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Infrared Laser Processing in Seed Treatment: A Biotechnical Approach

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Abstract: - This study investigates the impact of infrared laser irradiation on pre-sowing seed treatment across various crop species. Using the Lika-LED device, which allows precise control over irradiation parameters, seeds of wheat, barley, corn, oats, and rice were exposed to infrared light to assess its effects on germination, shoot growth, and overall seed viability. Results revealed that wheat seeds exhibited significant improvements in both germination rates and shoot length, demonstrating the effectiveness of infrared laser treatment in enhancing seed performance. Barley seeds showed increased shoot length after 3 minutes of irradiation, though germination rates remained unchanged. Conversely, corn seeds experienced a reduction in sprout length, while germination rates stayed constant, suggesting a negative impact on growth. Oats and rice seeds did not show statistically significant changes under the tested conditions. The study underscores the potential benefits of infrared laser treatment for certain crops and suggests further research to explore a broader range of irradiation conditions and different seed types. Future investigations will focus on optimizing laser parameters, assessing the effects of laser coherence, and evaluating long-term impacts on crop quality to refine and enhance agricultural practices.

Keywords: Agricultural technology, infrared laser irradiation, laser coherence, pre-sowing seed treatment, seed germination.

I. INTRODUCTION

Laser technologies have found wide applications in fields such as science, engineering, medicine, and agriculture. In the agricultural sector, their use goes beyond simple equipment manufacturing. Lasers are studied for their potential impact on biological systems and crops. They can stimulate plant growth, enhance resistance to adverse conditions, and optimize photosynthesis processes, leading to increased yields. Additionally, laser treatment can improve seed quality, protect plants from pests and diseases, and enable real-time plant health monitoring. This makes them a crucial tool in developing sustainable and efficient agriculture to address global food security challenges.

Modulating light parameters, such as spectral composition and intensity, allows us to profoundly affect various aspects of plant life. This includes the regulation of growth, development, and fruit formation, a process known as photomorphogenesis, as well as directing growth in response to light, or phototropism. Tailored lighting conditions can enhance plant resilience, improving resistance to drought, extreme temperatures, and pathogens. Moreover, specific light treatments can optimize photosynthesis efficiency and nutrient absorption, leading to healthier plants and increased agricultural productivity [1].

Advanced research explores the use of LED technology to provide precise light spectra that can trigger desired plant responses, minimizing energy consumption while maximizing growth outcomes. Integrating these insights into agricultural practices is crucial for developing sustainable farming systems capable of adapting to environmental changes. This innovative approach not only supports crop yield improvement but also contributes to global food security by promoting efficient and resilient agricultural methods.

Research shows that high coherence in laser radiation allows for targeted stimulation of metabolic pathways, potentially accelerating plant growth and development [2]. By adjusting wavelength and exposure time, lasers can

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be customized to optimize specific plant responses, enhancing resource use efficiency and resilience to environmental stresses.

Furthermore, laser treatment can improve photosynthetic activity and facilitate more efficient water and nutrient absorption, leading to increased crop yield and quality. Coherent laser technologies present new opportunities in agriculture by adapting farming systems to changing climate conditions and providing sustainable solutions for global food security. They also contribute to reducing the reliance on chemical fertilizers and pesticides, supporting ecological stability and biodiversity.

An important application of laser technologies in agriculture is pre-sowing seed treatment. Utilizing infrared radiation for this purpose stimulates biochemical processes within the seed embryo, enhancing germination energy and improving seed viability [3]. Research demonstrates that exposure to low-intensity coherent light boosts seed germination energy, increases resilience to environmental stressors, and supports overall plant growth. This method helps reduce reliance on harmful fungicides, aligning with current agricultural trends aimed at minimizing the use of chemicals and pesticides in crop cultivation.

Infrared radiation activates antioxidant systems within cells, potentially enhancing their functional activity. Although infrared treatment does not alter the primary micronutrient levels in seeds, it can affect the protein complex's fraction ratios. Short-term infrared exposure decreases albumin content while increasing levels of glutelins and insoluble proteins, indicating mild protein denaturation that improves protein digestibility and, consequently, the seeds' biological value [4].

Recent studies suggest that modern semiconductor diodes or lasers could replace or complement traditional helium-neon gas devices in agriculture. Advances in optical technology have expanded the use of infrared lasers [5], which offer several advantages. These lasers are compact, resistant to mechanical damage, and adaptable to harsh agricultural conditions. Their ability to customize spectral composition and regulate output power with semiconductor pump diodes makes them a valuable tool in agricultural practice.

In the conducted study, an infrared laser was utilized to evaluate the impact of near-infrared radiation on the germination of seeds from various agricultural crops.

II. MATERIALS USED AND METHODOLOGY

In laboratory experiments, dry seeds from five distinct crop varieties were treated with infrared radiation using the "Lika LED" device. The schematic representation of the "Lika LED" system, shown in Fig. 1, illustrates its design specifically for infrared exposure. This device features advanced capabilities for precisely controlling and adjusting irradiation parameters [6], such as wavelength, intensity, and exposure duration, to meet various research requirements.

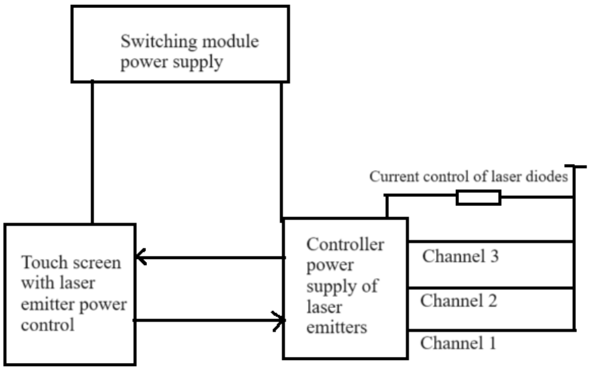

Fig. 1. Schematic representation of the "Lika LED" device

The "Lika LED" device is distinguished by its high-precision optical components and a user-friendly interface, which ensure stable and reproducible irradiation conditions. This allows researchers to thoroughly investigate the effects of infrared radiation on seed physiology, potentially enhancing germination rates and subsequent growth.

This experimental setup provides a robust platform for systematically exploring how infrared radiation influences seed viability and plant development stages. By enabling precise and adaptable experimentation, the "Lika LED" device plays a crucial role in refining seed treatment techniques, thereby contributing to improved agricultural practices and increased crop yields. It allows for in-depth studies of how infrared light influences key physiological processes, ultimately helping to optimize growth conditions and enhance crop resilience. This precise control over irradiation parameters facilitates the identification of optimal conditions for enhancing seed germination rates and promoting vigorous plant growth. Additionally, the device's capability to simulate various environmental conditions enables researchers to assess how infrared treatment interacts with other factors like soil type and water availability, providing a comprehensive understanding of its effects on crop performance. This comprehensive approach not only aids in optimizing growth conditions but also supports the development of more resilient crop varieties that can better withstand environmental challenges.

This laser setup facilitated continuous laser emission with a central wavelength of approximately 1080 nm. During seed irradiation experiments, the laser exhibited a spectral linewidth of around 1 nm, with an output power of about 0.5 W. To accurately measure the spectral composition, an optical attenuator was employed in conjunction with a spectrum analyzer. The spectral width at half-maximum intensity was similarly 1 nm. Additionally, the system achieved a suppression of spontaneous laser emission exceeding 40 dB, ensuring minimal noise and enhanced precision in the experiments. This configuration provides stable and well-defined laser parameters, crucial for investigating the effects of laser irradiation on seed performance and growth [7].

The laser light spot used in the experiments had a Gaussian power distribution with a radius of about 2.5 cm, resulting in a radiation power density of 250 W/m². By varying the radius of the laser spot, the power density can be adjusted to achieve precise control over the intensity of radiation applied to the samples. This flexibility was critical for investigating the dose-response relationship and optimizing irradiation parameters to enhance seed germination and growth [8]. Additionally, the Gaussian distribution of the laser spot facilitated gradual exposure gradients, enabling studies on how different intensity levels affect various stages of seed development. This capability is essential for developing tailored laser treatment protocols and understanding their impact on seed performance, ultimately contributing to more effective and sustainable agricultural practices.

In each experimental run, four containers were employed. Each container was prepared with a foil layer at the bottom, followed by a gauze cloth that had been moistened with water [9]. Seeds were then placed on top of the gauze. One container was designated as the control group, containing 50 seeds that were not exposed to any radiation. The other containers contained seeds that were subjected to infrared irradiation for different durations: 1, 3, and 5 minutes. Each treatment condition was replicated five times to ensure statistical reliability.

To further enhance the accuracy of the results, temperature and humidity within the containers were monitored and controlled to provide optimal and consistent growing conditions. Post-irradiation, seeds were observed for germination rates, and seedlings were assessed for growth metrics such as height and root length. This rigorous setup allowed for a comprehensive analysis of how infrared irradiation duration affects seed viability and development, contributing valuable insights into optimizing irradiation protocols for improved agricultural outcomes [10].

Seed germination energy and growth were assessed in accordance with established standards. After a period of 3 days, the germination results were evaluated by counting the number of seeds that had sprouted and measuring the length of the seedlings. This thorough methodology allows for a detailed analysis of how different durations of infrared radiation affect seed germination and growth, providing insights into optimizing seed treatment practices for improved agricultural outcomes. To ensure robust and reliable data, measurements were taken under standardized conditions, and results were compared across different irradiation durations and the control group [11]. Statistical analyses were employed to identify significant differences between treatment groups. This thorough methodology not only enables a detailed analysis of how varying durations of infrared radiation affect seed germination and growth but also provides critical insights into optimizing seed treatment practices, ultimately aiming to enhance agricultural outcomes and improve crop yields.

III. OBTAINED RESULTS

Fig. 3 presents the results of measuring seed germination rates in relation to different durations of irradiation. The data reveal a notable stimulating effect of irradiation on wheat seeds, which exhibited a significant increase in germination rates as irradiation time extended. The confidence interval for the proportion of germinated wheat seeds was consistently around 20%, indicating a robust and statistically significant effect of the treatment.

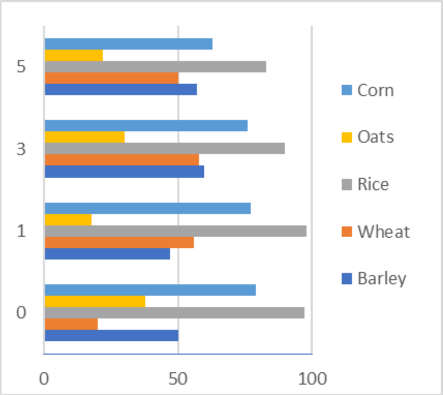

Fig. 3. Germination rates of seeds as a function of irradiation time

Conversely, irradiation of rice, corn, and barley seeds did not result in statistically significant differences in germination rates compared to the control. This lack of significant change suggests that the irradiation parameters employed, including wavelength, intensity, and exposure duration, were insufficient to influence the germination of these grains effectively.

In the case of wheat seeds, the positive effect of irradiation was not only evident in increased germination rates but also in the enhanced growth and vigor of the seedlings. This observation supports the hypothesis that the stimulation effect of irradiation on wheat is cyclical, potentially leading to cumulative benefits with repeated exposures.

For oat seeds, however, irradiation led to a slight reduction in germination energy, although this decrease was within the 20% margin of error. This result suggests that while irradiation may not always be beneficial, any observed changes in germination energy could be due to experimental variability rather than a definitive adverse effect.

Additionally, the data indicate that the optimal irradiation conditions for maximizing seed germination and growth may vary among different crop species. The differential responses observed highlight the need for tailored irradiation protocols to enhance seed viability and development effectively across a range of agricultural crops. Further studies are recommended to fine-tune irradiation parameters and explore their impact on other types of seeds to optimize agricultural practices and improve crop yields.

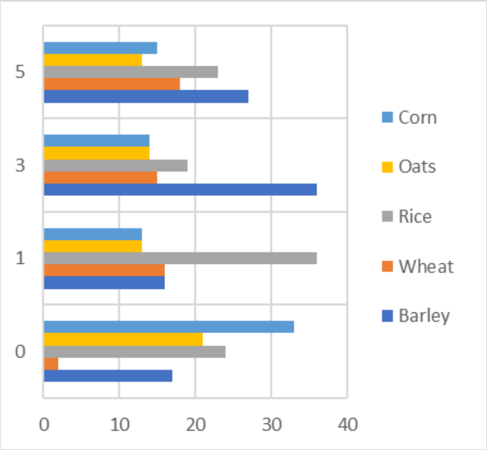

Fig. 4. Average length of sprouts as a function of irradiation duration

The second parameter analyzed was the average length of the sprouts, with the results illustrated in Fig. 4. The findings indicated that the application of infrared laser irradiation did not significantly enhance sprout growth for oat grains, as the observed changes fell within the margin of error. Therefore, it appears that irradiation does not provide a substantial benefit in stimulating oat sprout growth.

For corn grains, infrared laser irradiation had a consistently negative impact across all tested durations. This suggests that irradiation may not only fail to promote sprout development but could potentially inhibit it.

Rice grains exhibited a slight positive response with 1 minute of irradiation, although this improvement was also within the margin of error. This indicates a potential benefit, but further studies are necessary to confirm its significance and practical relevance.

In contrast, barley seeds showed a notable increase in sprout length with 3 and 5 minutes of irradiation, demonstrating a clear positive effect at these durations. Similarly, wheat grains experienced substantial growth in sprout length across all tested irradiation times, confirming a consistent positive response to the infrared laser treatment.

Based on these results, it is evident that barley and wheat seeds respond favorably to infrared laser irradiation under the tested conditions. Consequently, further experiments are planned to refine the irradiation parameters and explore their effects on these crops more thoroughly.

For corn and oat seeds, however, the lack of statistically significant results suggests that different irradiation parameters, such as varying wavelengths, power densities, or durations, might be necessary to effectively stimulate growth. Future research should focus on optimizing these variables to achieve better outcomes for these specific crops.

To evaluate the impact of thermal heating on the seeds being studied, a qualitative assessment of the heat generated by laser radiation was performed. The calculation considered a maximum irradiation duration of 300 seconds with a radiation power of 0.5 W. For this experiment, seeds were immersed in 2 cm³ of water, which absorbed the energy from the laser. The total energy imparted to the seeds was calculated as follows:

$$S = L \times t = 0,5W \times 300s = 150J \tag{1}$$

This calculation indicates that the seeds absorbed a total of 150 joules of energy during the irradiation period. To further understand the thermal impact, it is essential to consider how this energy is distributed and its potential effects on seed physiology. Factors such as the thermal conductivity of the seed material, the heat dissipation rate, and the specific heat capacity of the water could influence the overall heating effect.

Additional analyses might include measuring the temperature increase of the seeds and water, as well as evaluating any subsequent changes in seed viability and germination. This comprehensive approach will help determine whether the thermal effects contribute to the observed biological responses and optimize the irradiation conditions for better agricultural outcomes.

The calculated energy resulted in a change in the temperature of the seeds, the surrounding water, the gauze lining, and the foil placed beneath the irradiated material. The temperature change, excluding heat transfer effects, is estimated using the following formula:

$$\Delta T = \frac{S}{c \times m} = \frac{150}{4200 \times 0,005} \approx 7°C \tag{2}$$

where S is the supplied energy (150 J), c is the specific heat capacity of water (4200 J/kg·°C), and m is the mass of the irradiated material (0.005 kg). Given that the majority of the energy is absorbed by the water, the heat capacity of water is used for this estimation.

To estimate the heat transfer to the ambient air through the foil, which has an area of 20 cm², the following calculation is used:

$$S = \alpha \times P \times \Delta T \times \Delta t \approx 100J \tag{3}$$

where α is the heat transfer coefficient between the surface and the air, S is the surface area (20 cm²), ΔT is the temperature difference, and Δt is the time duration.

Taking into account the heat absorption characteristics of the materials involved and the thermal conductivity of the supporting slide table, the actual temperature rise in the seeds during irradiation is expected to be below 1 °C. This indicates that the thermal effect due to laser irradiation is relatively minor compared to the direct effects of the laser light.

Furthermore, the minimal increase in temperature suggests that the observed biological responses are likely due to the photobiological effects of the laser rather than thermal stress. This highlights the importance of understanding the specific interactions between laser irradiation and seed physiology, as well as optimizing irradiation parameters to maximize the beneficial effects while minimizing any potential thermal impacts.

Future investigations could focus on refining the thermal modeling, assessing the impact of different wavelengths and power densities, and exploring the precise mechanisms through which infrared laser irradiation influences seed growth and development.

IV. CONCLUSION

The investigations into the effects of pre-sowing seed treatment using infrared laser irradiation have yielded several key findings:

- wheat seeds: infrared laser treatment significantly enhances both the germination rate and the length of shoots. This indicates that wheat seeds benefit from the irradiation, showing improved early growth and seed viability;

- barley seeds: irradiation for 3 minutes leads to an increase in shoot length, although there is no change in the germination percentage. This suggests that while shoot development is positively influenced, the germination rate remains unaffected by the treatment;

- corn seeds: the treatment results in a reduction in sprout length, though the germination percentage remains constant. This indicates a potential negative impact on sprout growth, despite the seeds' ability to germinate;

- oats and rice seeds: no statistically significant effects were observed for these seeds under the current experimental conditions. This suggests that the infrared laser irradiation, as applied, does not produce measurable benefits for oats and rice.

Future research will focus on extending the scope of the study to include a wider range of irradiation conditions. This will involve varying the duration of exposure and testing different types of seeds to better understand the cyclic nature of the stimulation process and the impacts of infrared laser treatment.

Additionally, planned experiments will investigate the effects of altering the coherence of the laser radiation on seed development and subsequent stages of plant growth. Long-term studies will also explore potential delayed effects of infrared laser irradiation on crop quality, aiming to identify any sustained benefits or potential drawbacks. This comprehensive approach will help refine treatment protocols and enhance the practical applications of infrared laser technology in agriculture.

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