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ENHANCING PISTACHIO GROWTH: THE PHYSIOLOGICAL AND AGRONOMIC IMPACTS OF BIOSTIMULATORS ON VARIETAL PERFORMANCE AND YIELD

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Abstract. This study explores the physiological, biochemical, and agronomic impacts of biostimulants on pistachio trees, emphasizing their potential to enhance growth, yield, and stress tolerance across different varieties. Biostimulants, including microbial inoculants, plant extracts, and growth regulators, are shown to promote root development, nutrient absorption, and photosynthetic efficiency. They also improve pistachio resilience under abiotic stresses like drought and salinity by stimulating antioxidant activity and enhancing metabolic pathways. The findings underline the varietal specificity of responses, suggesting the need for targeted biostimulant applications. Moreover, the use of biostimulants supports more sustainable agricultural practices by reducing dependence on chemical fertilizers and enhancing soil health. The integration of these substances not only boosts pistachio productivity but also aligns with broader environmental and economic goals in modern horticulture
Keywords: Pistachio cultivation, biostimulants, plant growth regulators, abiotic stress, varietal response, nutrient absorption, antioxidant activity, yield enhancement, soil health.

Introduction. Biostimulators have become a pivotal component of sustainable agriculture, in particular in the culture of high value cultures such as pistachios. Defined by Calvo et al. [7] As substances that promote plant growth and improve resilience without acting as fertilizers or pesticides, biostimulants include a diverse range of organic and inorganic materials, including humic substances, algae extracts, microbial inoculants and plant extracts. The functional classification of biostimulants often focuses on their action mechanisms, which can be largely classified into three main groups: those which directly stimulate plant growth, those which improve the absorption of nutrients and those which induce resistance to biotic and abiotic stress (from the garden, 2015).

In the context of pistachio culture, which is characterized by its particular environmental and nutritional requirements, biostimulants have the potential to considerably influence performance and growth yield. Biostimulants have been shown to improve various critical physiological processes for plant development. For example, they can promote the development of roots, which is essential for effective absorption of nutrients and water, in particular in soils poor in nutrients or drought commonly found in regions cultivated by pistachio [15]. Studies have shown that biostimulant applications can lead to an increase in root biomass, a larger root surface area and root-to-shoot ratios, which all contribute to improved vigor and productivity in pistachios [13].

In addition, biostimulants can act on biochemical routes that improve the physiological performance of pistachios in stress conditions. For example, stimulation of antioxidant enzymatic activity and improving photosynthetic efficiency have been reported as key responses to biostimulant treatments. These biochemical changes improve not only the plant's ability to deal with environmental stressors such as drought and salinity, but also contribute to overall growth and yield results.

Previous research indicates that different varieties of pistachios can respond differently to biostimulant applications, stressing the importance of exploring specific responses to varietary in the context of biostimulant use. Investigations have shown that certain varieties have higher performance in terms of growth and yield when treated with specific biostimulants, alluding to a complex interaction between the plant genotype and the active components of the biostimulant. This variation underlines the need to personalize biostimulant applications not only with existing environmental conditions but also to the specific physiological needs of each variety of pistachio. The agronomic advantages of the use of biostimulants in pistachio culture extend beyond the simple promotion of growth; They can also lead to more sustainable agricultural practices by reducing dependence on chemical fertilizers. By improving the availability of nutrients and absorption efficiency, biostimulants can mitigate the negative environmental impacts associated with excessive use of fertilizers while simultaneously improving the quality and performance of crops. Thus, the incorporation of biostimulants promotes a double advantage: promoting agronomic productivity and improving environmental sustainability.

Given the growing interest in organic agricultural systems and sustainable practices, the growing body of literature highlights the important role that biostimulants can play in optimizing pistachio culture. This section establishes the platform for a more detailed exploration of specific biochemical and agronomic impacts associated with the use of biostimulants, highlighting their potential as a viable agricultural entre to improve the growth performance of pistachios through various varieties.

Methods. The methodological approach included the following steps:

Literature Analysis: Peer-reviewed articles, experimental studies, and review papers published between 2020 and 2025 were analyzed. These sources provided insights into the mechanisms, applications, and outcomes of biostimulant use in pistachio production.

Comparison of Biostimulant Types: The review covered a broad spectrum of biostimulants, including humic substances, microbial inoculants, amino acids, seaweed extracts (notably *Ascophyllum nodosum*), and plant growth regulators such as gibberellins and cytokinins. Their roles in enhancing plant growth and stress tolerance were evaluated.

Assessment of Physiological and Biochemical Parameters: Key plant performance indicators such as root biomass, chlorophyll content, photosynthetic activity, and antioxidant enzyme responses were examined based on reported findings across multiple studies.

Varietal Response Analysis: The study highlighted the differential responses of pistachio cultivars to biostimulant treatments, emphasizing genotype-specific interactions and the need for tailored application strategies.

Evaluation of Agronomic and Environmental Benefits: Beyond plant-level responses, the analysis also explored the contributions of biostimulants to soil health, water retention, microbial activity, and sustainable agricultural practices.

Discussion and results. Biostimulators have been shown, including micronutrients and plant growth regulators, significantly influence the physiological and biochemical responses of various varieties of pistachio. In particular, the application of biostimulators has shown potential in improving tolerance to abiotic stress and the success of reproduction. Tadayon and Hosseini [17] reported that the treatments with biostimulators have resulted in an improvement in the chlorophyll content of the sheets and photosynthetic efficiency, in correlation directly with improved growth performance under normative and stress conditions. The role of micronutrients, in particular under conditions of deficiency in nutrients, has been emphasized because they are essential for various physiological processes and can alleviate the limits that occur during environmental stressors.

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Khalid et al. [11] also explored the implications of plant growth regulators (PGR) on pistachios, noting that applications such as gibberellins and cytokinines increased fruit rating and development, leading to higher yields (fig.1). These PGRs not only promote cell division and elongation, but also improve the accumulation of carbohydrates and other metabolites, which are crucial for the development and maturation of seeds. Their results suggest that PGRs have synergistic effects when combined with biostimulators, leading to optimized growth conditions and to improve biochemical routes.

The incorporation of biostimulants has also been associated with an increase in essential amino acids and bioactive compounds in pistachio nuts. Alfosea-Simón et al. [2] have documented significant elevations of essential amino acid levels such as arginine and proline after the application of biostimulants. These amino acids play a crucial role in various physiological functions, including protein synthesis and stress responses. Gupta et al. [8] corroborated these results, demonstrating that the biostimulant treated pistachios had higher concentrations of bioactive compounds, such as polyphenols and flavonoids, known for their antioxidant properties. These improvements contribute not only to the nutritional value of pistachios, but also have implications for the quality and marketing of post-harvest.

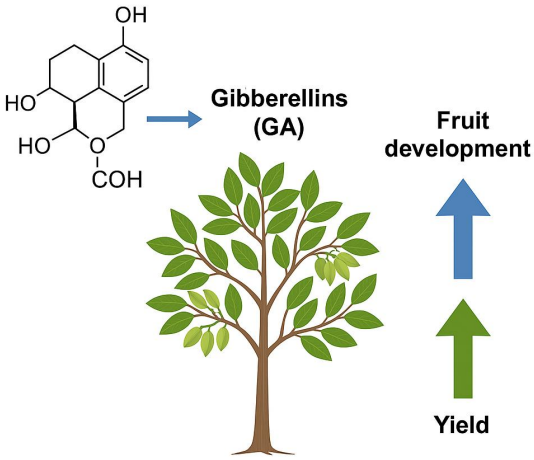

Figure 1. Role of gibberellins in promoting fruit development in pistachio cultivars

Another key survey area concerns the effects of foliar applications from algae extracts, in particular those derived from *Ascophyllum nodosum* (fig.2). Yahid et al. [20] highlighted their ability to alleviate abiotic stress such as drought and salinity, the common challenges faced by pistachio culture. The study revealed that the application of algae extracts improves physiological parameters such as leaf water potential and stomatic conductance, promoting better water use effectiveness. In addition, biochemical analysis indicated an increase in enzymatic activity linked to the response to stress and increased antioxidant capacity in treated plants. The interaction between these factors supports the hypothesis that biostimulators play a vital role in strengthening the resilience of pistachio varieties against difficult environmental conditions.

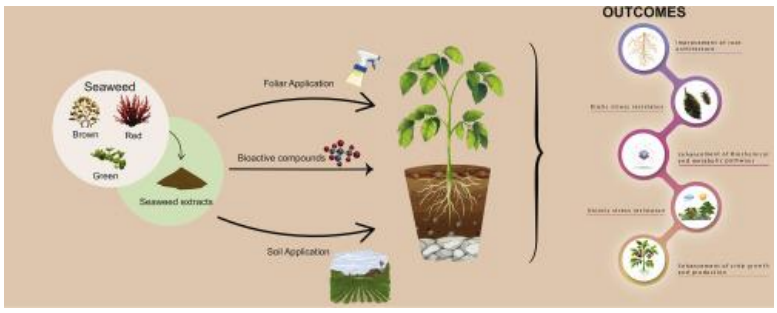

Figure 2. Mechanism of action and outcomes of seaweed extract application in plants. *Source: Reyes, C. A., et al. (2024).*

In summary, the physiological and biochemical advantages derived from the application of biostimulators in pistachios highlight their meaning in improving growth performance and yield. As researching in this area is progressing, additional elucidation of these mechanisms can provide valuable information on the optimization of cultivation practices for different pistachios varieties in various agricultural conditions., The agronomic performance of pistachio trees, in particular as regards the improvement of the surrender, have been significantly

influenced by the application of biostimulators. Recent results highlight the positive impacts of these substances on various yield metrics, including fruit size, general number and quality. For example, Kilic [12] has shown that the application of a specific biostimulator formulation has led to a significant increase in both the size and the amount of pistachio walnuts, which are critical factors for commercial vitality. Similar results were reported by Tegou et al. [19], which have quantified the improvements in the yield parameters in different pistachios cultivars subjected to biostimulating treatments. Their research has provided solid tests in support of the affirmation that biostimulators can actually increase productivity in pistachio orchards, thus presenting a precious tool to improve economic returns for farmers.

In addition, the application of biostimulants is not only related to improved performance results, but it also seems to extend to the agronomic practices that support sustainable agriculture. Batelja Lodeta et al. [4] explored the role of biostimulants in promoting biological agricultural practices, improving the availability of nutrients in the soil profile. Their results indicated that the use of biostimulator improves soil health, largely through the stimulation of the microbial activity that facilitates the cycle of nutrients and improves soil fertility. This is particularly salient in the cultivation of pistachio, in which the demand for sustainable practices is increasing due to growing environmental pressure and the need for resilience against climate change. Albasri et al. [1] have further confirmed this notion, illustrating how the biostimulating application leads to better soil structure and water retention capacity, which are crucial to optimize growth conditions in the arid and semi-arid regions in which pistachio trees are mainly cultivated.

The adoption of biostimulants in pistachio agriculture can therefore be seen as a multifaceted approach that not only elevates the performance potential, but also contributes to improving soil health and sustainable agronomic practices. The combined physiological and biochemical improvements detected in the previous sections can be connected to these improvements in agronomic performance. Biostimulants optimize the absorption and distribution of nutrients, thus translating molecular benefits into visible agronomic production. The empirical evidence underlines the potential for biostimulants to facilitate transitions to more sustainable agricultural systems, pushing the pistachio industry towards ecologically resistant and economically advantageous practices. This aligns with wider movements in agricultural research that support the integration of biostimulatory substances in traditional agricultural systems as a means of combating the challenges of modern agriculture, including the degradation of the soil and the search for organic certification. The strategic implementation of these products is about to revolutionize the cultivation of pistachios, promoting a holistic approach that interconnected produces improvements with sustainable development objectives. The exploration of this dimensions in the context of the agriculture of the pistachio is a crucial progress in agronomic science, creating a base for future research and practical applications on the field.

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