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THE EFFECT OF ELECTROSTATIC FIELD ON SOYBEAN SEED GERMINATION PARAMETERS

UTICAJ ELEKTROSTATIČKOG POLJA NA PARAMETRE KLIJANJA SOJE

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ABSTRACT

The aim of this study was to examine the influence of electrostatic fields on seed vigor (VI), mean rate of germination (MGR) and coefficient of velocity of germination (CVG) of five soybean genotypes. Testing was conducted at the Novi Sad Institute of Field and Vegetable Crops on the seeds of five soybean varieties: Sava, NS 2024, NS 1347, NS 3127, and NS Blackstar. The seeds were exposed to different voltages of direct current (DC): 0 V (control), 3 V, 6 V and 9 V, to which the seeds were exposed for 0 min (control), 1 min and 3 min. The application of DC can be a suitable method for improving VI, MGR and CVG. In addition, the results indicate that it is necessary to adjust the DC treatment (voltage and duration of exposure of seeds) to a particular genotype, since inadequate treatments may deteriorate the quality of seeds.

Keywords: *electrostatic field, vigor index, MGR, CVG, soybean*

REZIME

Cilj rada je bio da se ispita uticaj elektrostatičkog polja na vigor semena (VI), srednju brzinu klijanja (MGR) i koeficijent srednje brzine klijanja (CVG) pet genotipova soje. Testiranje je sprovedeno u novosadskom Institutu za ratarstvo i povrtarstvo na semenu pet sorti soje: Sava, NS 2024, NS 1347, NS 3127, i NS Blackstar. Seme je bilo izloženo različitim vrednostima jednosmerne struje (DC) napona: 0 V (kontrola), 3 V, 6 V i 9 V, u trajanju od 0 min (kontrola), 1 min i 3 min. Nakon toga seme je stavljeno na naklijavanje na temperaturi od 25°C u trajanju od osam dana, a posle toga utvrđene su vrednosti parametara klijanja. Rezultati su pokazali značajan uticaj elektrostatičkog polja na VI, MGR i CVG u zavisnosti od genotipa i napona. Najbolji uticaj na sve parametre klijanja ostvaren je kod genotipa NS 2024. Primenom elektrostatičkog polja od 6 V ostvaren je najbolji efekat kod svih ispitivanih parametara. VI je povećan za 19,75%, dok su MGR i CVG za 5.22% viši u odnosu na kontrolu. Pored toga, rezultati su pokazali da je potrebno utvrditi tačnu kombinaciju napona i vremena ekspozicije za određeni genotip, jer u suprotnom dolazi do značajnog pogoršanja parametara klijavosti semena.

Ključne reči: *elektrostatičko polje, vigor indeks, MGR, CVG, soja.*

INTRODUCTION

Soybean is one of the oldest cultivated plants that has been used in human nutrition for 5,000 years. However, it was only with the development of maritime traffic in the 18th century AD that soybeans slowly became known to other civilizations and appeared in botanical gardens in Europe and America (*Takhtajan, 2009*). The development of industry has contributed to soybeans today being one of the most important industrial plants, from which more than 20,000 different products are obtained (*Davydenko et al., 2004*). In addition to Italy and France, Serbia is among the largest soybean producers in Europe (*Mandić et al., 2017*). Soybean areas have been in an upward trend over the past 10-year period, ranging between 144.000 and 202.000 ha (*www.stat.gov.rs, 2020*). In order to sow such large areas, it is necessary to provide sufficient quantities of varietal seeds of high viability (*Vujaković et al., 2008*). However, weather conditions, and especially the amount and distribution of precipitation at the time of seed formation and filling, can significantly reduce the viability of seeds (*Miladinov et al., 2020a*). Seed viability or vigor is a set of traits that determine the activity and behavior of a batch of seeds of commercially acceptable germination in different environmental conditions (*ISTA, 2006*). The viability of seeds significantly affects the germination, growth and development of plants in the initial stages. Good viability of seeds can have a decisive influence, primarily on achieving an appropriate crop composition and thus on yield (*Srebrić et al., 2010*). Time, rate, homogeneity, and synchronization of germination are also critical issues (*Ranal et al. 2009)* simply because the dynamics of the germination process are indicative of the ecology of any plant species. Therefore, different methods are used to increase soybean seed vigor (*Miladinov et al., 2020a; Miladinov et al., 2020b*). In recent years, increased interest in the application of alternate physical dimensions for seed treatment (*Cvijanovic and Djukic, 2020*). Plant growth, as well as the biological processes of seeds, can be accelerated or inhibited by electric fields. Electrostatic treatment is assumed to enhance seed vigour by influencing the biochemical processes which involve free radicals, and by stimulating the activity of proteins and enzymes (*Morar et al., 1999*).

The present research was conducted to study the influence of 3 V, 6 V, and 9 V DC electrostatic fields on seed vigour, mean

rate of germination and coefficient of velocity of germination of five soybean genotypes.

MATERIAL AND METHOD

Seeds of 5 soybean genotypes: Sava, NS 2024, NS 1347, NS 3127, and NS Blackstar were included in the experiments. Those seeds belong to the collection of the Institute of Field and Vegetable Crops in Novi Sad, Serbia. Soybean genotypes used in this experiment were sown in 2020 on experimental fields at the Institute of Field and Vegetable Crops, to produce the seeds for this experiment. The trial was set up as a randomized block design with 4 replications under the conditions of dry farming. The plot size was 10 m^2. Inter-row spacing of 50 cm and intra-row spacing of 4.5 cm were applied. Soybean seeds were sown in the first 10 days of April. The soybean was harvested with a small plot combine harvester (Wintersteiger, Austria). After basic plot harvesting, seed weight was measured. Seed moisture ranged from 11% to 12%.

The electrostatic field to treat the seeds was generated by using the following equipment. Electrodes (10 cm × 10 cm) were made of aluminum foil. Each electrode was connected to one of the terminals of the DC batteries. The batteries were connected in a parallel connection so that the voltage value at the ends of the electrodes was independent of the resistance created by the soybean seed introduced between the electrodes, i.e., into the electrostatic field. The DC voltages used were 3 V, 6 V, and 9 V. A switch was placed between 1 electrode and the battery terminal so that the circuit between the mentioned electrodes could be interrupted at any moment. The distance between the electrodes was 1 cm, and it was fixed during the experiment in order to preserve a uniform electric field between the electrodes. A voltmeter was placed at the end of the electrode to measure the electrical voltage (Fig. 1). The voltage was monitored during the entire experiment in order to make sure that the electrostatic field between the electrodes was constant (invariable over time).

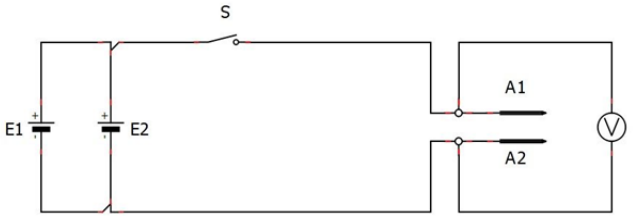

Fig. 1. Representation of electrical wiring (E1, E2 – batteries, S – electrical switch, A1, A2 – aluminum electrodes, V – voltmeter)

Overall, 4 × 100 seeds of each variant and control (untreated seed) were treated. The seeds were placed between the electrodes so that the seeds were placed directly on the electrode connected to the minus terminal of the battery source, and the second electrode (plus terminal of the battery source) was placed at a distance of 1 cm from the first electrode. Electrodes formed a square measuring 10 × 10 cm. Seeds were exposed during either 0, (control), 1, or 3 min to DC.

Seed germination was performed under laboratory conditions immediately after harvest with the standard laboratory method, for 4 × 100 seeds using sand. The incubation period was 8 days at 25°C and 95% relative humidity (*ISTA, 2006*). Every day the germination of the seeds was noted, considering that seeds with 2 mm or longer radicula were considered as germinated.

Mean germination rate (MGR) is the reciprocal of MGT (*Labouriau, 1983*):

MGR=1/MGT.

The mean time required for maximum seed lot germination (MGT) was determined based on the application of the following equation:

$$MGT = \frac{\sum D * n}{\sum n}$$

where is: D - number of days counting from the beginning of germination, n - number of germinating seeds per day D (*Ellis and Roberts, 1981*).

The coefficient of velocity of germination (CVG):

$CVG = 100 \times \sum Ni / \sum NiTi$

where is: Ni = Number of germinated seeds per day Ti = Number of days from the start of the experiment (*Nikolas and Heydeker, 1968*).

A three-way ANOVA was used to test the effect of genotype, electrostatic field and time exposure of seeds using software GenStat (VSN International, UK). When the ANOVA test produced significant results, the LSD's test was used to separate means in different groups ($p \leq 0.05$, $p \leq 0.01$, and $p \leq 0.001$).

RESULTS AND DISCUSSION

ANOVA was carried out considering as main factors: genotype (Gen), the strength of electrical field (applied DC voltage) (EF), and exposure time (ET), and their interactions (Table 1). Vigour index (VI) and mean germination rate (MGR) were significantly affected both by genotype and electrostatic field ($p \leq 0.001$).

Table 1. Analysis of variance (mean squares) for different parameters of five soybean genotypes after applied DC voltage (electrostatic field).

Factors	VI	MGR	CVG
Gen	27.39***	6.36 ***	2.41 *
EF	9.93***	5.89 ***	2.16 *
ET	1.97ns	0.52 ns	0.05 ns
Gen × EF	0.54ns	2.57 **	1.49 ns
Gen × ET	0.12ns	1.55 ns	1.36 ns
EF × ET	0.37ns	0.82 ns	1.01 ns
Gen × EF × ET	0.89ns	0.76 ns	0.87 ns

, **, * Significant at the 0.05, 0.01, and 0.001 probability levels, respectively (LSD test); ns = not significant. Gen: genotype; EF: electrostatic field; ET: exposure time; VI: vigour index; MGR: Mean germination rate; CVG=coefficient of velocity of germination.*

Seed vigor, an important indicator of seed quality, is the first guarantee for maintaining plant population as well as stable yield. High seed vigor determines the potential for rapid and uniform emergence of seed and can increase up to 20% yield (*Tao and Zhen, 1991*). Soybean seed contains higher concentrations of protein and fat than cereal crop seeds, and oxidation of these biomolecules significantly shortens seed longevity and decreases germination ability. Seed vigor loss is common in soybean production (Cao and Cui, 2005). The results presented here show that the application of the electrostatic field can have a significant impact on the vigor of soybean seeds. VI

ranged from 555.65–836.87 with a significant difference between certain genotypes. Genotype NS 2024 had the highest VI while genotype Sava had the lowest VI (Table 2).

Table 2. The effect of the electrostatic field on vigour index (VI), mean germination rate (MGR), coefficient of velocity of germination (CVG) of five soybean genotype

Factors	VI	MGR	CVG
Gen			
Sava	555.65c	0.2051a	20.51a
NS 2024	836.87a	0.2054a	20.54a
NS 1347	657.43b	0.1944b	19.44b
NS 3127	621.72b	0.1902c	19.02c
NS Blackstar	672.17b	0.1941b	19.41c
EF			
0 V	587.22c	0.1942c	19.42c
3 V	667.28b	0.1986b	19.86b
6 V	731.74a	0.2049a	20.49a
9 V	648.05b	0.1919c	19.19c
ET			
0 min	587.22c	0.1942a	19.42b
1 min	653.44b	0.1975a	19.75a
3 min	711.28a	0.1994a	19.94a

Genotype NS 2024 had a 33.60% higher VI compared to genotype Sava. In relation to other soybean genotypes, NS 2024 had a significantly better VI. Otherwise, NS 1347, NS 3127, and NS Blackstar had similar values of VI, ranging from 621.72 to 672.17. Among the applied treatments, the voltage of 6 V had the highest effect on the increase of VI compared to the respective controls. Using 6V, a VI of 731.74 was obtained, which is 19.75% higher than the control. The application of 6V had a significantly higher VI in relation to 3 V and 9 V (8.81% and 11.44%, respectively). Exposure time also had a significant impact on VI. Exposure of 3 min resulted in VI higher by 17.44% compared to the control or 8.13% higher compared to 1 min exposure.

Total percentage germination after a specific period of time does not give a full explanation of the dynamics of germination (*Joosen et al., 2010*). The real potential of seed germination was estimated using a number of parameters (*Singhal and Bose, 2020*). For example, two seed lots can have the same germination percentage but different speeds or uniformity. MGR and CVG are other ways to calculate germination speed and they are widely used by seed scientists and other plant biologists. Generally, it was predicted that a higher germination percentage, higher CVG and higher MGR seed lots have a higher rate of germination. The results of the analysis showed that MGR ranged from 0.1902 to 0.2054 no/day, with a significant difference between certain genotypes. Genotype NS 2024 had the highest MGR, 0.2054 no/day, while genotype NS 3127 had the lowest MGR, 0.1902 no/day. Genotype NS 2024 had a 7.4% higher MGR compared to NS 3127. Genotype NS 2024 also differed significantly from NS Blackstar and NS 1347. MGR was higher by 5.50% and 5.36%, respectively. Among the applied treatments, the voltage of 6 V increased MGR the most compared to the respective control. Using 6V, an MGR of 0.2049 no/day was obtained, which is 5.22% more than the control. The application of 6V had a significantly higher MGR compared to 3 and 9 V. The results showed that the application of the electrostatic field can have a significant impact on the coefficient of velocity of germination. Depending on the genotype, CVG ranged from 19.02 to 20.54%. Genotype NS 2024 had the highest CVG, while genotype NS 3127 had the lowest CVG by 7.40%. Genotypes NS 1347 and NS Blackstar NS 2024 had significantly better CVG than the others. Among the applied treatments, the voltage of 6 V increased CVG the most compared to the respective control. This increase amounts to 5.22%. The application of 6V had a significantly higher CVG compared to both 3 V and 9 V. Exposure time also had a significant impact on CVG. Exposure of 3 min a significantly higher effect on CVG was obtained compared to the control. Such type of increased germination rate and germination percentage due to the application of electricity is attributed to the physiological and biochemical changes (*Celestino et al., 2000*), such as free radical excitement, increase in the activity of proteins and enzymes to increase seed vigor (*Ahmet, 2003*). The mechanism of action of the electric field consists of the activation of macromolecules within the seed and the improvement of the enzyme systems that control germination (*Pittman, 1977*).

A significant difference in the interaction of genotype x electrostatic field is determined for VI (Figure 1). In particular, the application of 6 V VI significantly increased the genotypes NS 1347, NS 3127 and NS Blackstar. Compared to the control, the increase was 14.67-34.67%. There was no significant difference in the interaction between Sava and NS 2024 genotypes. Using 3 V, a significant increase was achieved only in the genotype NS 1347, 22.22%. By applying 9 V, the NS 2024 VI genotype was significantly reduced, by as much as 27.70%. Only in the NS 1347 genotype, there was a significant increase, by 24.62%. *Mamlić et al.* (2021) suggest how the electrostatic field (applied electrical voltage) has the potential to be used as a method to improve germination and initial growth of soybean seedlings, depending on genotype, electrostatic field strength (applied electrical voltage), and exposure time. The same authors point out that it is not possible to talk about the universal application of certain values of electrostatic field and exposure time, because it can happen that it does not correspond to a certain genotype, so the quality of seeds can deteriorate.

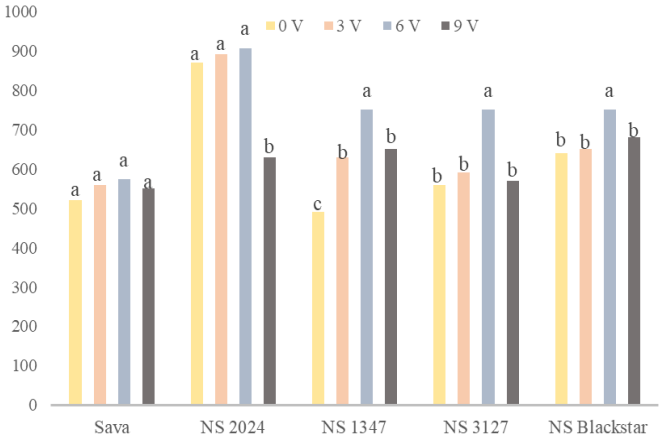

Fig. 1. Effect of interaction between soybean genotypes and electrostatic field on mean germination rate (MGR). Different letters above the bars represent significant differences at the $p \leq 0.05$

CONCLUSION

- The influence of the electrostatic field i.e., the voltage on seed vigor, mean rate of germination and coefficient of velocity of germination soybean seeds depended on the

genotype, strength of electrical field (applied DC voltage), and exposure time.

- The best effect on VI, MGR and CVG was achieved with genotype NS 2024.
- The electrostatic field of 6 V had the best effect on all tested parameters. Vigor increased by 19.75%, while mean germination rate and coefficient of velocity of germination were 5.22% higher than control.
- The 3 min exposure increased VI the most by 17.44% compared to the control).
- Besides the positive influence which electrostatic field may have on germination, it may as well have a negative effect, depending on genotype and other conditions.

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