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The Impact of Pre-Sowing Laser Treatment on Wheat Seed Germination and Quality

Abstract: - Laser technologies play a crucial role in enhancing the productivity of agricultural crops, particularly in improving seed quality and germination. This study investigates the effects of laser irradiation on wheat seeds using various wavelengths (450–1200 nm) and laser operation modes (continuous and pulsed). The experiment involved three different treatment durations: 5, 10, and 15 minutes. Key parameters such as seed germination, germination energy, seedling biomass, and the activity of antioxidant enzymes — catalase and peroxidase — were evaluated. The results showed that the most pronounced effects were observed with 10 minutes of laser treatment. Seed germination increased by 23%, and seedling biomass by 20%, compared to the control group. Laser treatment also activated the plants' antioxidant system, which enhanced their resistance to environmental stress factors such as drought and oxidative stress. In addition, it was found that laser treatment significantly accelerated the initial stages of seed germination, leading to earlier seedling development. These findings demonstrate that laser treatment stimulates important biochemical processes in seeds, contributing to their growth and development. This technology can be effectively used to increase wheat yield and other crops, providing an eco-friendly method for growth stimulation that reduces the need for chemical growth stimulators, fostering more sustainable agriculture.

Keywords: laser treatment, wheat, pre-sowing treatment, yield, biostimulation, enzymatic activity.

I. INTRODUCTION

Modern agriculture faces numerous challenges, including soil degradation, climate change, water shortages, and the growing global population. These factors require scientists and farmers to search for new ways to improve crop productivity and resilience while reducing the use of chemical fertilizers and pesticides. One promising approach is the implementation of laser technologies for seed treatment, which can significantly enhance seed biological properties, improve germination rates, and increase resistance to environmental stress.

Laser technologies, initially developed for industrial and medical applications, have found their place in agriculture. Laser seed treatment involves exposing seeds to coherent light of a specific wavelength, which triggers a cascade of biochemical reactions, leading to improvements in physiological characteristics. As demonstrated in studies [1], laser irradiation activates processes related to plant growth and development, including photosynthesis, metabolism, and phytohormone synthesis. These processes play a key role in plants' adaptation to external stress factors such as drought, high temperatures, and diseases.

One of the key tasks in agriculture is to improve seed germination — an important indicator that determines the speed and quality of plant germination. Seed germination refers to the percentage of seeds that successfully sprout over a specific time period. To increase germination rates, various seed treatments have traditionally been used, such as thermal, chemical, or mechanical treatments. However, these methods have drawbacks, including high costs, the need for special resources, and potential negative environmental impacts. In contrast, laser treatment is a safer alternative as it does not require chemicals and does not have a harmful effect on soil and the environment [2].

Research shows that laser exposure to seeds can significantly increase germination rates and accelerate early growth stages. For example, in [3], it was demonstrated that pre-sowing laser treatment of soybean seeds increased germination by 15% and improved resistance to pathogenic microorganisms. Another study [4] showed that laser treatment of corn seeds promoted seedling biomass growth and accelerated germination.

One of the key mechanisms underlying the effects of laser irradiation on seeds is the activation of plant light-sensitive pigments — phytochromes. Phytochromes respond to light of a specific wavelength and trigger a cascade

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of biochemical reactions related to plant growth and adaptation to light conditions. Lasers operating in the red and infrared light range (600 to 1200 nm) are most effective at activating phytochromes, which enhances photomorphogenesis — the formation of plant structure in response to light [5].

Laser treatment also affects the plant antioxidant system. Reactive oxygen species (ROS), which form in plant cells under stress, can damage cell membranes, proteins, and DNA. However, laser irradiation stimulates the activity of antioxidant enzymes such as catalase and peroxidase, which neutralize ROS and protect plant cells from oxidative stress. Studies [6] show that laser exposure increases the activity of these enzymes, which improves plant resistance to adverse factors such as drought and high temperatures.

To assess the effectiveness of laser seed treatment, parameters such as germination rate, germination energy, and seedling biomass are commonly used. Germination rate is determined as the percentage of seeds that sprout over a set period (usually seven days). Germination energy indicates how many seeds germinated during the early stage (e.g., by the fourth day after planting). This parameter is important for assessing seed germination speed, which is particularly relevant in stressful or extreme climate conditions. Seedling biomass allows researchers to evaluate plant growth characteristics, such as the length and mass of stems, roots, and leaves.

Additionally, enzyme activity is an important parameter for assessing plant responses to oxidative stress. Catalase and peroxidase play crucial roles in protecting plant cells from oxidative stress, which can arise under unfavorable conditions such as drought or high temperatures. Measuring these enzymes' activity helps evaluate how effectively laser treatment aids plants in adapting to stress.

Wheat is one of the key crops grown worldwide and plays a vital role in food security. Its productivity directly depends on seed quality, germination rates, and the ability to withstand adverse environmental conditions. In the context of climate change and increasing demand for food, wheat remains one of the most important crops for agriculture. Improving wheat yield and quality using modern technologies, such as laser seed treatment, can significantly increase the efficiency of agricultural production and reduce the environmental impact [7].

An important aspect of studying laser effects on seeds is choosing optimal treatment parameters. As shown in previous studies, wavelength, laser power, and treatment duration are critical factors in determining the effectiveness of exposure. For example, the red spectrum (650 nm) is most effective for activating wheat phytochromes, while infrared wavelengths (700–1200 nm) are more suitable for improving corn germination [8]. Moreover, treatment duration is a critical factor. Too short exposure may not yield the desired effect, while excessively long exposure can damage cells and reduce their viability.

Laser seed treatment of wheat is a relatively new and understudied method, requiring further research to optimize its parameters and reveal its long-term effects. This study aims to investigate the impact of laser irradiation of various spectra on wheat seed germination, germination energy, seedling biomass, and enzyme activity. Particular attention is paid to evaluating different laser operation modes (continuous and pulsed) and treatment durations to determine the most effective parameters for wheat seed treatment.

Thus, the goal of this study is to investigate the effects of laser treatment on wheat seeds and assess the effectiveness of various laser exposure modes [9]. This research will help identify optimal laser treatment parameters to improve wheat yield and quality, which is particularly relevant in modern agriculture.

II. Materials And Methods

To evaluate the effects of laser irradiation on wheat seed germination and development, a comprehensive experimental approach was used. This included laser seed treatment, germination trials, and physiological and biochemical parameter analysis. The main objective was to study how different laser wavelengths and operation modes affect parameters such as germination, germination energy, seedling biomass, and the activity of antioxidant enzymes — catalase and peroxidase. All experiments were conducted under controlled laboratory conditions using modern equipment and measurement techniques.

For laser seed treatment, the "LIKA LED" device (Photonika Plus, Ukraine) was used. This device enables seed irradiation with coherent light in the visible and infrared ranges. It is highly accurate and allows for controlling wavelength, power, and duration of exposure [10].

The setup consists of two parts: a metal chamber and a glass component. The metal chamber, made of stainless steel, is used for treating large seed batches of up to 100 grams. It is equipped with a rotation mechanism to ensure even irradiation of each seed. The glass part is used for irradiating both seeds and soil, allowing for combined experiments evaluating the effects of laser treatment on the environment and material.

The device's main technical parameters are as follows:

- Red light: wavelength — 650 nm;
- Blue light: wavelength — 450 nm;
- Green light: wavelength — 325 nm;
- Violet light: wavelength — 405 nm;
- Infrared light: wavelength — 1200 nm;
- Laser power for all spectra: 100 Mw.

To calculate the laser power density used in the experiment, the following formula was applied:

$PS=P\backslash A$,

where PS is the power density (W/cm²), P is the laser power (W), and A is the surface area on which the laser beam is applied (cm²). For example, with a laser power of 100 mW and an irradiated surface area of 1 cm², the power density is:

$PS=0.1\backslash 1=0.1 W/cm^2$.

For optimal exposure of wheat seeds, a power density of approximately 0.1 W/cm² was used, based on experimental data for effective plant growth stimulation.

Wheat seeds were divided into four groups:

1. Control group — seeds that were not exposed to laser irradiation.
2. First experimental group — seeds irradiated for 5 minutes.
3. Second experimental group — seeds irradiated for 10 minutes.
4. Third experimental group — seeds irradiated for 15 minutes.

Each group was further divided into subgroups based on the type of laser emission:

- Continuous emission — seeds were exposed to continuous laser irradiation throughout the entire treatment duration.
- Pulsed emission — seeds were exposed to laser irradiation at a frequency of 100 Hz.

Seed treatment was conducted under controlled temperature (22°C) and humidity (50%) to eliminate external factors that could affect the results. Laser exposure was applied at a distance of 10 cm from the seed surface. Depending on the group, treatment duration varied from 5 to 15 minutes. Continuous emission involved uninterrupted laser exposure, while pulsed emission alternated between laser pulses and pauses (100 mW, 100 Hz).

After treatment, all seeds were placed in containers with prepared sterile soil. The containers were placed in a climate chamber at 25°C and 60% humidity. Seed germination was monitored daily for seven days, after which the total germination rate was assessed.

Germination rate was calculated as the percentage of germinated seeds relative to the total number of seeds planted in each group. Germination rate is a key parameter that demonstrates seed viability after treatment and their ability to adapt to growth conditions [11]. The following formula was used to calculate the germination rate:

$G=(N_s\backslash N_t)\times 100$

where G is the germination rate (%), N_s is the number of germinated seeds, and N_t is the total number of seeds in the group.

Germination energy was assessed on the fourth day after planting. This parameter indicates how many seeds germinated during the early stages and serves as an important indicator of the speed and efficiency of germination. The following formula was used to calculate germination energy:

$E=(N_g\backslash N_t)\times 100$

where E is the germination energy (%), N_g is the number of seeds germinated by the fourth day, and N_t is the total number of seeds planted [12].

Seedling biomass was measured on the seventh day after planting. All seedlings were carefully removed from the soil, cleaned from soil residues, and weighed on analytical scales with an accuracy of 0.001 g. This parameter is essential for evaluating plant mass, which directly depends on the effectiveness of laser exposure during the early stages of plant development.

The following formula was used to calculate the seedling biomass index:

$BM=W\backslash N$

where BM is the seedling biomass index (g/plant), W is the total seedling mass (g), and N is the total number of seedlings in the group.

To evaluate the effects of laser treatment on the plant antioxidant system, enzyme activity — catalase and peroxidase — was analyzed. These enzymes play a critical role in protecting plant cells from oxidative stress caused by reactive oxygen species (ROS), which can form in cells under stress conditions.

Catalase and peroxidase activities were determined using spectrophotometric methods. Samples were taken from seedlings on the seventh day after planting. The analysis was performed using standard protocols with reagents to assess enzyme activity levels. Catalase neutralizes hydrogen peroxide formed in cells by converting it into water and oxygen, protecting cells from damage. Peroxidase detoxifies various oxidative compounds, and its activity serves as an indicator of the plant's antioxidant system status.

The following formula was used to calculate enzyme activity (catalase and peroxidase):

$A=(V_s \backslash V_t)\times C$

where A is enzyme activity, V_s is the sample volume (ml), V_t is the total solution volume (ml), and C is substrate concentration.

Standard statistical methods, including analysis of variance (ANOVA), were used to evaluate the significance of differences between groups. All experimental results were presented as mean values ± standard deviation. The statistical significance of differences between experimental and control groups was evaluated using Student's t-test at a significance level of p<0.05p < 0.05p<0.05. SPSS Statistics version 25.0 software was used for all analyses.

To eliminate potential external factors affecting the experimental results, all containers with seeds and seedlings were kept under identical conditions. Temperature and humidity control was maintained using an automated climate chamber [13]. Containers were labeled to avoid errors during data registration.

III. RESULTS AND DISCUSSION

The experiment provided data on the impact of laser treatment on wheat seed parameters, including germination, germination energy, seedling biomass, and antioxidant enzyme activity (catalase and peroxidase). The key results are discussed below, along with graphs and tables to visualize the data.

Seed germination is a critical indicator that characterizes the viability of seeds after treatment and their ability to adapt to growth conditions. The experiment showed that laser treatment significantly increased the percentage of germinated seeds compared to the control group, which did not undergo treatment.

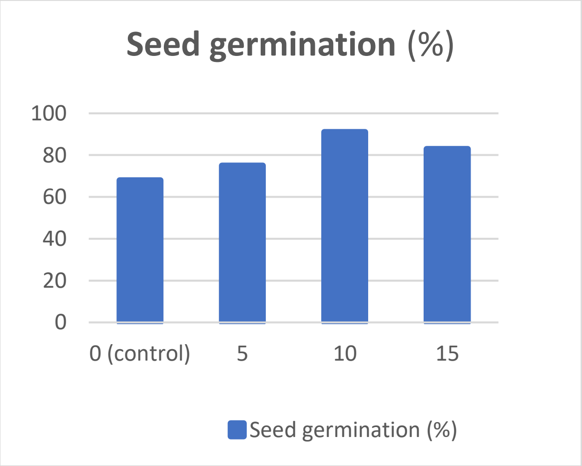

Fig. 1. Effect of laser treatment duration on wheat seed germination

As shown in Fig. 1, seed germination increased with longer laser treatment durations. The highest germination rate (91%) was recorded in the group treated with laser for 10 minutes, which was 23% higher than the control group (68%). However, increasing the treatment duration to 15 minutes led to a decrease in germination to 83%, likely due to over-saturation of cellular energy and activation of stress mechanisms. This confirms that 10 minutes of treatment is optimal for improving germination.

Germination energy indicates how quickly seeds can sprout during the first few days after planting. This parameter is crucial for evaluating the speed of germination and the early stages of plant development.

Table I. Germination Energy of Seeds after Laser Treatment

Group	Germination energy (%)
Control group	63
5 minutes of treatment	72
10 minutes of treatment	88
15 minutes of treatment	79

The data in Table I shows that the highest germination energy was observed in the seeds treated with the laser for 10 minutes, reaching 88%. In the control group, the germination energy was 63%. This suggests that laser exposure stimulates the acceleration of early germination stages, particularly with 10-minute treatment [14].

Seedling biomass is a key indicator of plant health and growth and shows how effectively laser treatment stimulates plant development. Seedling biomass was measured on the seventh day after planting, and the results are shown in Table 2.

Table II. Seedling Biomass after Laser Treatment

Group	Seedling biomass (g)
Control group	0.35
5 minutes of treatment	0.39
10 minutes of treatment	0.42
15 minutes of treatment	0.40

As seen in Table II, seedling biomass increased with longer laser treatment durations. The highest biomass was recorded in the 10-minute treatment group, at 0.42 g, 20% higher than the control group. Increasing the treatment duration to 15 minutes slightly reduced seedling biomass to 0.40 g, further confirming the need for precise parameter optimization.

The activity of antioxidant enzymes (catalase and peroxidase) is an important indicator of cellular protection against oxidative stress [15]. Laser exposure stimulates the production of these enzymes, allowing plants to better adapt to external stress conditions such as drought or high temperatures.

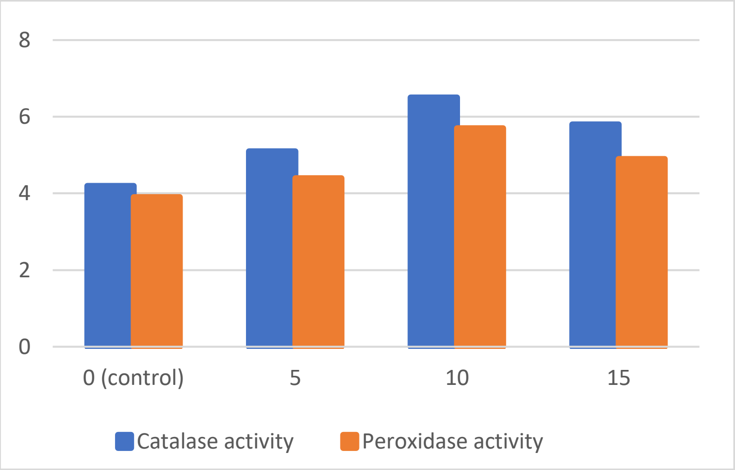

Fig. 2. Effect of laser treatment on catalase and peroxidase activity

As shown in Fig. 2, catalase and peroxidase activity significantly increased after laser seed treatment. The highest catalase activity was observed with 10-minute treatment, confirming the results of improved germination and seedling biomass. Catalase activity peaked at 6.5 (compared to 4.2 in the control group), while peroxidase activity increased to 5.7 (compared to 3.9 in the control group).

Increased antioxidant activity indicates that laser treatment helps activate mechanisms that protect plants from oxidative stress. This may explain the higher resilience of laser-treated plants to environmental stress.

The results confirm that laser treatment of wheat seeds positively affects physiological and biochemical characteristics. The most pronounced results were achieved with 10-minute treatment, which led to a significant increase in germination, germination energy, seedling biomass, and enzyme activity.

Increasing the treatment duration to 15 minutes resulted in a slight decrease in all parameters, which may be due to excessive cell activation and potential damage from prolonged laser exposure. This effect is consistent with studies [16] showing that excessive laser treatment can negatively impact plant cells by generating reactive oxygen species (ROS).

Thus, 10-minute laser treatment was the most effective in stimulating wheat seed growth and development. This is confirmed by the data on germination, seedling biomass, and enzyme activity, which showed the highest values in this experimental group.

Laser exposure stimulates important physiological and biochemical processes in seeds, accelerating germination and increasing seedling biomass [17]. Additionally, the activation of the plant antioxidant system makes them more resistant to stress, which is particularly important in the context of climate change and increasing drought frequency.

IV. CONCLUSION

The results of this study showed that pre-sowing laser treatment of wheat seeds significantly positively impacts their physiological and biochemical characteristics. Laser exposure improved seed germination, increasing it by 23% compared to the control group, which did not undergo treatment. The best results were achieved with 10 minutes of laser exposure, which also contributed to an increase in germination energy to 88% and improved seedling biomass by 20%.

It was established that laser exposure stimulates key physiological processes, such as the increase in antioxidant enzyme activity (catalase and peroxidase). These enzymes' activity reached a maximum with 10 minutes of treatment, allowing plants to more effectively cope with oxidative stress and adapt to adverse environmental conditions. These data confirm that laser treatment can be used to increase plant stress resistance, such as drought and high temperatures, which is particularly relevant in the context of climate change.

However, increasing the treatment duration to 15 minutes resulted in a slight decrease in all parameters, possibly due to excessive cell activation and stress. This confirms the need for careful selection of laser treatment parameters to achieve optimal results.

The introduction of laser technology into agricultural practice can provide an environmentally friendly and efficient way to stimulate plant growth, reducing the need for chemical growth stimulants. This study demonstrates the potential of laser treatment to improve wheat yield and quality, which can contribute to increased agricultural production efficiency.

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