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PROSPECTS FOR THE USE OF LASER TECHNOLOGY IN AGRICULTURAL CROP PRODUCTION

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Annotation. Rapid global population growth, climate change, soil degradation, and the depletion of water resources necessitate the introduction of new innovative technologies into agriculture. One of the most promising technologies in this regard is laser technology. In recent years, laser radiation has been widely used for pre-sowing seed treatment, stimulation of physiological processes in plants, weed control, yield enhancement, improvement of product quality, and agricultural monitoring. This article provides a comprehensive analysis of the application of laser technologies in agriculture, the results of scientific studies, the mechanisms of laser interaction with plant organisms, and future development prospects.

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Introduction. One of the major challenges facing agriculture in the twenty-first century is achieving high productivity under conditions of limited resources. Alongside traditional agronomic methods, innovative technologies based on the use of physical factors are continuously developing. One such technology is the application of laser radiation.

A laser (Light Amplification by Stimulated Emission of Radiation) is a source of highly monochromatic, coherent, and directed electromagnetic radiation that enables precise and controlled effects on biological objects. Initially applied in medicine, military technology, and industry, lasers have now gained significant importance in agriculture as well [1].

Studies conducted over recent decades have demonstrated that laser radiation can improve seed germination, stimulate photosynthetic processes, enhance plant tolerance to environmental stress factors, and significantly increase crop productivity [2].

Research and methodology. The biological effects of lasers are explained by the phenomenon of photobiomodulation [3]. Low-power laser radiation alters the activity of intracellular enzyme systems and photoreceptors, thereby accelerating metabolic processes. According to researchers, red light with a wavelength of 632.8 nm emitted by helium-neon (He-Ne) lasers is particularly important. This radiation is absorbed by the phytochrome system, resulting in accelerated cellular respiration, increased ATP synthesis, enhanced biosynthesis of proteins and nucleic acids, strengthened activity of antioxidant enzymes, improved photosynthetic efficiency, and greater resistance to environmental stress factors [4].

Laser irradiation improves the permeability of the seed coat to water and gases, thereby accelerating germination processes. Several studies have shown that creating microscopic pores in hard-coated seeds using laser technology can significantly increase germination rates [4].

Results and analysis. The most extensively studied application of lasers in agriculture is the pre-sowing laser treatment of seeds. Long-term research in this field was conducted by Professor Ryszard Koper and his colleagues at the University of Agriculture in Lublin, Poland. R. Koper worked at the Lublin

Agricultural Academy and spent more than thirty years investigating the effects of laser radiation on seeds and plants. In his studies, he primarily used helium-neon (He-Ne) lasers. The scientist sought to determine the effectiveness of pre-sowing laser treatment of wheat, barley, maize, sugar beet, rapeseed, and other crop seeds. According to his findings, laser treatment increased maize yield by 10–20%, spring wheat yield by 20–30%, barley yield by 20–25%, and sugar beet yield by 10–35%. In addition, sugar beet plants exhibited increased root mass and sugar content, enhanced resistance to cold and drought stress, and significantly improved seed germination energy [5].

Koper's scientific work was also focused on understanding the biological mechanisms underlying laser effects. He emphasized that laser radiation can stimulate cellular metabolism, enhance mitochondrial activity, and accelerate energy exchange processes. According to Koper, laser biostimulation increases ATP synthesis within cells, which in turn promotes faster plant growth and development. The results obtained by Koper's research school were later confirmed in other European countries and played an important role in establishing the scientific foundations of laser biostimulation [5].

Mexican scientist Carlos Hernández-Aguilar is one of the researchers who made a significant contribution to the study of the effects of laser technologies on plant physiology. Together with his colleagues, he investigated the influence of laser radiation on maize, bean, pepper, and tomato seeds. During these studies, red and green lasers of different power levels were applied. The researchers found that laser treatment increased the rate of water uptake by seeds, improved seed coat permeability, enhanced the activity of the enzyme α-amylase, accelerated starch degradation, and promoted stronger root system development [6].

Hernández-Aguilar demonstrated that the primary mechanism underlying laser effects is associated with the activation of the phytochrome system. He provided scientific evidence that laser radiation positively influences the synthesis of photosynthetic pigments. These studies contributed significantly to explaining the effects of lasers on the physiological and biochemical processes occurring within plant organisms [6].

A research group led by Hasan conducted an in-depth investigation into the effects of laser photobiomodulation on maize seeds. Using green lasers, they analyzed germination percentage, seed germination energy, root and shoot length, photosynthetic intensity, and biomass accumulation. The results showed that the germination rate of laser-treated seeds was significantly higher than that of the control group. Due to the stronger development of the root system, the plants were able to absorb water and mineral nutrients from the soil more efficiently. Hasan emphasized that lasers can be used in agriculture as environmentally safe biostimulants [7].

Studies of S. Aftab and colleagues on wheat. Pakistani scientist S. Aftab conducted a series of experiments on the biostimulation of wheat seeds using laser irradiation. His research examined seed germination, root and shoot length, chlorophyll content, protein synthesis, and the activity of antioxidant enzymes. The results showed that plants grown from laser-treated seeds exhibited increased activity of catalase, peroxidase, and superoxide dismutase enzymes. These enzymes protect plants against the harmful effects of free radicals. As a result, plants originating from laser-treated seeds were more resistant to unfavorable environmental conditions. Aftab's studies demonstrated that laser irradiation activates plant defense mechanisms against physiological stress factors [8].

A research team led by M. Nadimi investigated the potential use of laser technology for restoring the germination capacity of seeds that had been stored for extended periods. During the study, physiologically aged seeds resulting from long-term storage were subjected to laser treatment. The results indicated improved germination performance, restoration of seed metabolic activity, enhanced functioning of enzyme systems, and accelerated energy metabolism. The authors concluded that laser irradiation can partially compensate for seed aging processes. These findings have considerable practical importance for seed production and seed storage enterprises [9].

In recent years, a research group headed by Eman Yousef investigated the role of laser technologies in garlic cultivation. Using helium-neon (He-Ne) lasers to treat planting materials, the researchers evaluated

parameters such as yield, nutrient use efficiency, photosynthetic performance, bulb weight, and chlorophyll content. In a study published in 2026, the effects of He-Ne laser irradiation on garlic crops were examined. The results showed that laser-treated plants exhibited a 20.5% increase in plant height, a 48.1% increase in green biomass, a 29.1% increase in bulb weight, and up to a 29% increase in total yield. Furthermore, nitrogen use efficiency increased by 146%, while phosphorus and potassium uptake improved significantly. The researchers demonstrated that laser irradiation optimizes plant nutrient acquisition systems and enhances the uptake of mineral elements [10].

Numerous experiments conducted by scientists from Egypt, India, Poland, and Mexico have also demonstrated that laser treatment increases chlorophyll content, stimulates photosynthetic activity, enhances protein and carbohydrate accumulation, and improves the uptake of mineral nutrients. In particular, sugar content in sugar beet was reported to increase from 15% to 17%, while protein content in wheat grains increased by approximately 2% [11].

At present, lasers are used not only as biostimulants but also as an important component of modern agricultural production. For example, LiDAR (Light Detection and Ranging) technology is used to create three-dimensional maps of agricultural fields, assess plant biomass, identify diseases and stress conditions, and predict crop yields [12]. Laser land-leveling technology improves irrigation efficiency and reduces water consumption. Research indicates that such technologies can reduce crop production costs and significantly improve water-use efficiency in agriculture.

Another promising area of laser application in agriculture is weed control. Danish scientists Ivan Rakhmatulin and Christian Andreasen have made significant contributions to the development of automated robotic systems based on laser technology. According to their concept, a camera system detects weeds, artificial intelligence classifies them, and a laser beam is directed at the weed’s growth point, causing thermal damage to its cells. This method reduces the need for herbicides and ensures a high level of environmental safety. These studies provide an important scientific foundation for the development of future robotic agricultural systems [13].

Under conditions of climate change, the development of crop varieties that are resistant to drought, salinity, low temperatures, and heavy metal stress has become increasingly important. Numerous studies have demonstrated that laser treatment can enhance drought tolerance, improve adaptation to saline conditions, increase cold resistance, and strengthen the antioxidant defense system of plants. In particular, helium-neon (He-Ne) lasers have been shown to improve plant growth in lead-contaminated environments and activate plant stress-response mechanisms [14].

Despite the many advantages of laser technologies, several challenges remain. These include the need to determine the optimal dose and exposure time individually for each crop species, the possibility of tissue damage caused by high-power lasers, the relatively high cost of equipment required for large-scale applications, and the fact that the biological mechanisms of laser action have not yet been fully understood. Therefore, a deeper investigation of laser effects on plant physiology at the molecular and genomic levels remains an important scientific challenge [15].

Conclusion. The scientific literature analyzed in this study demonstrates that laser technologies possess considerable potential for agricultural applications. Laser irradiation can be used to improve seed germination, accelerate plant growth and development, increase crop productivity, and enhance product quality. In addition, lasers play an important role in precision agriculture, environmentally friendly weed management, remote monitoring, and resource-saving technologies. In the future, the integration of artificial intelligence, robotics, LiDAR systems, and laser technologies is expected to bring agriculture to a new stage of development. Therefore, comprehensive research into laser technologies and their widespread implementation in agricultural practice are among the key factors for ensuring global food security.

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