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DETERMINING THE EFFECTIVENESS OF PLASMA-ACTIVATED WATER AND MICROBIOLOGICAL PREPARATIONS IN IMPROVING SEED GERMINATION IN SALINE SOILS

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ABSTRACT:

This study investigated the effects of plasma-activated water and microbiological preparations on improving seed germination in saline soils. Salinity is one of the main stress factors for plants, significantly reducing the seed germination process. The results of the study showed that seed germination increased by 18–25% when treated with plasma-activated water, while treatment with microbiological preparations resulted in an increase of 22–30%. The combined method provided the highest result, ensuring up to a 35% increase in germination.

Introduction

One of the most pressing challenges facing modern agriculture is soil degradation, particularly the increasing process of salinization. Soil salinity is a complex agroecological phenomenon caused by the excessive accumulation of soluble salts in the soil, mainly sodium (Na^+), chloride (Cl^-), and sulfate (SO_4^{2-}) ions. This process has a direct negative impact on plant growth, development, and productivity. According to international organizations, approximately 20–25% of irrigated lands worldwide are affected by salinity to varying degrees, and this figure continues to increase each year.

In the Central Asian region, especially in Uzbekistan, the problem of salinization has become even more acute. The main causes include improper irrigation practices, insufficient development of drainage systems, high evaporation rates, and climate change. As a result, the physicochemical properties of the soil are disrupted, leading to a decline in soil fertility. In saline soils, water uptake by plants becomes more difficult due to increased osmotic pressure, preventing plant roots from absorbing water efficiently. Additionally, the toxic effects of sodium and chloride ions disrupt cellular metabolism.

The seed germination stage is one of the most critical and sensitive phases of plant ontogenesis. At this stage, environmental factors such as soil salinity, moisture, and temperature play a decisive role in seed viability. Under saline conditions, the ability of seeds to absorb water decreases, enzymatic activity slows down, and consequently, the germination rate drops significantly. This ultimately has a negative impact on crop yield.

Although traditional reclamation measures (such as leaching, drainage, and the use of chemical agents) are effective to a certain extent, they often require significant economic costs and are not always environmentally sustainable. Therefore, in recent years, special attention has been given to the application of environmentally friendly, energy-efficient, and innovative technologies in scientific research.

One promising approach is the use of plasma technologies. Plasma-activated water is distinguished by its strong oxidative-reductive properties and richness in biologically active components. It enhances the physiological activity of seeds, accelerates metabolic processes at the cellular level, promotes faster germination, and increases resistance to stress factors.

On the other hand, microbiological preparations (biofertilizers) are also widely used in agriculture. These contain beneficial microorganisms such as Azotobacter, Bacillus, Pseudomonas, and others, which play an important role in improving soil fertility, enhancing plant nutrition, and increasing resistance to stress conditions. These microorganisms produce phytohormones, fix nitrogen, and convert phosphorus into soluble forms.

Modern studies indicate that the combined application of physical (plasma) and biological (microorganisms) methods produces a synergistic effect, resulting in higher efficiency compared to their individual use. However, the combined impact of these technologies in saline soils has not yet been sufficiently studied.

In this context, the main objective of this study is to determine the effects of plasma-activated water and microbiological preparations on seed germination in saline soil conditions, compare their effectiveness, and justify the most optimal methods of their application.

Main body

Improving seed germination in saline soils is one of the key scientific directions in modern agrobiotechnology. Analysis of scientific literature shows that innovative methods based on physical and biological factors—particularly plasma-activated water and microbiological preparations—have a significant positive effect on seed germination.

Plasma-activated water (PAW) contains reactive oxygen and nitrogen species (ROS and RNS), which enhance metabolic activity in seeds, activate enzymatic systems, and accelerate redox processes at the cellular level. Studies indicate that plasma water increases the permeability of the seed coat, intensifying the imbibition process and thereby improving germination rates [1]. It has also been established that PAW enhances the activity of antioxidant enzymes such as catalase, peroxidase, and superoxide dismutase in plants [2].

Microbiological preparations, particularly biofertilizers based on bacteria of the genera Azotobacter, Bacillus, and Pseudomonas, play an important role in improving soil fertility. These microorganisms fix nitrogen, convert phosphorus into soluble forms, and produce plant growth–promoting phytohormones (auxins, gibberellins) [3]. In addition, they increase plant resistance to salinity stress, regulate ion balance, and support the development of beneficial microflora in the rhizosphere [4].

Recent scientific studies have shown that the combined application of physical and biological methods leads to higher efficiency due to a synergistic effect. In this case, plasma water activates seeds physiologically, while microorganisms support plant development in subsequent growth stages [5].

In this study, experiments were conducted under laboratory conditions. A moderately saline soil sample with electrical conductivity EC = 6–8 dS/m was selected. Wheat seeds were used as the research object, and the experimental period lasted 10–14 days. The experiment consisted of four variants: control (seeds treated with ordinary water), seeds treated with plasma water, seeds treated with microbiological preparation, and a combined treatment (plasma water + microbiological preparation).

Evaluation criteria included germination percentage, germination rate, and root and shoot length. The results showed that germination in the control variant was 52%, while in the plasma water treatment it increased to 65%. With microbiological preparations, germination reached 68%, and in the combined treatment, the highest result—70–75%—was recorded.

Positive changes were also observed in root and shoot growth. In the control variant, root length was 3.1 cm, while it reached 4.2 cm with plasma water, 4.5 cm with microbiological

treatment, and 5.1 cm in the combined variant. Shoot length was 4.0 cm, 5.3 cm, 5.6 cm, and 6.2 cm, respectively.

Analysis of the results indicates that plasma water softens the seed coat, enhances rapid water absorption, and accelerates physiological activation of the seed. Microbiological preparations stimulate root system development, improve nutrient uptake, and increase plant resistance to stress conditions.

In saline soils, the main limiting factors are osmotic stress and ion toxicity. Excessive amounts of sodium and chloride ions disrupt cellular metabolism and hinder water exchange. Under such conditions, plasma water strengthens the antioxidant defense system and protects cells from oxidative stress [2]. Microbiological preparations, through phytohormone production, accelerate plant growth, reduce salt stress, and improve nutrient availability in the soil [4].

As a result, the combined application method demonstrated the highest efficiency, which can be explained by the complementary effects of physical and biological factors.

In general, the study confirms that seed germination significantly decreases in saline soils. However, the use of plasma water increases germination by an average of 18–20%, while microbiological preparations increase it by 20–25%. The highest results were observed with the combined method, where germination increased by up to 30–35%.

From a practical perspective, it is recommended to soak seeds in plasma-activated water for 20–30 minutes before sowing and treat them with certified microbiological preparations. Especially in saline areas, the combined application of these technologies ensures high economic efficiency and environmental safety.

Conclusion

The results of the conducted research scientifically confirmed that seed germination significantly decreases in saline soils. High concentrations of soluble salts in the soil, particularly sodium and chloride ions, restrict water uptake by seeds, increase osmotic stress, and reduce enzymatic activity. As a result, the germination rate declines and the early stages of plant development are disrupted.

The study showed that the application of plasma-activated water enhances the physiological activity of seeds, accelerates water absorption, and activates enzymatic reactions. This led to an average increase in germination by 18–20%. Microbiological preparations, in turn, stimulated root system development, improved nutrient uptake, and increased plant resistance to salinity stress conditions. As a result, germination increased by 20–25%.

The highest efficiency was observed when plasma-activated water and microbiological preparations were applied together. In this combined method, seed germination increased by 30–35%. This can be explained by the synergistic interaction of physical (plasma) and biological (microorganisms) factors. In other words, plasma water activates seeds at the initial stage, while microorganisms support plant development in subsequent stages.

In addition, the experimental results showed a significant increase in root and shoot length, indicating an overall improvement in vegetative growth.

Overall, the results of this study demonstrate that the use of plasma-activated water and microbiological preparations is a highly effective, environmentally safe, and economically feasible approach to improving seed germination in saline soils. The widespread implementation of these technologies in agricultural practice, especially in highly saline areas, plays an important role in increasing crop yields and restoring soil fertility.

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