeling systems to find out the yield and profitability of the soybean crop in relation to the climat conditions and categories of farms (management practices, soil conditions, etc.) and highlighted a large variability between the types of farms.

Soybean genotypes from an impressive collection (560 varieties, from more than 2371 genotypes generated in the last 100 years of soybean crop in China), were analyzed under the pedigree aspect for genetic differentiation (Li et al., 2022). Based on some representative genetic indicators, the authors of the study made assessments on the eco-subpopulations of inclusion, and formulated some recommendations for the improvement of the germplasm in future breedings programs.

Different soybean varieties have been studied in relation to the degree of tolerance / resistance to certain pathogens (Eid et al., 2023). The authors of the study recorded the differentiated response of the tested genotypes, and based on gene expression, they identified defense genes, which can play an important role for plants in culture systems. Along with the diversification of analysis methods, some studies used techniques based on imaging analysis to comparatively evaluate different soybean varieties, looking at vegetation stages, ripening period, crop health and production estimation (Polukhin et al., 2023). Representative agronomic traits of soybean plants were studied to characterize different varieties in order to effectively use germplasm to increase production and yield in soybean crops (Liu et al., 2017).

Easier access to protein food resources and lipids is essential in order to ensure food security, and soybean culture represents an important vegetable resource in this sense (Xu et al., 2022). Starting from the practical consideration among farmers that grain production, as well as biometric quality indices of grains (e.g. grain size) represent a premise for protein and lipid yield, the authors of the study tested different soybean varieties in this direction. Considering in the study 64 soybean varieties grown in 35 locations, the authors determined seed yield and quality indices in relation to seed size.

The reaction of soybeans to various stress factors and the decrease in yield is known. Kezar et al. (2023) analyzed how different stages of fruiting on the soybean stem contribute to yield formation, and formulated certain management practices to anticipate the limitations given by stress, in order to recover the relative yield.

Physiological and biometric parameters were used to characterize the relationship of some soybean varieties in relation to vegetation factors, and especially in response to the water stress generated by drought (Poudel et al., 2023). The authors of the study identified from the ten varieties analyzed some with good tolerance to drought, as well as some sensitive ones, and based on the results they established the traits/parameters useful in assessing the drought tolerance of soybean plants.

The study analyzed the behavior of some soybean genotypes in a non-irrigated culture system, by quantifying the variation of some morphological and productivity parameters, and the comparative analysis between genotypes.

MATERIAL AND METHODS

The study considered the comparative analysis of some soybean genotypes, in the crop conditions specific to the Western Plain of Romania. The experimental researches in field conditions were carried out in the conditions of ARDS Lovrin, Romania.

The following genotypes were considered: 'Calma', 'Caro TD', 'Isa TD', 'Karavukovo', 'Perla', and 'Ziana TD'. The experimental crops were organized on a chernozem type soil, distance between rows of 70 cm, in a non-irrigated system. The cultivation technology ensured adequate vegetation conditions (control of weeds, diseases and pests).

At physiological maturity (BBCH code 9, Senescence) (Meier, 2001), plant samples were taken and biometric determinations were made at representative parameters, to create a soybean genotype.

Plant density (PD, number of plants/m^2) was evaluated. Plant weight (PW, kg/m^2), soybean pod weight (SpW, kg/m^2), soybean grain weight (SgW, kg/m^2), soybean pod shells weight (SpsW, kg/m^2), and yield of grains from pods (Y, %), relation (1), were measured and calculated.

$$Y = (SgW/SpW) \times 100 \quad (1)$$

Based on the values recorded for the considered parameters, the ratios: PW/SpW, PW/SgW, and SpW/SgW were calculated. The statistical reliability of the recorded experimental data was evaluated (ANOVA

Test). A descriptive statistical analysis was performed. Values were obtained for representative statistical parameters in the characterization of experimental data series. Based on the results of the statistical parameters, comparative analyzes were made between the soybean genotypes considered in the study.

For the analysis and statistical processing of the experimental data, the statistical calculation module in EXCEL and the PAST software were used (Hammer et al., 2001).

RESULTS AND DISCUSSIONS

Based on the observations and samples collected from each soybean genotype, measurements and determinations were made for biometric parameters, and the values shown in table 1 resulted. Plant density (PD) presented values between PD = 11.429±1.246 ('Karavukovo'), and PD = 18.571±1.246 ('Calma'). Plant weight (PW) presented values between PW = 0.757±0.022 kg/m^2 ('Karavukovo'), and PW = 0.900±0.022 kg/m^2 ('Perla'). The weight of soybean pods (SpW) showed values between SpW = 0.226±0.036 kg/m^2 ('Karavukovo'), and PsW = 0.471±0.036 kg/m^2 ('Ziana TD'). The weight of soybeans grains (SgW) presented values between SgW = 0.124±0.026 kg/m^2 ('Karavukovo'), and SgW = 0.301±0.026 kg/m^2 ('Ziana TD'). The weight of soybean pods shells (SpsW) showed values between SpsW = 0.101±0.010 kg/m^2 ('Karavukovo'), and SpsW = 0.170±0.010 kg/m^2 ('Ziana TD'). Grain yield (Y, %), related to pod weight (SpW) presented values between Y = 55.063±1.494% ('Karavukovo'), and Y = 65.085±1.484% ('Perla'). Based on the values of the recorded parameters, three ratios were calculated (PW/PsW, PW/SgW, and PsW/SgW). The experimental data showed statistical reliability, according to the results of the ANOVA test, Alpha = 0.001, table 2.

Table 1. Biometric and quantitative parameter values for the soybean genotypes studied

Soybean genotype	PD (plt/m^2)	PW	SpW	SgW (kg/m^2)	SpsW	Y (%)	PW/PsW	PW/SgW ratio	SpW/SgW
'Calma'	18.571	0.871	0.410	0.263	0.147	64.111	2.13	3.32	1.56
'Caro TD'	18.571	0.814	0.363	0.226	0.137	62.205	2.24	3.61	1.61
'Isa TD'	17.143	0.786	0.454	0.287	0.167	63.208	1.73	2.74	1.58
'Karavukovo'	11.429	0.757	0.226	0.124	0.101	55.063	3.35	6.09	1.82
'Perla'	12.857	0.900	0.421	0.274	0.147	65.085	2.14	3.28	1.54
'Ziana TD'	14.286	0.829	0.471	0.301	0.170	63.939	1.76	2.75	1.56
SE	±1.246	±0.022	±0.036	±0.026	±0.010	±1.494	±0.241	±0.511	±0.043

Table 2. ANOVA Test results

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	19806.17	8	2475.771	903.8143	4.86E-47	4.089542
Within Groups	123.2661	45	2.739247			
Total	19929.43	53				

The assessment of variability, within each parameter, was based on the coefficient of variation (CV). Low values of the coefficient of variation (CV < 10) were recorded in the case of the PW parameters (CV = 6.4083), in the case of the grain yield (Y, %) in relation to the weight of the pods (CV = 5.8754), and in the case of the SpW/SgW ratio (CV = 6.5007). Low values of the coefficient of variation were recorded in the case of the PD parameter (CV = 19.7242) and in the case of the SpsW parameter (CV = 17.2387). In the case of these parameters, the level of variability is considered to be low, based on the recorded CV values. Moderate variability was recorded in the case of the SpW parameter (CV = 22.7816), in the case of the SgW parameter (CV = 26.4017), and in the case of the PW/SpW ratio (CV = 26.5386). High variability was recorded in the case of the PW/SgW ratio (CV = 34.4736), which explains the different weight of the plant mass in relation to the formation of grain production.

The correlation analysis was used to evaluate the interdependence between the parameters analyzed in the soybean genotypes. The values of the correlation coefficient obtained are presented in figure 1.

The SgW parameter showed a weak positive correlation with PD (r = 0.418), and with the PW parameter (r = 0.583), and a very strong correlation with the SpW parameter (r = 0.998). Grain yield (Y, %) showed weak positive correlation with the PD parameter (r = 0.481), moderate correlation with the PW parameter (r = 0.781), strong correlation with the SpsW parameter (r = 0.852) and very strong correlation with the SpW parameter (r = 0.923), and with the SgW parameter (r = 0.944).

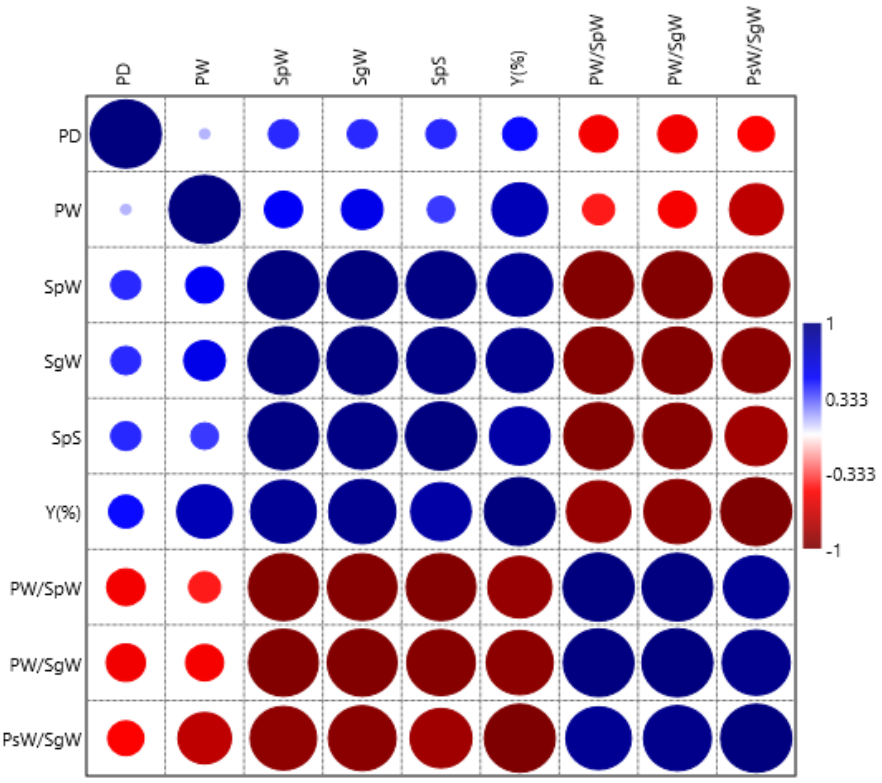

Figure 1. **Graphical representation of the correlation between the considered biometric parameters and the ratios calculated for soybean genotypes**

According to PCA, the diagram in figure 2 resulted, in which the soybean genotypes considered in the study were positioned differently in relation to the considered parameters. PC1 explained 74.369% of variance, and PC2 explained 14.769% of variance. The independent positioning of the 'Karavukovo' genotype was found, which recorded low values for the considered parameters, and especially for parameters related to grain production. Associated with important productivity parameters (SpW, SgW, Y) the genotypes 'Calma' and 'Ziana TD' were positioned. The 'Caro TD' genotype was associated with the PD parameter. The 'Isa TD' genotype was positioned intermediate between PD and SpsW. Associated with the PW parameter, the genotype 'Perla' was positioned. Cluster Analysis led to the dendrogram in figure 3 (Coph.corr. = 0.972).

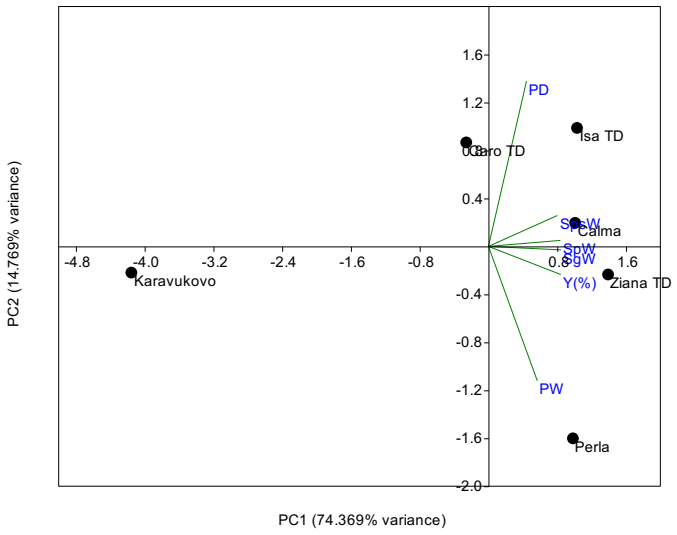

Figure 2. **PCA diagram for the characterization of soybean genotypes in relation to considered parameters**

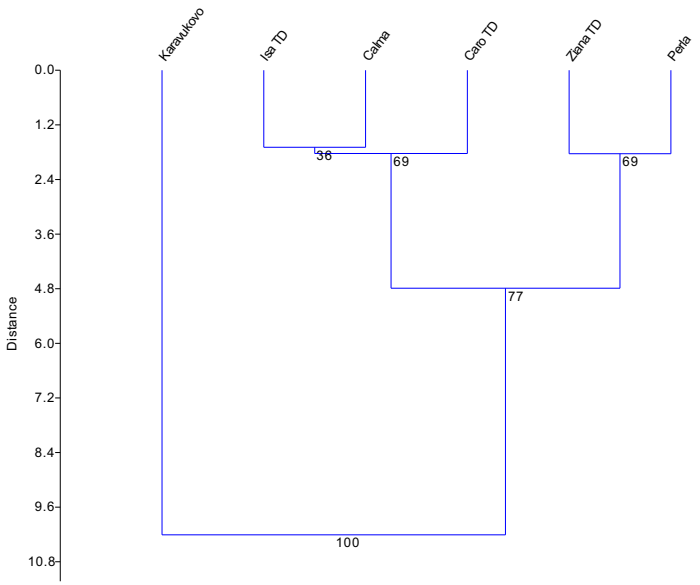

Figure 3. Dendrogram of soybean genotype grouping based on Euclidean distances

The independent positioning of the 'Karavukovo' genotype and the grouping of the other genotypes into two subclusters, based on similarity, were found. Within a subcluster, the genotypes 'Ziana TD' and 'Perla' were associated, and in the case of another subcluster, the other three genotypes, 'Isa TD', 'Calma' and 'Caro TD', were positioned. The level of similarity was also quantified based on the SDI values, presented in table 3. The highest level of similarity was recorded between the genotypes 'Calma' and 'Isa TD' (SDI = 1.6926).

Table 3. SDI values in the case of analyzed soybean genotypes

	'Perla'	'Ziana TD'	'Isa TD'	'Caro TD'	'Karavukovo'	'Calma'
'Perla'		1.8342	4.6806	6.3998	10.1273	5.7965
'Ziana TD'	1.8342		2.9494	4.6246	9.3299	4.2893
'Isa TD'	4.6806	2.9494		1.7490	9.9536	1.6926
'Caro TD'	6.3998	4.6246	1.7490		10.1020	1.9078
'Karavukovo'	10.1273	9.3299	9.9536	10.1020		11.5301
'Calma'	5.7965	4.2893	1.6926	1.9078	11.5301	

For PW, SpW, SgW and Y parameters, the average values were calculated within the experiment and the position of each genotype compared to the average value was analyzed. In the case of the PW parameter, the average value was PW_m = 0.826 kg/m^2. In the case of this parameter, the genotypes 'Calma' and 'Perla' (above mean value) were highlighted, with positive increases, figure 4.

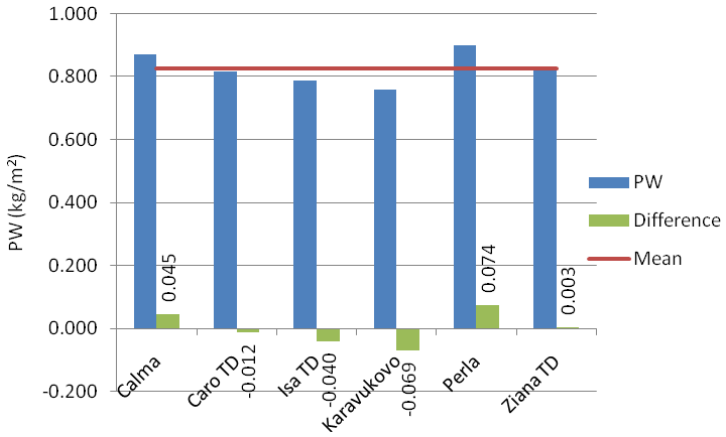

Figure 4. Graphic representation of the average value and the differences in the case of the PW parameter for the soybean genotypes studied

In the case of the SpW parameter, the average value was SpW_m = 0.391 kg/m^2. In the case of this parameter, the 'Calma', 'Isa TD', 'Perla' and 'Ziana TD' genotypes were highlighted (above mean value), figure 5. In the case of the SgW parameter, the average value was SgW_m = 0.246 kg/m^2. In the case of this parameter, the genotypes 'Calma', 'Isa TD', 'Perla' and 'Ziana TD' were highlighted (above mean value), figure 6. In the case of yield (Y, %), the average value was Y_m = 62.269%. In the case of this experimental parameter, the genotypes 'Calma', 'Isa TD', 'Perla' (above mean value), and 'Ziana TD' were highlighted, figure 7.

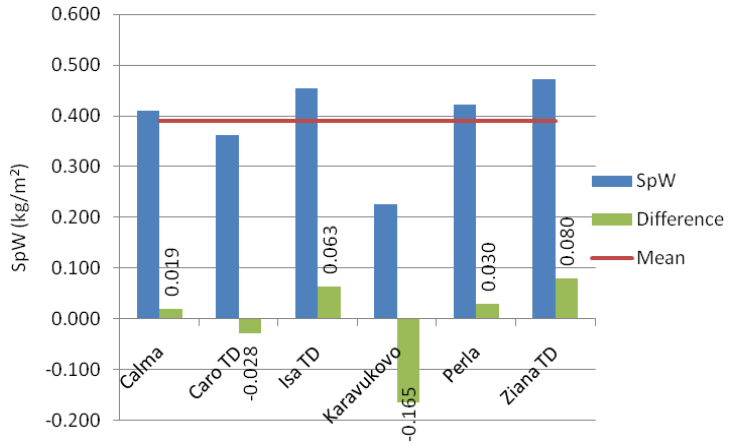

Figure 5. Graphic representation of the average value and the differences in the case of the SpW parameter for the soybean genotypes studied

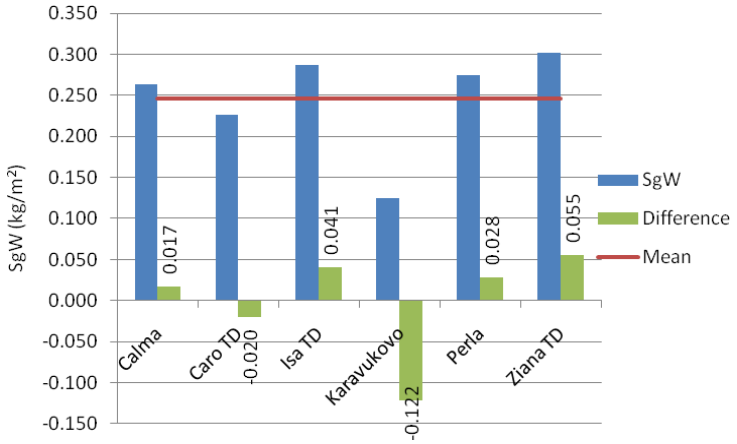

Figure 6. Graphic representation of the average value and the differences in the case of the SgW parameter for the soybean genotypes studied

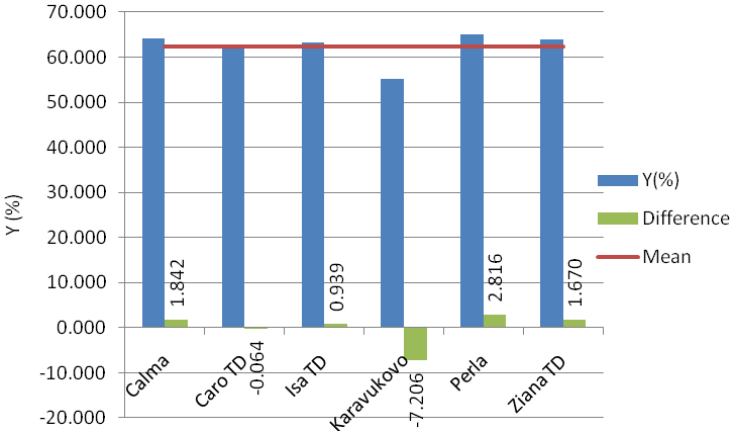

Figure 7. Graphic representation of the average value and the differences in the case of the Y parameter for the soybean genotypes studied

From the analysis of the experimental data, it was observed different variability of the biometric and productivity parameters considered in the study of the six soybean genotypes. Low values of the coefficient of

variation were recorded for PW (CV = 6.4083), in the case of grain yield in relation to pod weight (Y, %) (CV = 5.8754). Moderate values were recorded in the case of the SpW parameter (CV = 22.7816) and in the case of the SgW parameter (CV = 26.4017), values that show the differentiated response of the six soybean varieties under the study conditions. The moderate variability given by the PW/SpW ratio (CV = 26.5386) also expresses the imbalance recorded between plant weight (biomass) and fruiting (number of pods), in response to growing conditions.

Foliar parameters were analyzed in different soybean genotypes to characterize leaf geometry, useful in morphological characterization and genotype differentiation (Agapie et al., 2020a,b), and the imaging analysis method used was also confirmed in other studies on leaf geometry (Sala et al., 2017).

Differentiated variability was also reported in other studies on soybean varieties, in relation to physiological indices, biometric parameters and seed quality indices (Bheemanahalli et al., 2022). The authors communicated the significant phenotypic variability for flowering, yield and qualitative indices of the seeds. Also, the authors recorded correlations of the oil content with the yield (positive correlations) and with the ripening group of the plants (negative correlations). Positive correlations of the protein were recorded in the plant maturation group.

In the present study, very strong correlations of pod production (SpW) were recorded with grain production (SgW) and yield (Y, %). With plant biometric parameters (PD, PW) the SpW parameter recorded weak correlations (r = 0.420 with PD; r = 0.531 with PW), and these correlation levels confirm the values of the coefficient of variation (CV), in the sense of the plants' response to the conditions environment, and the reduction of fruiting formations.

Variable levels of correlation have been reported in other studies regarding biometric parameters and quality indices in soybeans. Xu et al. (2022) reported negative correlations between the lipid content and the weight of one hundred seeds, and in the case of protein, they observed that the content did not increase with the size of the seeds. Differentiated stability and variability for different soybean traits was recorded in the comparative analysis of 50 soybean varieties and quantified based on the values of the stability coefficients (Liu et al., 2017). The authors of the study also communicated different values of the level of correlation between plant biometric parameters and plant productivity elements, with useful recommendations for soybean breeding programs from the perspective of dedicated yields and high stability.

The present study contributes with the results presented to the databases and information regarding the behavior of some soybean genotypes in non-irrigated system crop conditions, by quantifying the biometric and productivity parameters considered representative in the study conditions.

CONCLUSIONS

The six soybean genotypes responded differently in the culture conditions, non-irrigated system, assessed on the basis of some representative biometric and productivity parameters. Moderate variability was recorded in the case of the SpW parameter (CV = 22.7816), in the case of the SgW parameter (CV = 26.4017) and in the case of the PW/SpW ratio (CV = 26.5386). High variability was recorded in the case of the PW/SgW ratio (CV = 34.4736).

The SgW parameter showed a very strong correlation with the SpW parameter (r = 0.998). Grain yield (Y, %) showed a strong correlation with the SpsW parameter (r = 0.852) and a very strong correlation with the SpW parameter (r = 0.923) and with the SgW parameter (r = 0.944).

According to PCA, PC1 explained 74.369% of variance, and PC2 explained 14.769% of variance. According to the cluster analysis, a high level of similarity was recorded between the genotypes 'Calma' and 'Isa TD' (SDI = 1.6926).

In relation to the experience average, the 'Ziana TD' genotype presented the best value for the SpW, and SgW parameters, and in the case of yield (Y, %), the 'Perla' genotype presented the best result.

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