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Evaluation of soybean accessions (*Glycine max* L.) for pod shattering resistance at ripening

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Abstract

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The resistance to pod shattering is an important trait of the soybean crop, which helps to preserve the yield. This characteristic can be influenced by genotype, as well as by many environmental factors. The careful selection of cultivars resistant to pod shattering, combined with good practices during harvest, can greatly help to reduce the seed losses. The aim of the present study was to evaluate a part of the Bulgarian soybean (*Glycine max* L.) collection, stored in the National gene bank, for its resistance to pod shattering under different humidity conditions. The energy consumed to shattering a single pod and the proportion of pod shattering as a function of the moisture content, were also the subjects of the current study. The highest energy of pod shattering was reported for sample BGR3171, followed by BGR1827, BGR4177 and two Bulgarian varieties (Avigeya and Mira). The lowest energy was found for sample BGR37971. In a moisture range of 12% to 16%, about 60% of the studied soybean samples showed pod shattering. At humidity $w < 8\%$, the proportion of pod shattering reached to 100%. As a result of the study, it was found that the soybean collection has a rich genetic potential for future breeding work in terms of pod shattering resistance.

Keywords: Glycine max L.; pod shattering; resistance; humidity conditions

Introduction

Among the grain legume crops, soybean is of the greatest economic importance due to its high nutritional and industrial value. It is a major source of protein and vegetable oil for humans and animals. With an average yield of 2.2 t/ha, soybean is on the fifth place in distribution after maize, rice, wheat and barley (FAOSTAT, 2010). World soybean production currently stands at 339 million metric tons (FAO, 2020). Soybean yield losses from pod shattering are 37% of total losses, the biggest of any other source of losses. The pod shattering in modern soybean cultivars can be affected by genotype, as well as by many environmental factors. Soybean cultivars differ genetically related to their resistance to pod shattering (Jeschke, 2017; Romkaew et al., 2008). Studies show that pod shattering resistance in soybean is a trait (Caviness, 1969), controlled by multiple genes (Carpenter & Fehr, 1986; Tukamuhabwa et al., 2000). The pod shattering losses can be divided into two components – pre-harvest and those caused by the header of the combine harvester. The physical characteristics of the pod, including length of the pod, thickness of the pod wall, and cell lignification at the junction of the two pod carpels, affect pod-shattering resistance (Dong et al., 2014; Krisnawati & Adie, 2017). The effect of drought on pod shattering can be enhanced by infection caused by the pest *Tetranychus urticae* (Ostlie & Potter, 2012). The high temperatures at the period of maturity can increase pod shattering (Bara et al., 2013). The losses of pod shattering can increase significantly, when moisture of the soybean seed decrease below 11%. Soybean plants dry very quickly after reaching period of maturity. At physiological maturity, grain moisture is above 50%, but for harvest, it should reach 13% in less than two weeks under good drying conditions. By using modern technologies in mechanized harvesting, the losses are about 15% at a grain moisture content of 13-15%. This is achieved with a harvester forward speed of 1.34 m/s and a 25% higher reel peripheral speed (Jin at al., 2019). Determining the optimal technological maturity for mechanized soybean harvesting is difficult. If the conditions differ from the optimal ones, or if have technological problems, losses from pod shattering increase significantly (Gaikwad & Bharud, 2018).

The aim of the present study was to evaluate a part of the Bulgarian collection of soybean (*Glycine max* L.), stored in the National gene bank, in terms of pod shattering in different soybean genotypes under different humidity conditions.

Material and Methods

Plant material

The experiments were carried out in the field of IRGR – Sadovo.

Eleven promising soybean genotypes with different geographical origins from the National Gene Bank of Bulgaria were included in the study (Table 1). Most of the studied genotypes were with foreign origin (BGR 1827, BGR 3317, BGR 4085, BGR 3171, BGR 13735, BGR 38141, BGR 4177) and four of them with Bulgarian origin (BGR 37971, BGR 40899, BGR 40900 and BGR 43585).

Determining the effect of mechanical impact

The consumed energy for shattering of a single pod – ΔT, J; the proportion of shattering pods – D, % depending on the given shock pulse S, kg.m/s and the humidity of the pods w, % were investigated. It was an experimental study and it was conducted according to the existing methodology (Ishpekov et al., 1997).

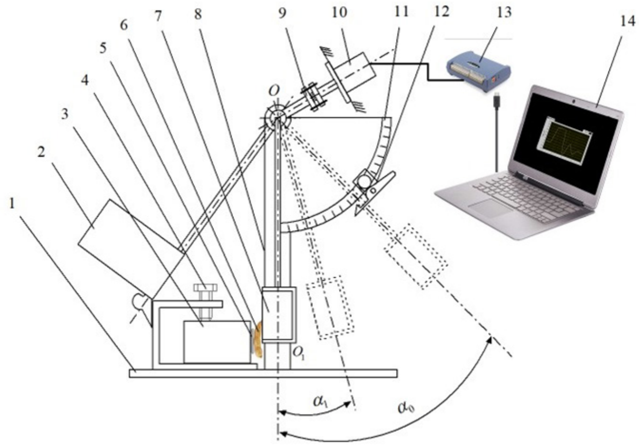

Fig. 1. Schematic of the experimental setup

An existing experimental system was used, consisting of a pendulum apparatus and a data acquisition system (Figure 1) (Ishpekov, 2019). The tested pod – 6 was positioned by double – sided tape 5 on the anvil 3, so that the connection between the two carpels was directed towards the pendulum (Figure 2). It deviated at an angle α_0, it was fixed with the trigger – 12. After a second the pendulum was released and descends to the pod, and after the impact it deviated back to an angle α_1.

The energy consumed for shattering of a pod – ΔT, J was determined according to the generalized inertia moment of the pendulum and the difference between the angle of incidence and the angle of recoil of the pendulum. The mentioned angles were read by the photo-raster converter and visualized by the computer 14. The proportion of the shattering pods D, % was calculated for each variety separately depending on:

$$D = \frac{N_s}{N}.100, \%$$

Table 1. Passport data of soy bean accessions, included in the study

№	Instcode	Bgr №	Year	Cat. №	Genus	Species	Accename	Status	Storage
1	BGR001	1827	1973	731070	*Glycine*	*max*	Foreign	Cultivar Flora	Long term storage
2	BGR001	3317	1976	761750	*Glycine*	*max*	Foreign	Cultivar Hersonskaya	Long term storage
3	BGR001	4085	1973	731059	*Glycine*	*max*	Foreign	Cultivar Norma	Long term storage
4	BGR001	3171	1977	771787	*Glycine*	*max*	Foreign	Cultivar EC137	Long term storage
5	BGR001	13735	1971	71899	*Glycine*	*max*	Foreign	Cultivar Domaca Soja	Long term storage
6	BGR001	38141	2003	A3000533	*Glycine*	*max*	Foreign	–	Long term storage
7	BGR001	4177	1963	63460	*Glycine*	*max*	Foreign	Cultivar Avril	Long term storage
8	BGR001	37971	2008	A8BM0475	*Glycine*	*max*	Local	Cultivar Char	Long term storage
9	BGR001	40899	2001	B0BM0011	*Glycine*	*max*	Local	Cultivar Mira	Long term storage
10	BGR001	40900	2010	B0BM0012	*Glycine*	*max*	Local	Cultivar Srebrina	Long term storage
11	BGR001	43585	2019	B9BM0025	*Glycine*	*max*	Local	Cultivar Avigea	Long term storage

where:

N_s is the number of shattering pods, pcs.;

N – the number of tested pods of one genotype, no.

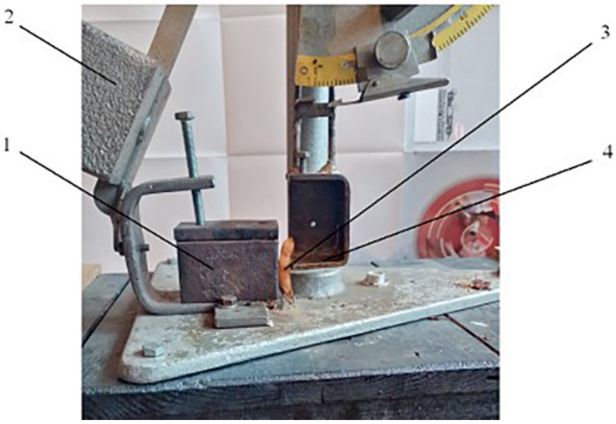

Fig. 2. Measurement of the consumed energy for shattering of a single soybean pod
1 – anvil, 2 – counterweight, 3 – pendulum, 4 – pod

The measurements were carried out at three fixed values of the angle of incidence of the pendulum 5^0, 10^0 and 15^0, at three different grain humidity and in three replications. From the angle of incidence of the pendulum, the impulse and energy on the tested pods were calculated. The energy of the deformation of the tested pod was calculated by the difference between the angle of incidence and the angle of recoil.

The moisture in the grains was determined by weight method (BDS 601-85).

Determining the effect of genetic potential

The phenotypic and genotypic variants were evaluated according to the method proposed by Burton & Devane (1953):

Environmental variance (σ2e) = Mse;

Phenotypic variance (σ2p) = (σ2g + σ2e);

Genotypic variance (σ2g) = Mse – Mst.

Phenotypic and genotypic coefficients of variation:

Phenotypic coefficient of variation $(PCV) = 100\frac{\sqrt{\sigma^2 px}}{x}$

Genotypic coefficient of variation $(GCV) = 100\frac{\sqrt{\sigma^2 gx}}{x}$,

where:

σ is the variance;

p – the phenotypic coefficient;

g – genotypic coefficient;

e – the coefficient of the environment;

x – is the average value of the sample;

Mse – the standard deviation of the environmental conditions;

Mst – the total standard deviation of the experiment.

According to Deshmukh et al. (1986), if the values of PCV and GCV are bigger than 20% are considered high, while values below 10% are considered low and values between 10 and 20% – medium.

Statistical analysis

The obtained experimental data were subjected to the following statistical procedures:

The method of significant differences with visualization of the results by Box and whisker plot for mean, mean ± SD and mean ± 1.96SD (SD – standard deviation). The analyses are conducted using the STATISTIC 12 statistical processing program (STATISTIC, 2012).

Two-factor analysis of variance was used to determine the effect of energy for shattering the pod on the genotype-environment system. The dependent variable was the energy required for shattering of the pods, and the independent variables were the type of genotype and the humidity of the pods.

The results for the proportion of shattering pods and the absorbed energy for shattering of pods depending on the moisture of the grains and the application hit are approximated by the method of least squares at a level of significance α = 0.05. The analyses were conducted using the SPSS 19 statistical processing program (IBM, 2019).

Results and Discussion

The interaction between the studied factors of the experiment is shown in Table 2. The data in the table showed that the angle of deviation had a high degree of variation and affected the energy required for shattering of the pods. The second most important degree of variation was observed for the genotype type and the moisture of the pods as independent factors in the process and had a statistically significant effect on the firmness of the pods.

The phenotypic coefficient of variation (PCV) was 59.8% and the genotypic coefficient of variation (GCV) was 30.4%. According to the argument used by Deshmukh et al. (1992), both coefficients were with high values and reflect the degree of influence of the environment and the genotype on the pod firmness. This indicator and its phenotypic manifestation could be effectively used in breeding process to assess the genetic potential of the materials.

The genetic progress reached a high value (GA = 31.8%), which was an evidence that the studied collection possessed

Table 2. Test for the interaction between the studied objects

Source	Mean Square	Sig.
Corrected Model	3.81	0.000
Intercept	1336.36	0.000
Genotype	3.163***	0.000
Deviation angle	107.545***	0.000
Moisture	3.545***	0.000
Genotype x Angle	1.7454***	0.000
Genotype x Moisture	1.245***	0.000
Angle x Moisture	1.590***	0.000
Genotype x Angle x Moisture	1.340***	0.000
Error	0.00	
Total		
Corrected Total		

valuable genotypes suitable for breeding to pod shattering resistance.

The statistically significant differences in pod shattering energy between the studied soybean genotypes are presented on Table 3. Based on the same experimental data a Box and whisker plot were building (Figure 1). The highest energy for pod cracking was observed in genotype BGR3171, and the lowest one – in BGR37971. Comparative analysis showed that the other genotypes differed from genotype BGR3171 but not significantly (Table 3).

The results from Table 2 and Figure 3 showed insignificant differences in the pod shattering energy ΔT between the studied soybean genotypes. This gives basis for building a generalized model for the tested genotypes.

Figure 4 shows the effect of humidity and shock impulse on the proportion of the pods shattering. At high grain moisture, the proportion of pods shattering was smaller because they had a relatively higher resistance to destruction. With lowing the humidity, the resistance decreased and the pro-

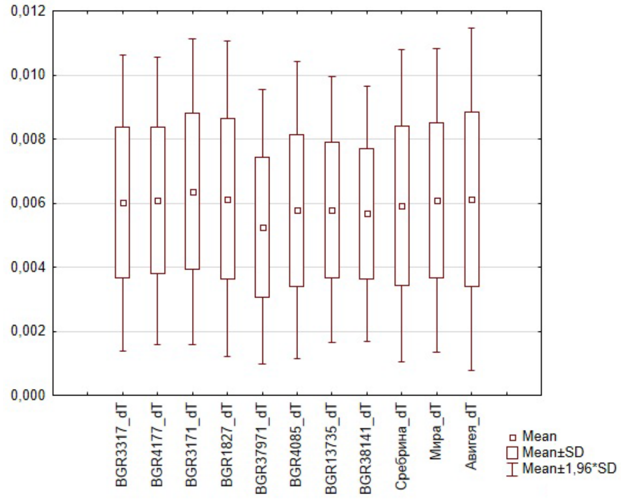

Fig. 3. Box and whisker plot for mean, mean ±SD and mean ±1.96SD (SD – standard deviation) for consumed Energy – ΔT by the tested pod

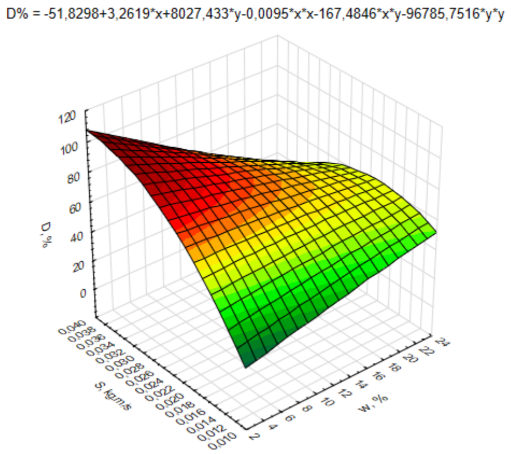

Fig. 4. Proportion of pod shattering D, %, depending on the grain moisture w, % and the shock pulse S, kg.m/s

Table 3. Statistically significant differences for pod shattering energy ΔT between the studied soybean genotypes

	t-value	df	p	Std.Dev. Group 1	Std.Dev. Group 2	F-ratio Variances	P Variances
BGR3171_dT vs. BGR37971_dT	1.024883	16	0.320665	0.002436	0.002185	1.243266	0.765551
BGR3171_dT vs. BGR3317_dT	0.315458	16	0.756491	0.002436	0.002355	1.070057	0.926053
BGR3171_dT vs. BGR4177_dT	0.254786	16	0.802134	0.002436	0.002290	1.131762	0.865309
BGR3171_dT vs. BGR1827_dT	0.198872	16	0.844868	0.002436	0.002510	1.061400	0.934902
BGR3171_dT vs. BGR4085_dT	0.524013	16	0.607452	0.002436	0.002369	1.057180	0.939245
BGR3171_dT vs. BGR13735_dT	0.538385	16	0.597722	0.002436	0.002118	1.322895	0.701733
BGR3171_dT vs. BGR38141_dT	0.653088	16	0.522974	0.002436	0.002034	1.434043	0.622090
BGR3171_dT vs. Сребрина_dT	0.384596	16	0.705600	0.002436	0.002492	1.046638	0.950178
BGR3171_dT vs. Мира_dT	0.246461	16	0.808459	0.002436	0.002422	1.011758	0.987215
BGR3171_dT vs. Авигея_dT	0.205410	16	0.839843	0.002436	0.002734	1.259450	0.752098

portion of pods shattering increased. In the humidity range from 12% to 16%, pod shattering was about 60%. With decreasing the humidity, the carpels become more fragile and at w <8% the share of pod shattering reached D = 100%.

The energy for pods shattering ΔT, J (Figure 5.) increased with increasing the humidity w, % and the increasing of the shock/hit pulse S, kg.m/s. High energy values indicated higher resistance of pods to mechanical impacts. This was observed at w = 12 ÷ 16%. At lower humidity, the energy decreased and the pods become more susceptible to shattering. Obviously, the minimum losses from scattering during the mechanized harvesting should be expected at 12 – 16% humidity. In this range of humidity, the pods of the studied soybean genotypes were ripped and relatively more resistant to mechanical influences.

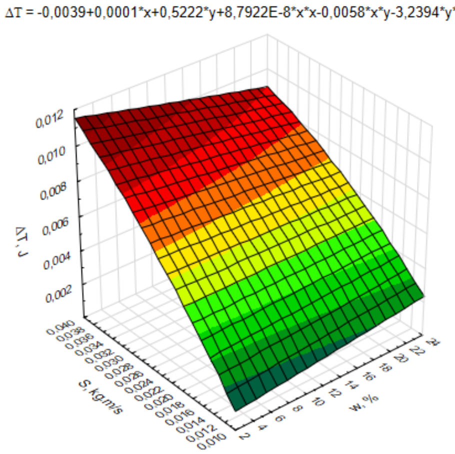

Fig. 5. Graph of the absorbed energy for cracking of soybean pod ΔT depending on the seed moisture w,% and shock pulse S, kg.m/s

The obtained results were fully consistent with the studies of Gaikwad & Bharud (2018). They explained their results with the influence of the variety and the degree of maturity, in which soybean were harvested. These factors had a significant impact on the lignin content in the pod wall. As much as the humidity was higher, the less lignin was deposited in its wall and back their deposition began to increase along with humidity decrease in the walls. The increased lignification increased the pods shattering. Similar results have been reported by other authors – Moore & Jung (2001), Roberts et al. (2002) and Romkaew et al. (2008). Gaikwad & Bharud (2018) found that bothenzymatic activities, cellulose and polygalacturanase in both areas (shattering and non-shattering) of pod walls were increased after physiological maturity. The polygalacturanase activity in the shattering zone of pods showed higher activity in resistant and tolerant to pod shattering genotypes and lower activity in shattering zones in sensitive varieties. The cellulose activity in the pod shattering zones showed reduced activity in resistant and tolerant varieties and increased activity in the shattering zone of sensitive soybean genotypes.

Conclusions

Several accessions with high energy of pod shattering were selected – BGR3171, BGR1827, BGR4177 and varieties – Avigeya and Mira.

The highest absorbed energy for destruction of soybean pods was observed the humidity of 12 – 16%. In this range the pod shattering did not reach maximum values and it was in the order of 60%. With lowing the humidity, the resistance of the pods shattering decreased. It reached 100% at humidity w = 8% and values of the shock pulse S> 0.038 kg.m/s.

The present study evaluated the resistance of pod shattering in some soybean genotypes and provided rich information for determining genotypes suitable for mechanized harvesting.

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