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Influence of spring wheat seed treatment with low-temperature plasma on growth processes

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Abstract. In the Russian Federation in recent years, fallow lands have been actively put into circulation. On fallow lands a complex of agromeliorative measures is carried out. The demand for high quality seeds for sowing in the newly introduced into turnover lands is also increasing. The purpose of our research is to study the influence of corona discharge of low-temperature plasma on seeds and growth processes of spring wheat. The research was conducted on the basis of the Institute of Artificial Intelligence, Robotics and Systems Engineering KFU To conduct experiments in the laboratory of the Department of Biomedical Engineering and Artificial Intelligence in Biotechnical Systems of the Institute of Artificial Intelligence and Systems Engineering KFU in 2022–2024 developed a scheme and assembled the installation of corona discharge generation of low-temperature atmospheric plasma. The experiments were carried out in tenfold repetition. Seeds were treated with corona discharge at the following parameters: voltage 4 and 8 kV; frequency 0.2 kHz; 0.3 kHz; 0.5 kHz; seed distance from the plasmatron 3 cm; seed treatment time: 20, 25, 30, 35 seconds. Seeds of control variant and variants with corona atmospheric plasma treatment were germinated by roll method in Lamsystem laminar flow cabinet. The data obtained show that at a voltage of 4 kV, the highest growth of wheat seedlings was observed at a frequency of 0.5 kHz and a treatment time of 30 seconds. The length of seedlings for seven days, on this variant of seeds treated with corona discharge on average reaches up to 34.4 cm, and the length on the control variant of the experiment 11.7 cm, which is 22.7 cm shorter. The greatest length of seedlings at a voltage of 8 kV is observed at a treatment time of 30 seconds, where the length of the seedling reaches 36.2 cm, which is 24.5 cm more from the control variant of the experiment.

Keywords: low-temperature plasma, spring wheat, corona discharge, treatment time, voltage.

1. Introduction

Seeds of agricultural crops are living organisms and they are the basis of crop production. High field germination, germination energy, norms and methods of sowing, high percentage of safety before harvesting are the key to formation and obtaining high stable yields with good grain quality. The results of long-term studies usually show that the yield of sown seeds with low germination is about 5–40% lower than that of seeds with high germination [1–3]. Consequently, increasing germination and sowing high quality seeds are of great practical importance in agricultural production.

In practice, several methods are used to improve seed germination, including chemical treatment (chemicals, fungicides, etc.) [4, 5] and physical treatment (ultrasonic treatment, electric field treatment, magnetic treatment, ion beam treatment, etc.) [6–8]. Chemical methods, as a rule, are labour-intensive and expensive, besides, chemical pesticides applied in the process of inoculation on the seed coat contribute to the contamination of soil, groundwater, and they also pose a danger to the working personnel. In recent years, much attention has been paid by scientists and practitioners to physical methods of seed disinfection and protection against harmful pathogens [9, 10]. As physical methods, ultrasonic and ion-beam treatments are used to increase seed germination, electromagnetic treatment, while increasing seed germination, also affects biochemical processes such as protein and enzyme activity [11]. However, these physical methods have negative effects on seeds in addition to their positive effects. For example, strong ultrasonic vibration or collision with an ion beam damages seed cells, resulting in reduced germination under field conditions [12].

Seed treatment with low-temperature plasma is a highly productive, economical and environmentally friendly method of crop seed disinfection, also plasma treatment helps to improve seed germination and rapid seed growth, which contributes to a significant increase in yield. A number of researchers have noted that when seeds were treated with low-temperature plasma, there

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was no destruction of seeds because the active particles penetrated to a depth of only about 10 nm [13, 14]. In addition, no environmental pollutants are emitted after seed treatment with low-temperature plasma, as no chemicals are used for this purpose.

Literature sources indicate that the term ‘NTP’ – (low-temperature plasma, cold plasma) denotes the state of ionised gas at ambient temperature with dominant collective behaviour of charged particles [15]. The common ways to produce NTP are electric discharges (corona, dielectric barrier, radiofrequency, microwave, etc.).

In our research we used corona discharge. Corona discharge (CD) is usually generated by high voltage at sharp electrodes such as tips, spicules or thin wires. An electric field is formed near such points and an active region of corona discharge and plasma generation occurs. The active region of corona discharge appears only near the point electrode and is limited to units of mm. [16].

Wheat is one of the most important cereal crops and is widely grown all over the world as a staple food, the demand for it is constantly increasing as the arable land area decreases and the population increases. In many regions of the Russian Federation, fallow lands have been brought into agricultural turnover in recent years with the active implementation of a set of reclamation measures [17]. Therefore, increasing production, improving the quality of agricultural seeds becomes an urgent problem.

The aim of our research is to study the effect of corona discharge of low-temperature plasma on seeds and growth processes of spring wheat of Arhat variety.

The research was conducted at the Institute of Artificial Intelligence, Robotics and Systems Engineering of KFU in 2022-2024.

2. Materials and methods

The object of research was calibrated spring wheat seeds of Arhat variety without macrocracks and without signs of embryo damage. To conduct experiments in the laboratory of the Department of Biomedical Engineering and Artificial Intelligence in Biotechnical Systems of the Institute of IRSI KFU developed a scheme and assembled a corona discharge generation unit of low-temperature atmospheric plasma. Seeds of the control variant and variants with corona atmospheric plasma treatment were germinated by the roll method in a Lamsystem laminar flow cabinet.

Experiments were carried out in tenfold repetition. Seed treatment with corona discharge was carried out under the following parameters:

- voltage 4 and 8 kV;
- frequency 0.2 kHz; 0.3 kHz; 0.5 kHz;
- distance of seeds from the plasmatron 3 cm;
- seed treatment time: 20, 25, 30, 35 seconds.

3.Results and Discussion

The high voltage was selected in such a way as to prevent arc discharge between the needle of the upper electrode and the base. Corona discharge was ignited starting at 2 kilovolts. Depending on the distance between the electrodes, arc discharge did not occur up to 4–8 kilovolts, so the operating voltage at the electrodes was set within 2–8 kilovolts.

From literature sources it is known that the greatest effect of low-temperature plasma on seeds was observed at duration $t \approx 30$ sec, so the time of exposure of seeds was chosen [16].

The biological effect of low-temperature corona discharge plasma is multicomponent. The main ones are: flow of electrons and ions, free radicals, ultraviolet radiation, which acts stimulatingly on seeds, ozonisation of air. These components contribute to enhancing the biological activity of the seeds. Plasma treatment increases germination, seeds become highly resistant to external stresses. Sprouts become more uniform, plants are less susceptible to diseases and are able to resist weeds.

The main part of our plant is a high-voltage power supply unit, which allows us to supply the corona discharge electrodes (CD) with a voltage of up to 12 kilovolts.

The unit is a complex of the following assemblies:

1. Laboratory autotransformer for changing the corona discharge voltage;
2. High-voltage step-up transformer (50 Hz);
3. Voltage multiplier on 0.1μF high voltage capacitors;
4. Resistor voltage divider block with a microamplifier for measuring the output voltage;
5. Corona discharge electrode block (Fig. 1).

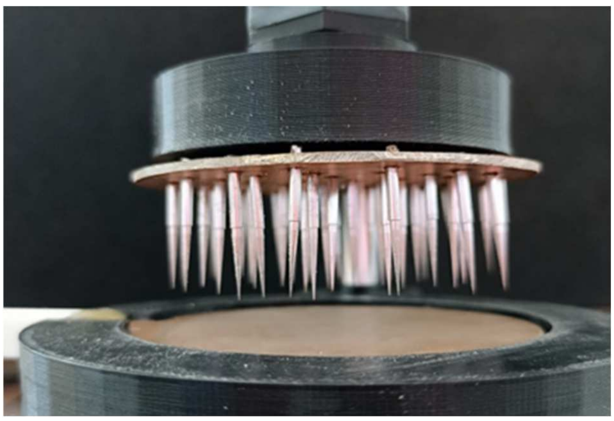

Fig. 1. Corona discharge electrode unit

Gas-discharge low-temperature plasma contains various charged (ions and electrons), neutral (molecules and atoms) particles and activation products of plasma-chemical reactions, X-ray and ultraviolet radiation. Plasma can oxidise various microorganisms and destroy not only their shells but also the DNA of viruses and bacteria [18].

To produce an electric discharge in a gas, a high electric field strength (30 kV/cm for air) is required. In corona discharge, high electric field strength occurs near pointed electrodes, the small radius of which provides dense force lines of the electric field.

In a strong electric field, an electron, which appeared during accidental ionisation of a neutral molecule, is accelerated in the electric field and acquires energy sufficient to ionise it when colliding with the next molecule. As a result, there is an avalanche increase in the number of charged particles (Fig. 2).

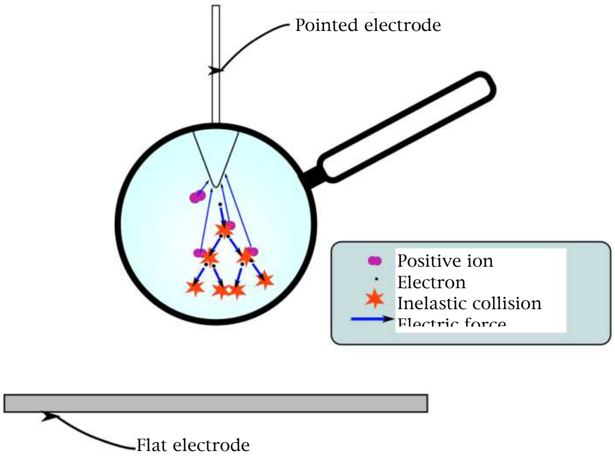

Fig. 2. Avalanche increase in the number of charged particles

The particles accelerated in the electric field of the corona discharge have energy and, consequently, wavelengths characteristic of the UV part of the light spectrum. Short-wave ultraviolet radiation destroys microorganisms by breaking their DNA and RNA.

The predominant decay products of corona discharge plasma in air are nitrogen dioxide NO2 and ozone O3. These reagents have bactericidal and fungicidal properties, which determines the action of corona discharge in seed treatment [19].

To produce plasma using corona discharge, an electric current source with a voltage of 2–10 kilovolts and an electrode system in which the electrodes have a large curvature are required. To carry out the research, a constant voltage source with a regulated output of 2–10 kilovolts and a unit with needle electrodes for corona discharge treatment of seeds were designed and fabricated.

A low-frequency power supply circuit was selected, which is characterised by simplicity and reliability. The disadvantage of the low-frequency unit is the large size, because it is necessary to use high-voltage capacitors of large capacitance. Nevertheless, the low-frequency circuit was chosen because large dimensions are not important for a laboratory unit. The block diagram of the setup is shown in Fig. 3.

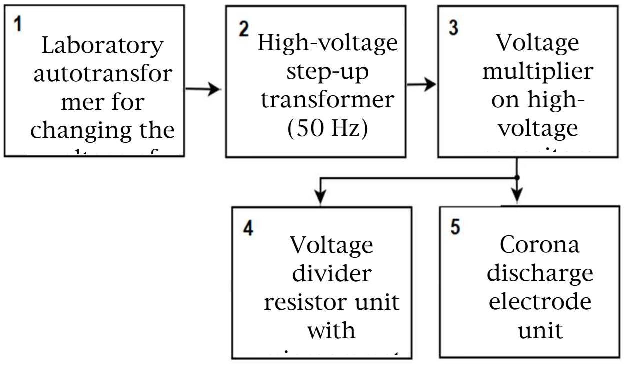

Fig. 3. Block diagram of the installation

The mains voltage is fed to a laboratory autotransformer, then the regulated voltage is fed to a high-voltage transformer, which increases the voltage by a factor of ten.

The main part of the power supply is a multiplier made on capacitors C1–C6 and diodes D1–D6. Each capacitor is charged to the amplitude value of the input voltage, thus the input voltage is multiplied 6 times. The entire circuit of series connected capacitors is charged in six periods, i.e. 120 ms, at an output voltage of 10 KV, the total charge of the circuit:

$$Q = \frac{CU}{n} = 0.1 * 10^{-6} * \frac{10^4}{6} = 1.6 * 10^{-4} K$$

When discharging the capacitors, the current value can be about 1 mA, thus the corona discharge processes can use power of about 10 Watt.

To measure the output voltage, a voltmeter for high voltage measurement is realised on resistors R1–R12 and a microammeter. The voltage divider on resistors R1–R11 reduces the output voltage 100 times, by resistor R12 the current is fed to the microammeter, the readings of which are proportional to the high voltage at the output.

The complete circuit diagram of the plant is shown in Fig. 4.

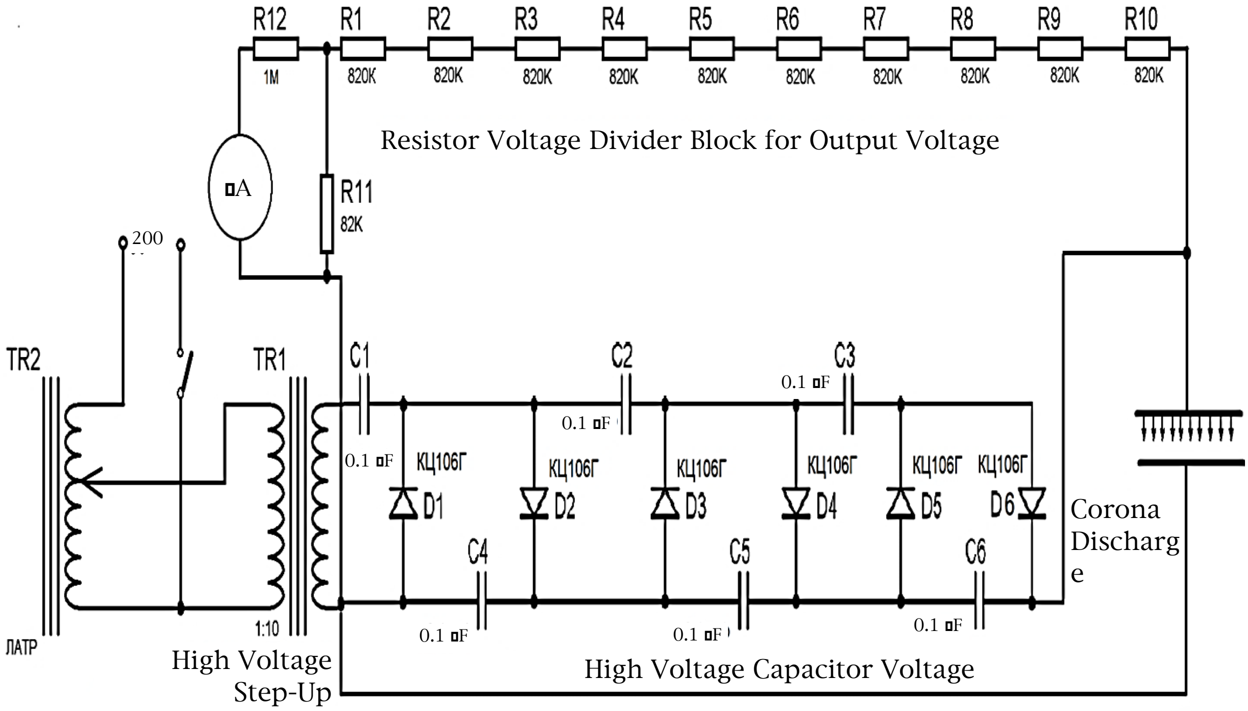

Fig. 4. Complete circuit diagram of the plant

The output voltage of the power supply is obtained by multiplication of the input voltage and is regulated by the input laboratory autotransformer.

The main unit that increases the voltage is a multiplier using KC106G diodes and 0.1 μF high-voltage capacitors.

This large capacitance of capacitors is necessary because the multiplier operates at a low frequency of 50 Hz. A high-voltage transformer (up to 2 kilovolts) located between the autotransformer and the multiplier provides the voltage pre-emphasis.

The output voltage from the power supply unit is supplied to the electrode block, a large number of needle elements of the upper electrode provides a sufficiently large volumetric corona discharge (Fig. 5).

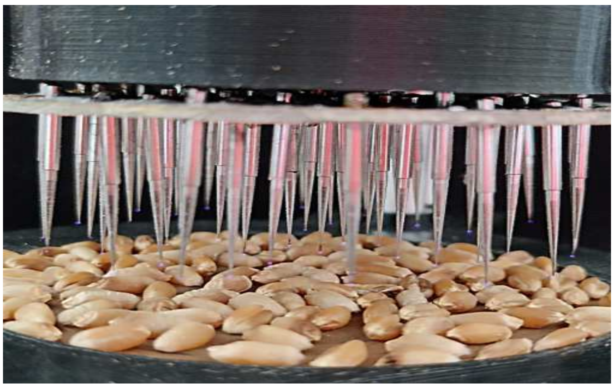

Fig. 5. Corona discharge electrode unit. Treatment of spring wheat seeds of Arhat variety

Wheat seeds have an oblong shape with a dense structure. Since the importance of this crop cannot be exaggerated, even a slight increase in useful properties by corona discharge will be of great national economic importance. Experimental treatment was carried out with change of working voltage of corona discharge and time of exposure of seeds.

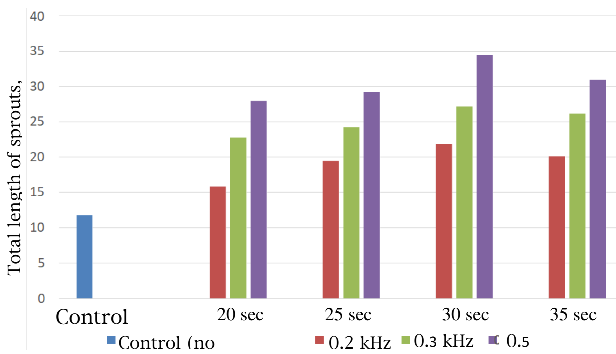

Fig. 6. Dependence of spring wheat seedling length on time and frequency of treatment at 4 kV (germination time 7 days)

Figure 6 shows the dependence of seedling length on time and frequency of treatment at a voltage of 4 kV, the greatest growth of seedlings is observed at a frequency of 0.5 kHz and treatment time of 30 seconds. Thus the length of seedlings for seven days, treated by corona discharge of seeds on average reaches up to 34.4 cm, and the length of the control variant of the experiment 11.7 cm, which is 22.7 cm shorter.

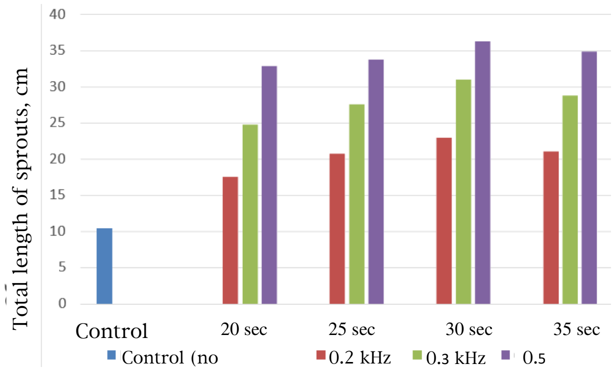

Fig. 7. Dependence of spring wheat seedling length on time and frequency of treatment at 8 kV (germination time 7 days)

In Figure 7, the same dependence was found as in Figure 6. The greatest length of seedlings at 8 kV is observed at treatment time of 30 seconds, where the length of seedlings reaches 36.2 cm, which is 24.5 cm more than the control.

4. Conclusion

The developed installation of corona discharge generation of low-temperature atmospheric plasma allows to treat seeds at the following parameters: voltage 4 and 8 kV; frequency 0.2 kHz; 0.3 kHz; 0.5 kHz; seed distance from the plasmatron 3 cm; seed treatment time: 20, 25, 30, 35 seconds.

Spring wheat seeds of Arhat variety when treated with low-temperature corona discharge plasma at a voltage of 8 kV, frequency 0.5 kHz and treatment time of 30 seconds have the best results. The length of seedlings reached 36.2 cm, which is 24.5 cm more than the control.

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