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SOYBEAN VARIETIES ASSESSMENT BASED ON DEGREE OF INJURY AND SEED QUALITY FOR BIOLOGICAL TRAITS IN PRIMARY AND ELITE SEED PRODUCTION

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SUMMARY

Best-quality seeds of high-yielding commercial cultivars are the foundation of the future harvest in all crops. Significant seed damage arises from seed injury during harvesting and tillage. With the use of machinery in all harvesting and processing stages, the issue of seed injury has become severe. Therefore, the presented research sought to determine commercial soybean seeds' properties and seeding qualities, depending on the cultivar properties and the influence of machinery used in harvesting. The identified degree of soybean seed injury of commercial soybean cultivars depends on the growing strength after harvesting with drum threshing combined with the harvesting equipment's influence. Based on biological characteristics, the soybean cultivars differed significantly in the number of damaged seeds during harvest using the drum thresher type 'Sampo SR 2035'. However, the soybean cultivar Birlik KV showed the minimum seed damage (49.5%), whereas the cultivar Zhansaya had the most seed injuries (83.0%). According to laboratory tests, high intensity of initial growth resulted in seeds of soybean cultivars Birlik KV (86.0%), followed by Perizat (82.0%), and Lastochka (78.0%). Seeds of the soybean cultivars Ivushka and Zhansaya had the lowest growth strength (52.0%–60.0%). The most injury-prone soybean cultivar Zhansaya exhibited 21.3% crushed and inured seeds when their threshing used a drum thresher, but when threshed with a rotary thresher, the number of damaged seeds decreased to 2.9%. For injury-resistant soybean cultivar Lastochka, the harvester Sampo SR 2035 produced 12.4% injured seeds, and the harvester 'John Deere' generated 2.2% crushed seeds.

Keywords: Soybean (*Glycine max* L.), cultivars, seeds, sowing qualities, seed injury, seed production, harvesting combines

Key findings: The findings revealed that different soybean cultivars grown under the same conditions gained damage in varying degrees and showed various growth strengths due to varietal characteristics.

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INTRODUCTION

Soybean (*Glycine max* L.) belongs to the genus *Glycine* L. of the legume family Leguminosae and subfamily Papilionoideae. Soybean is the most versatile crop in terms of its use in all sectors of the global economy (Statista, 2022). The main advantage of soybean is its high content of complete vegetable protein and oil, used for food and various roles in the food industry and other technical purposes (Alam *et al*., 2019; Hanafiah *et al*., 2023).

Global soybean production is increasing annually, with a planted area of 131.04 million ha in 2021–2022 and an average yield of 2.71 t ha^{-1} (Statista, 2022)**.** The USA, Brazil, and Argentina currently lead soybean-producing countries, accounting for 80% or more of the world's soybean production. Over the past 10 years, the soybean area in Kazakhstan has grown by more than 2.5 times from 53,600 ha in 2009 to 123,500 ha in 2022, and its yield during this period rose from 1.8 t/ha to 2.07 t/ha **(**Bureau of National Statistics, 2022**).** The Republic of Kazakhstan currently has 66 soybean cultivars registered in the State Register of Breeding Achievements, 20 of which were allowed for use, developed through domestic breeding by the Kazakh Research Institute of Agriculture and Plant Growing LLP, Almalybak, Kazakhstan (State Register, 2022).

High-quality seeds of promising cultivars are the foundation of the future yield in all crops. These genotypes carry the complete genetic information of the cultivars and have a complex of biological, physical, mechanical, and biochemical properties, which determine the seed yield and efficiency of technological methods of cultivation in production. The requirements for seed quality must be very high (Tsukanova *et al.,* 2017). Seed quality refers to the seed value, characterized by several traits (physical purity, moisture, 1000-seed weight for seed rate, germination energy, germinability, and initial growth strength) and the realization of the biological potential of the cultivar, i.e., yield (Kudaibergenov *et al.,* 2017).

In seed production, in addition to general organizational and agronomic measures, it is also necessary to apply several specific cultivation techniques that are less required in conventional production (State Standard, 1974). These measures ensure high varietal purity, high seed quality, and an improved multiplication rate. Producing healthy seeds can materialize if agronomic practices, including the best predecessors, high-quality seed, optimum sowing dates and methods, spatial isolation, appropriate agricultural background, harvesting and post-harvest handling (threshing, sorting), and efficient production organization are present (Nechaev, 2010). It is also a well-known fact that soybean yield depends largely on seed quality, which varies considerably depending on the cultivar, growing conditions, and farming practices (Oborskaya, 2009; Durnev and Yatchuk, 2014; Shpilev, 2016).

Significant seed damages result from seed injury during tillage and harvesting. With the use of machinery in all seed harvesting and processing stages, seed injury has become an urgent issue. Various machines are now widely available for threshing, transport, grading, and other processes, and the percentage of injured seeds can be as high as 93%–96%, which causes significant losses to yield **(**Seed Injury, 2019**).** According to agronomic requirements, seed grain degeneration should not exceed 1%; however, in most cases, it varies between 2% to 10%. As the crushing increases, the number of seeds with micro-damage also increases, which is not feasible for seed production as it is impractical to separate by cleaning and sorting machines. The moisture content of the seeds has a crucial influence on seed damage during threshing. Each crop has an optimum moisture range, where minimal seed damage occurs, and it requires accounting when harvesting seed crops (Fadeyev, 2012).

Seeds with low and high moisture injure easily, hence, their immediate harvest at optimum moisture depends on the zone and crop (between 12%–20% for legumes) (Seed Injury, 2012; State Standard, 2005). The extent of reduction inflicted on seed germination, initial growth intensity, and ultimately yield depended on the nature of seed damage. Past studies reported that depending on the degree of injury, the seed yield decline reached 0.3 tons per hectare (Strona, 1972).

Factors of seed injury during harvesting and threshing

a. Seed properties - crop cultivar, yield, grain-to-straw ratio, moisture, grain size, 1000-seed weight, stem weediness, maturity stage, and harvesting method.
b. Technological settings for the threshing unit and other threshing machinery drum speed, threshing clearances, cleaning adjustment, augers, and elevators.
c. Mode of operation of the threshing units - number of ears fed into the threshing unit, ears' position in the bread mass, and how evenly feeding the grain and the ears over the drum length.
d. Design features of the threshing drum - type (beater and pin), drum parameters (number and diameter), beaters' design (number and reef direction), concave design (drum coverage angle), and implementation of the material.
e. Technical condition of the threshing elements - wear and tear of the tine bars and the technical condition of the augers and elevators.
f. The harvester's skill - experience, knowledge, and attention (Shpilev and Prachik, 2014; Novitskaya and Martynov, 2018).

The fact that the injury's effects are not always immediately apparent and are unknown heightens risk, allowing other causes of yield reduction to occur. The mineral nutrition background of soybean markedly influences its seed injury during harvesting and threshing. The number of injured seeds increases at a 1.3% increase in the dose of mineral nutrition. It is necessary to use the calibration machine 'Sad-10-01' to guarantee high-quality seeds of soybean, which will significantly enhance the seed germination energy (6.7% to 21.8%) and seed germinating ability (5%–20%) (Bragina *et al.,* 2018).

Rapid, non-destructive methods for measuring germination and seed vigor are valuable. For germination and vigor, qualitative models provided better discrimination between high and low seed lots versus quantitative ones (Al-Amery *et al.,* 2018; Boelt *et al.,* 2018). High yields with good quality mostly come from sowing seeds in good sowing conditions. However, seed quality depends on seed purity, germination, germination energy, moisture, and free from diseases and pests. The parameters that determine a good harvest are the number of plants per area, the number of productive stems, 1000-grain weight, and all other stages responsible for these, and thus are controllable.

Seed quality can be regarded as an integral part of seed yield with good quality, although it has an independent value and is currently the only criterion for seed evaluation. In assessing seed-sowing properties, the size of seedling organs, particularly the length of roots and their number, considerably impacting the index of field germination, power, and friendliness of seedlings, are unaccounted for (State Standard 12038-84). The rate and nature of root growth are determining indicators of the potential of the future plant, vital for evaluating seed material in the early stages of plant growth and development.

The intensity of initial seed growth is a pertinent indicator of seed viability, mainly influencing subsequent plant growth and development. Despite seed vigor potential in seed evaluation, a universally accepted method has yet to exist for such indicator's accurate determination in the laboratory and field conditions. Thus, growth vigor chiefly characterizes the seed quality, i.e., the ability of seeds to germinate quickly and rapidly and grow intensively in the field. Germinating seeds under controlled conditions determined this through a method expressed as a percentage of sturdy seedlings to the total number of seeds in the sample. Therefore, the presented research aimed to determine commercial soybean seeds' properties and seeding qualities, depending on the cultivar properties and the influence of machinery used in harvesting.

MATERIALS AND METHODS

Genetic material and procedure

The choice of five commercial soybean cultivars comprised Lastochka, Zhansaya, Birlik KV, Ivushka, and Perizat for their immediate study. The varietal traits of all the soybean cultivars are in Table 1. Sowing transpired in the third day of April, with a plot size of 25 m^2, seed rate (600,000 pcs/ha), row spacing (30 cm), and seed embedding depth (4 cm). The soybean cultivars at random had four replications. Agro-technological measures proceeded following generally accepted methods and recommendations for the study area (Kudaibergenov and Didorenko, 2014). The arrangement of the experiment, cultural practices, fertilizers and irrigation, harvesting, and eventually, the yield formulation ran as per soybean recommended production technology and according to Dospekhov field experiment methodology (Dospekhov, 2012).

Harvest on soybean plots began with 'Sampo SR 2035,' combined at 12%–13% seed moisture. Seed sampling followed the State Standard 12036-85 (1985). The strength of growth determination occurred on day 10 of germination in roll, and the degree of seed injury was by staining in aniline dye. Two samples of 100 seeds each, taken from the freshly threshed portion of each cultivar, got placed in a beaker filled with tint and then shaken. The concentration of the solution was 1%. After a minute, with the solution drained, the seeds gained rinsing with water several times (until the water staining had disappeared), and spread out on filter paper. The seeds' screening and arranging followed according to the type of injury.

Two production plots of the soybean cultivars Lastochka and Zhansaya received harvesting with two types of combines: Sampo SR 2035 combine with the drum-type threshing and the 'John Deere 3070' rotary thresher combine at 12%–13% seed moisture. Seed quality determination followed generally accepted State Standards, i.e., cultivar purity and waste (State Standard 12037-81, 1981), laboratory germination (State Standard 12038-84, 1984), 1000-seed weight (State Standard 12042-80, 1980), seed humidity (State Standard 12041-82, 1982), and seed viability (State Standard 12039-82, 1982) (State Standard, 2005). All the recorded data of the various parameters underwent statistical analysis using an open-source R software environment (https://cran.r-project.org/) and MS Excel.

Table 1. Morphological, yield, and quality-related traits of soybean cultivars.

Varieties	Plant height (cm)	Growth type	Pubescence color	Corolla color	Seed color	Hilum color	1000-grain weight (g)	Maturity group	Vegetation period (days)	Yield (t/ha)	Protein (%)	Oil (%)
Lastochka	95-105	Semi-determinant	Grey	White	Yellow	Brown	170-175	III	135-145	3.5-4.0	38-39	19-20
Zhansaya	90-100	Semi-determinant	Brown	Purple	Yellow	Black	170-175	II	120-125	3.9-4.5	40-41	19-20
Birlik KV	60-70	Semi-determinant	Brown	White	Yellow	Black	180-190	0	105-110	2.3-2.5	40-42	21-22
ivushka	60-70	Semi-determinant	Brown	Purple	Yellow	Light brown	175-185	00	90-95	2.0-2.4	43-44	21-22
Perizat	85-95	Determinant	Grey	Purple	Yellow	Yellow	160-165	I	118-123	3.1-3.5	41-42	19-20

RESULTS AND DISCUSSION

Based on the nature of the seed damage, reduction, to a greater extent, may occur in seed germination and the strength of initial growth. Low germination results surfaced in sparse seedlings with less plant population, unequal distribution of the feeding area, and consequently, a decrease in the crop's yield and quality. The laboratory studies showed that during harvesting with drum threshing, the soybean cultivars differed significantly in the number of damaged seeds depending on their biological characteristics. However, the less damaged seeds appeared with the cultivar Birlik KV (49.5%) and by types of injuries, i.e., macro- and micro-seedpods, macro- and micro-injuries of the seed coat with low ratios emerged (5.5%–6.5% and 4.5%–33.5%, respectively). The soybean cultivar Zhansaya's seeds had the maximum injuries (83.0%), showing more seed coat macro-injuries (10.5%) and seed coat injuries (25.5%). A high percentage of damaged seeds with macro- and micro-seed coat injuries also occurred in three other soybean cultivars, and macro-seed coat injuries ranged from 13.5% (cultivar Lastochka) to 21.0% (cultivar Perizat), and the micro-seed coat injuries ranged from 34.5% to 51.5% in the cultivar Ivushka (Figures 1 and 2). Studying the varietal specificity of the degree of soybean seed damage also indicated the minimum damage to seeds was in soybean cultivar Cassidy (28%–35% - Canada), whereas the highest was in cultivar Luch Nadezhda (52%–70% - Russia) (Oborskaya and Ran, 2017).

In assessing the sowing properties of seeds (laboratory germination), the size of the seedling parts, particularly the number and length of roots, mainly impacting the field germination rate, power, and friendliness of seedlings, were unaccounted for. Thus, the power of growth, i.e., the ability of seeds to germinate quickly and amicably, and the intensive progress of plants under field conditions mainly characterized the seeding qualities of soybean cultivar seeds. Germination vigor and germination's drastic reduction can be due to significant seed damages; however, it also depends on the type of damage.

Micro-damage of seeds usually leads to an increase in germination energy due to better access of moisture to the germ; however, it might be a temporary stimulation, and subsequently, these values become the same as those of whole seeds, or even occasionally, a slump also occurs. Notably, injured seeds absorb more water intensively during the first three days after injury, then swell and germinate faster; however, later on, the process falters, and these injured seeds lag behind the whole spores in development (with shorter root and sprout length). Injured pits have weakened, having abnormal seedlings, which are sometimes unable to break through the soil surface, ultimately reducing field germination severely (Seed Injury, 2019).

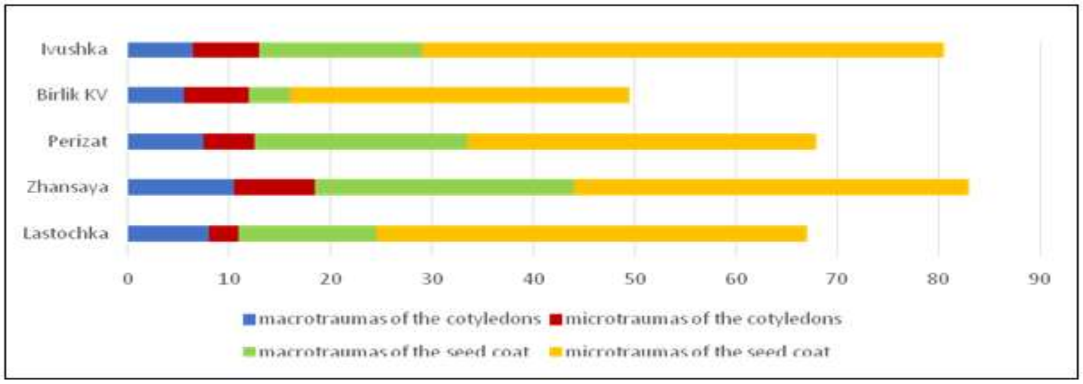

Figure 1. The number of injured seeds of different soybean cultivars, depending on their biological characteristics during harvesting with 'SAMPO SR 2035' (with drum type threshing machine).

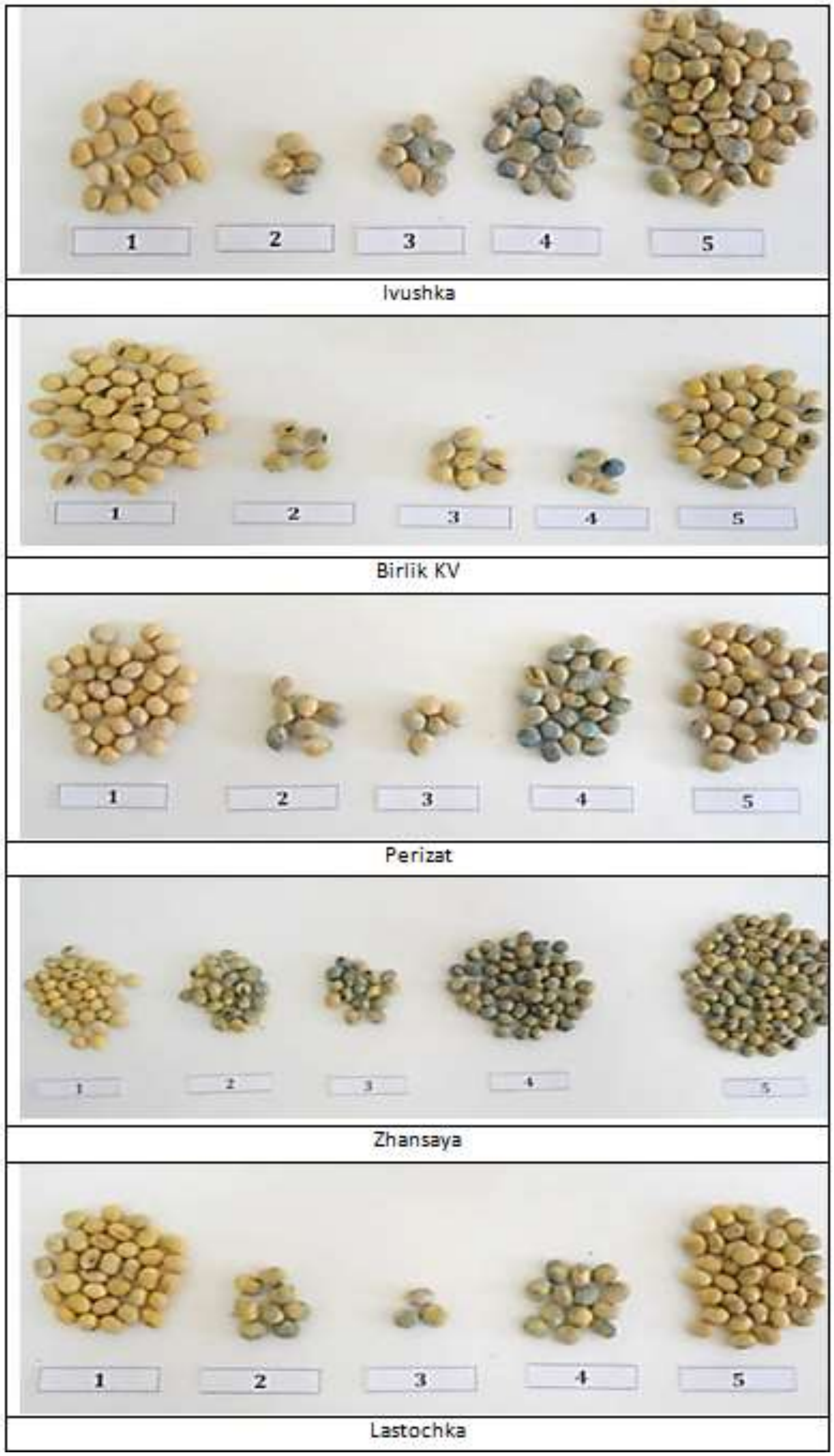

Figure 2. Degree of injury to soybean seeds during production harvesting.
Note: 1 – whole seeds, 2 – macro-injuries of the cotyledons, 3 – micro-injuries of the cotyledons, 4 – macro-injuries of the seed coat, 5 – micro-injuries of the seed coat.

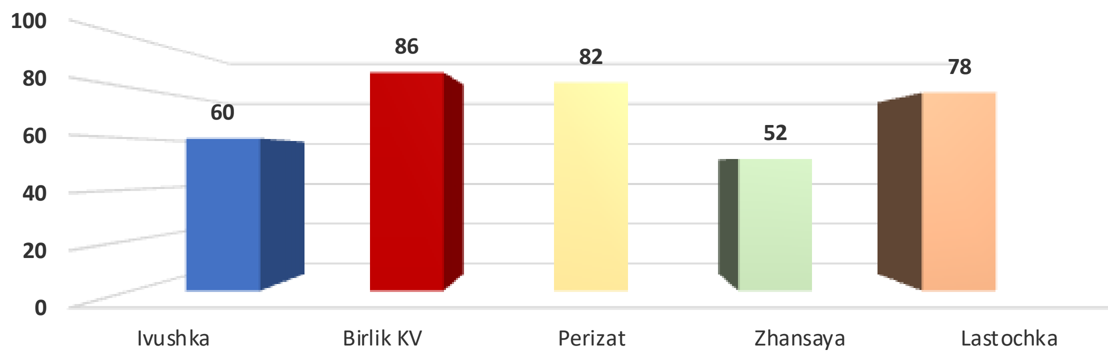

Figure 3. The growing strength of the different soybean cultivars after 10 days of germination (%).

Seed growth vigor determination provides a more effective assessment of seed germination and seedling establishment, affecting the plant yield. According to the laboratory tests results, initial growth with high intensity resulted in the seeds of three soybean cultivars, Birlik KV (86.0%), Perizat (82.0%), and Lastochka (78.0%), with the germinated seedlings dominated by sprouts with 50 lateral roots. The seeds of two soybean cultivars, viz., Ivushka and Zhansaya, had low rates of growth force, ranging from 52.0% to 60.0%, with 20 lateral roots dominating the seedlings at germination (Figure 3). A comparative study of seedlings under laboratory conditions can help predict yield levels under field conditions and formulate recommendations for selecting higher-yielding seed lots. Past studies revealed the impact on germination energy of soybean seeds of cultivar Sultana during harvesting (79%), and its germination percentage was 88%; however, whole soybean seeds of the same variety had germination energy of 90%, with a germination rate of 95% (Novitskaya, 2018).

Forming a resilient root system during the early stages of plant development provides the basis for further growth and development. As soybean plants are dicotyledons, a pivotal root system with a well-defined main root is formed. The chief root length in the studied soybean cultivars after 10 days of germination ranged from 5 to 20 cm. In most studied seedlings, the root length ranged around 10–15 cm. In the soybean cultivars Ivushka and Birlik KV, on average, the extent of the prime root was about 15–20 cm, with no single seedling with a main root length of 5 cm coming out (Figure 4).

Lateral root formation refers to the conduction zone, and the greater the number of lateral roots, the better the supply of absorbable substances to the other organs of the plant. The number of lateral roots ranged from 20 to 50 (Figure 5). The two soybean cultivars, Ivushka and Zhansaya, initially showed low growth strength and had mainly several lateral roots (20). The number of lateral roots in the seedlings of the studied soybean cultivars with high growth strength, i.e., Birlik KV and Lastochka, was proportional, that is, 36.5% - seedlings with up to 20 pieces of lateral roots, 20.3% - up to 30, 17.1% - up to 40, and 26.0% - up to 50 bits. Thus, about 25% of the seedlings of soybean cultivars with high growth strength had an increased number of lateral roots. According to the research, micronutrients can affect the root length, yet without seed pretreatment, the root length of 10-day-old seedlings in soybean cultivars Svetlaya and Kasatka was 14.3 and 9.2 cm, respectively, while with pretreatment of seeds with Nitroammophos + Co, the root length of these genotypes reduced to 8.5 and 6.1 cm, respectively (Kokorina *et al.,* 2015).

The length of the above-ground part under artificial climate conditions does not reflect the field data. This figure had substantial influences from the density of the plants and the competition for light. However,

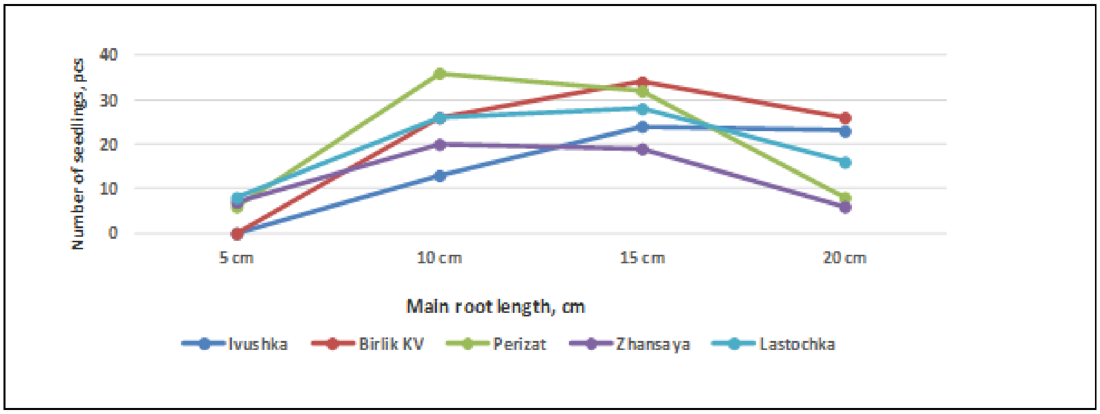

Figure 4. Range of variability of the trait 'main root length' in soybean cultivars after 10 days of germination (pcs).

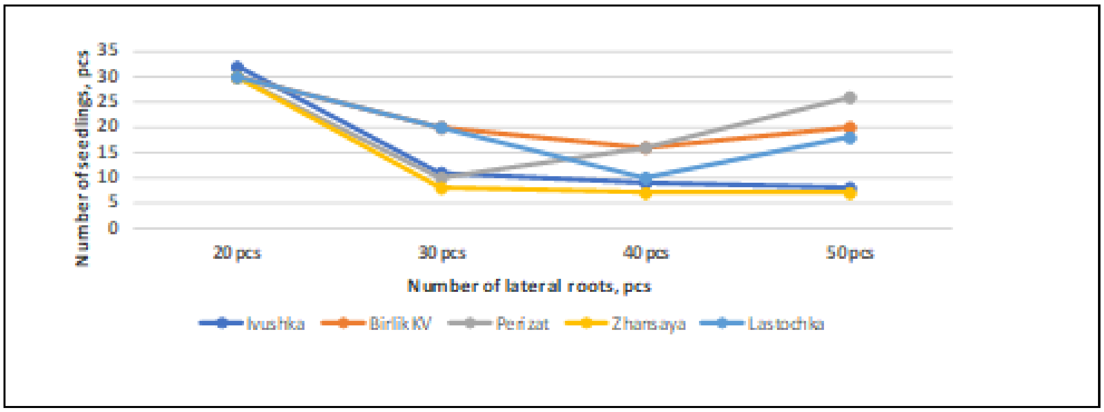

Figure 5. Range of variability of the trait 'the number of lateral roots' in soybean cultivars after 10 days of germination (pcs).

note worthily that most 10-day-old seedlings studied had around 10–15 cm seedling length. In the soybean cultivar Perizat, about 50% of the seedlings were 20 cm long, while in the cultivar Lastochka, 20% were only 5 cm long (Figure 6). The recent experiment has used a new generation of rotary threshing combines to produce high-quality seeds. The 'John Deere combine harvester' is the most popular worldwide. These combine harvesters equipped with ground contour following enabled them to work equally well on sloping and uneven fields, even at night. Soybean plants' development in the initial period gained influence not only by harvesting and threshing equipment and seed treatment, but also by desiccation before harvesting. Without desiccation, the size of 10-day soybean sprouts of cultivar Nega 1 was 18.4–19.5 cm, but with desiccation, the length was 7.7–8.5 cm (Kamanina *et al*., 2017). In the ultra-rapid cultivars Svetlaya and Kasatka, the 10-day-old seedlings were 14.3 and 10.9 cm long, respectively (Kokorina *et al.,* 2015).

Grain harvesters consist with various types of headers. The manufacturer offers several types of cutter bars, i.e., mounted and corn cutter bars, and cutter bars for small grains, straw, sunflowers, and soybeans. The 'S-series' has a rotary threshing system for maximum separation efficiency. Given these factors, it is possible to use this series for wet grain harvesting. For legumes, the threshing is

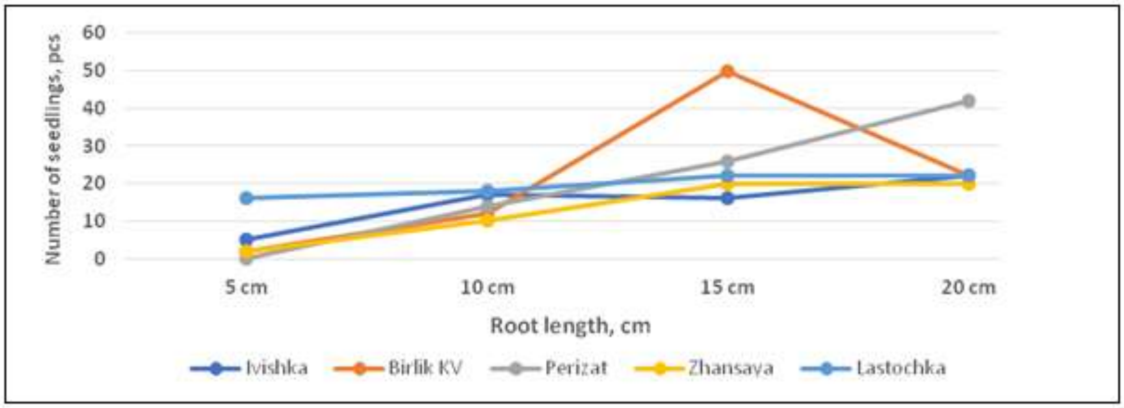

Figure 6. Range of variability of the trait 'seedling length' in soybean cultivars after 10 days of germination (pcs).

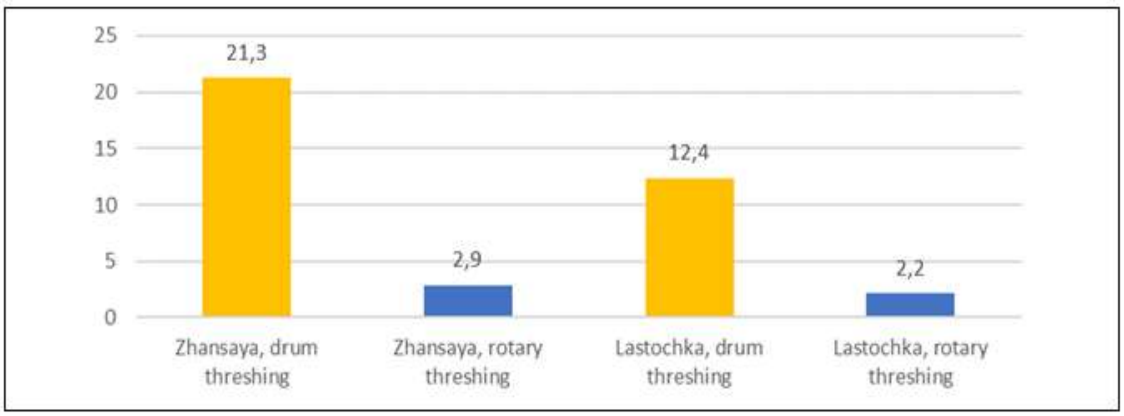

Figure 7. Percentage of crushed seeds in soybean cultivars 'Zhansaya and Lastochka' with different threshing methods.

much gentler, the seeds get crushed to a lesser degree, avoiding micro-injuries.

The soybean cultivar Zhansaya, with its fragile seed coat, when threshed with a drum thresher, showed 21.3% crushed seeds, but when threshed with a rotary thresher, the number of crushed seeds decreased to only 2.9%. The more injury-resistant cultivar of soybean Lastochka, threshed by 'Sampo SR 2035,' yielded 12.4% crushed seeds, and when threshed with 'John Deere,' it gave only 2.2% (Figures 7, 8, and 9). Seeds that appear intact suffer seed coat and seedpod injury during threshing. The staining with special dyes reveals macro- and micro-injuries. Analysis of spores at different types of threshing indicated that the share of injured seeds was lower with rotor threshing. Moreover, this type of threshing reduces the extensive form of injury, the cotyledon injury, by a factor of 4-5 (Figure 10). In past research, soybean cultivars harvested with different types of harvesters, i.e., Amur-Lida 1300, Tucano 430, Vector 450, and Palesse 812, and the cultivars with spherical seed shapes, i.e., Dauria and Luch Nadezhda, showed the maximum damage, with the cultivar Dauria having an injury of 49% with Tucano and Vector harvesters, and 58% with Palesse 812 harvester. Meanwhile, cultivar Luch Nadezhda had 48% injury with harvester Vector 450, and the Canadian soybean cultivars Cassidy and Saska, with their elliptical seed structure, have the minimum damage (Oborskaya, 2021).

1 2

Figure 8. Soybean cultivar 'Zhansaya' harvested with a drum (1) and rotary (2) thresher.

1 2

Figure 9. The soybean cultivar 'Lastochka' harvested with a drum combine (1) and rotary (2) thresher.

Analysis of seed injury shows that with rotary threshing, the number of seedling macro injuries in cultivar Zhansaya was 1.7% against 8.0% with drum threshing, and in cultivar Lastochka, the value was 1.3% against 5.3% with drum threshing. The number of whole seeds in the cultivar Zhansaya increased by 6.4% and in the cultivar Lastochka by 5.0% with rotary threshing compared with drum threshing. In general, the seed quality of soybean cultivars Zhansaya and Lastochka was at the same level when harvested with a rotary thresher, even though the seed coat of Zhansaya was lesser robust than Lastochka (Figure 11). Rotary threshers have become particularly popular in areas with variable weather conditions and rain during harvesting.

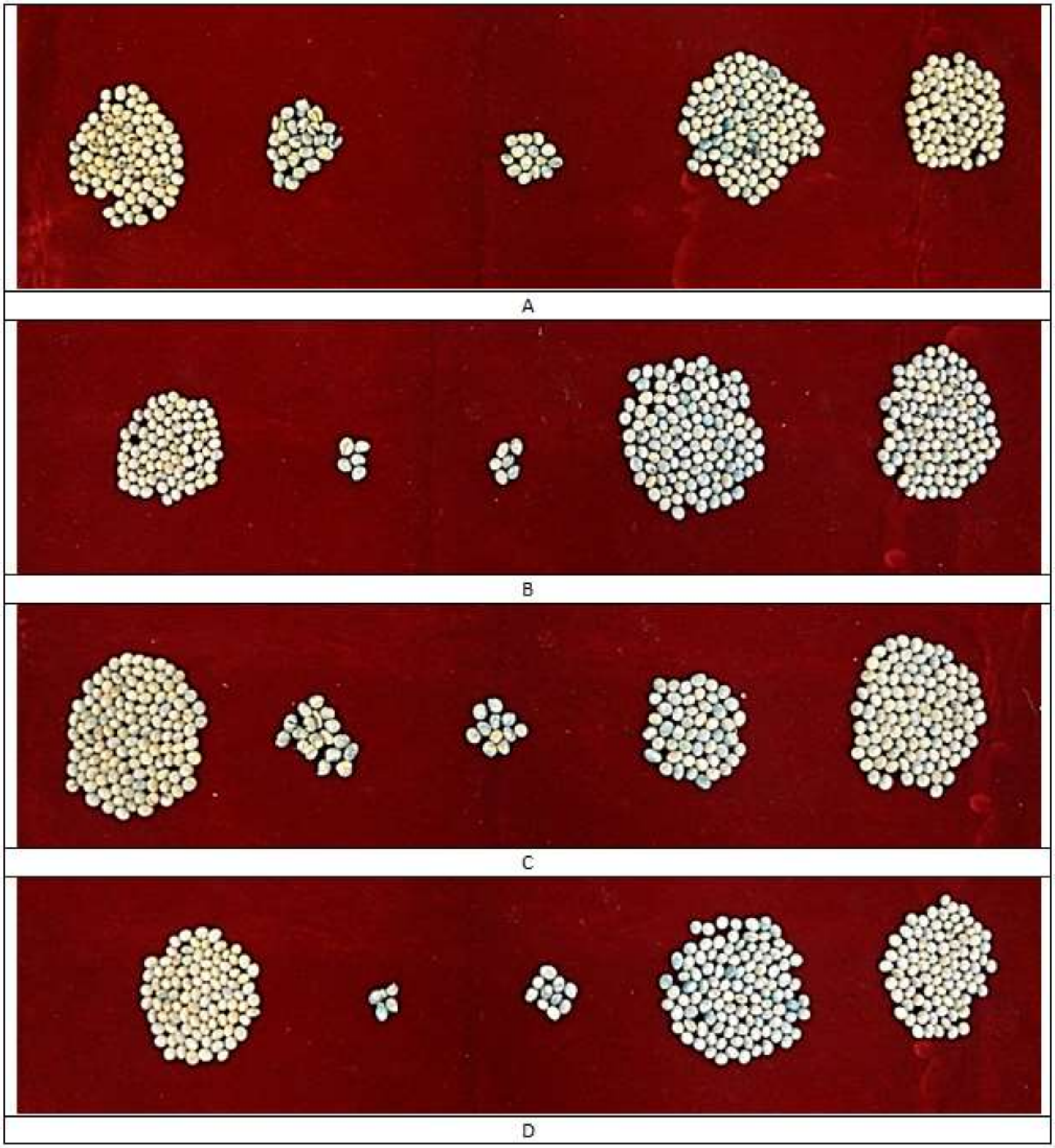

Figure 10. The degree of injury to seeds of soybean cultivars, a) Zhansaya and c) Lastochka by drum threshing, and in cultivars b) Zhansaya and d) Lastochka with rotary threshing.
Note: 1 - whole seeds, 2 – macro-injuries of the cotyledons, 3 – micro-injuries of the cotyledons, 4 – macro-injuries of the seed coat, 5 – micro-injuries of the seed coat.

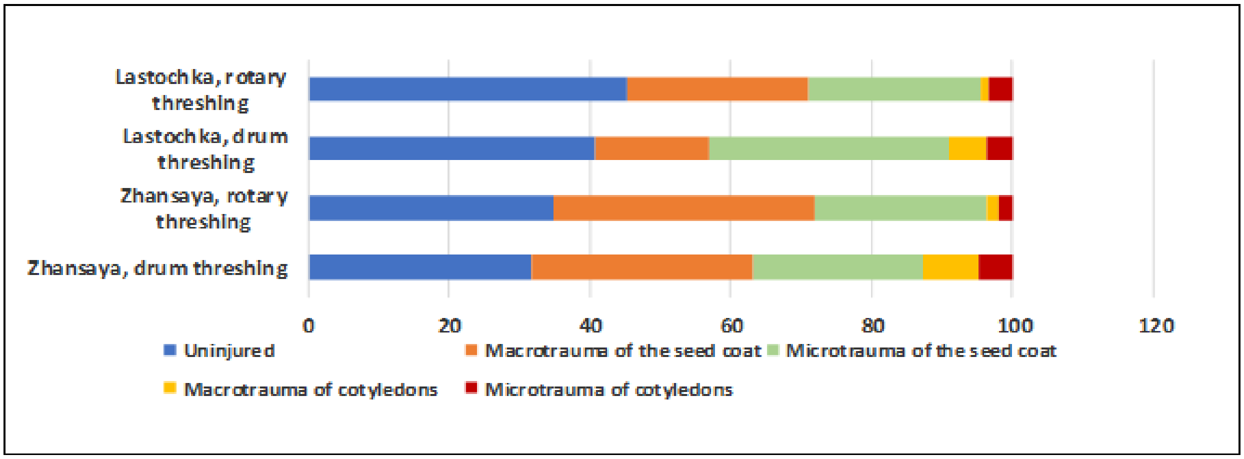

Figure 11. Degree of cotyledon and seed coat injuries with drum and rotor threshing (%).

CONCLUSIONS

According to this research, the results showed that different varieties have different degrees of injury. Thus, seed sorting is according to the degree of coverage with a thin seed coat and the damages it acquired to a greater extent during threshing. This fact was remarkably different when obtaining high-quality seeds with higher reproduction in seed creation. After soybean harvest in ordinary farms, the seeds are sold as marketable grain, regarding seed injury as less valuable. However, in seed farms, soybean seeds obtained after harvesting go through the stages of seed preparation for sowing in the next season. In this case, the presence of macro and microtrauma affects the sowing qualities of seeds. The study recommends harvesting soybeans with John Deere combines with a rotary threshing type to maintain the high quality of seed material in seed farms. A new machine costs around USD 300,000, but its high availability and resistance to wear and tear ensure a good return on investment during its lifetime. Using this new generation of machinery is essential for producing high-quality seeds in soybean crops.

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