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# BIOTECHNOLOGY FOR INCREASING IMMUNE SYSTEM RESILIENCE AND COTTON PRODUCTIVITY TO ABIOTIC STRESS USING CHLORELLA VULGARIS GROWN IN A "SPECIALLY MODIFIED NUTRIENT MEDIUM"

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According to numerous literature sources and scientific studies conducted by both international and domestic researchers, the unicellular microalga Chlorella vulgaris contains more than 650 organic and inorganic compounds.

Plants such as cotton activate a range of internal defense mechanisms in response to abiotic stress factors, including soil salinity, high temperatures, and drought. Among these mechanisms, amino acids and other biologically active compounds play a crucial role in enhancing stress tolerance and maintaining physiological functions.

Several amino acids, including proline, glycine betaine, asparagine, glutamine, arginine, and citrulline, are particularly important in improving plant resistance to adverse environmental conditions. These compounds contribute to osmotic adjustment, cellular protection, and the stabilization of metabolic processes under stress.

Under saline and drought conditions, proline accumulates in large quantities within plant cells, functioning as an osmoprotectant. It helps prevent water loss, maintains cellular osmotic balance, and protects proteins and cellular structures from stress-induced damage. In cotton plants exposed to salinity and heat stress, increased proline accumulation has been associated with enhanced stress tolerance and improved adaptation to unfavorable environmental conditions [1].

Similarly, glycine betaine plays an important role in maintaining osmotic balance in plant cells under conditions of salinity and high temperatures. It also enhances the ability of cotton roots to absorb water when irrigated with saline water. In addition, glycine betaine supports the photosynthetic process and contributes to the maintenance of cellular metabolism under stress conditions.

Asparagine and glutamine serve as important compounds for nitrogen storage and transport within plants. Under saline conditions, plants accumulate nitrogen in the form of asparagine and glutamine, which contributes to increased stress tolerance and improved adaptation to adverse environmental conditions [2].

Under drought and salinity stress, the concentrations of arginine and citrulline increase in cotton tissues. These amino acids enhance the antioxidant defense system and protect cells from oxidative stress caused by reactive oxygen species and free radicals [3].

In addition to amino acids, other biologically active compounds play significant roles in helping cotton plants survive under stressful environmental conditions. Antioxidant enzymes, including superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD), are particularly important in mitigating the damaging effects of salinity and heat stress. These enzymes protect cellular components by scavenging reactive oxygen species and reducing oxidative damage.

Furthermore, polyamines such as putrescine, spermine, and spermidine contribute to enhanced tolerance to salinity and heat stress. These compounds strengthen cell wall integrity, promote cell growth and development, and improve the overall adaptive capacity of plants under adverse environmental conditions.

Osmolytes such as trehalose, mannitol, and sorbitol contribute to the maintenance of osmotic balance in cotton cells and help prevent water loss under adverse environmental conditions.

Jasmonic acid and salicylates, which belong to the jasmonate and salicylate signaling pathways, activate plant signaling systems and trigger defense mechanisms that enhance tolerance to abiotic stresses.

Seed treatment with compounds such as proline or glycine betaine at the time of sowing can enhance the stress-response capacity of plants, improving their ability to withstand unfavorable environmental conditions.

The application of microalgae and beneficial microorganisms, including Azotobacter and Rhizobium species, supports cotton root development under saline conditions and stimulates the biosynthesis of amino acids and other stress-related metabolites, thereby improving plant growth and stress tolerance.

Unicellular green microalgae are highly efficient photosynthetic organisms and among the largest biological producers of oxygen on Earth. They play a crucial role in maintaining ecosystem functions and promoting environmental sustainability. Consequently, microalgae represent a promising biological resource for improving crop productivity and supporting sustainable agricultural practices.

Microalgae contain a wide range of bioactive compounds, including enzymes, free and organic amino acids, phytohormones, secondary metabolites, vitamin precursors, and vitamins [4]. In addition, they provide essential nutrients and plant growth regulators such as auxins and cytokinins, which play key roles in regulating plant growth, development, and physiological processes [5].

Due to their rich biochemical composition and biological activity, microalgae have attracted considerable attention as environmentally friendly biostimulants for enhancing plant growth, improving stress tolerance, and increasing agricultural productivity.

Based on the available data, it can be concluded that the current anomalous climate changes, water scarcity in the Bukhara region of the Republic of Uzbekistan, rising temperatures, and the prolonged occurrence of hot and dry winds (garmsil) are contributing to increased soil salinity and land degradation.

At the same time, despite these unfavorable environmental conditions, the population continues to grow, increasing the demand for food and agricultural products. Therefore, the development and implementation of sustainable agricultural technologies capable of maintaining crop productivity under abiotic stress conditions have become increasingly important.

To mitigate the adverse effects of salinity, drought, and other abiotic stresses, and to ensure the production of high-quality and high-yielding cotton and other agricultural crops, the use of the green microalga Chlorella vulgaris represents a promising approach. Owing to its broad-spectrum biological activity and beneficial effects on plant growth, stress tolerance, and environmental sustainability, Chlorella vulgaris may serve as an effective biotechnological tool for improving agricultural productivity while contributing positively to the agroecosystem as a whole.

The application of Chlorella vulgaris cultivated in a specially modified nutrient medium may also contribute to reducing the incidence of fungal and viral diseases, as well as decreasing the accumulation of toxic substances in the soil. This effect is achieved through the enrichment of the culture medium with macro- and micronutrients that enhance plant tolerance to soil salinity, water deficiency, and hot dry winds (garmsil), as well as through the supplementation of compounds that stimulate the biosynthesis of osmolytes.

Under the saline and unfavorable soil conditions of the Bukhara region, particularly in fields where crop rotation is not practiced, plants often experience difficulties in absorbing phosphorus and other essential nutrients during their growth and development. As a result, nutrient utilization efficiency decreases, negatively affecting plant productivity and stress resistance.

To prevent root rot, gummosis, and plant wilting, and to enhance the disease resistance and overall immunity of cotton plants, cotton seeds were treated with two different concentrations (40% and 60%) of Chlorella vulgaris cultivated in a specially modified nutrient medium. In addition, the microalgal suspension was applied during the growing season through a drip irrigation system to evaluate its effects on plant health, stress tolerance, and productivity under field conditions.

The greatest reduction in disease incidence compared with the control treatment was observed in Variant 3, in which Chlorella vulgaris was applied at a concentration of 60%. The plant population density in this treatment reached 1,050 plants per 100 $m^2$.

Assessment of disease incidence revealed a 17% reduction in root rot, a 13.5% reduction in gummosis, and a 27% reduction in plant wilt compared with the control treatment. In addition, an overall enhancement of plant immunity was observed.

These findings indicate that the application of Chlorella vulgaris cultivated in a specially modified nutrient medium can effectively improve cotton resistance to abiotic stress conditions. The treatment appears to reduce the accumulation of reactive oxygen species (ROS), which are major contributors to stress-induced cellular damage, while simultaneously activating the antioxidant defense system. Furthermore, the observed increase in plant immunity may be associated with elevated salicylic acid levels, which play a key role in the regulation of plant defense responses and stress adaptation mechanisms.

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