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# REVIEW OF THE USE OF BIOSTIMULANT MICROALGAE TO INFLUENCE THE GROWTH AND DEVELOPMENT OF ORNAMENTAL PLANTS

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## ABSTRACT

The concept of plant biostimulants refers to substances or microorganisms used to improve the efficiency of nutrient uptake of a plant, improve stress tolerance, and improve overall quality. Extracts of microalgae are gaining increasing attention among biostimulants due to their rich bioactive content. Microalgae offer new opportunities in agriculture, wastewater treatment, pharmaceuticals, etc. These tiny organisms are known for their role in carbon dioxide sequestration, bioremediation, and the production of valuable compounds. Biostimulants act on plants through various mechanisms, promoting growth, nutrient mobilisation, and resistance to stress. The abundant amino acids and protein hydrolyzesate in microalgae improve nutrient absorption and act as osmoprotectants against stressors such as heavy metals and salt. The visual appearance of the potted plants plays a crucial role in determining their quality. Although research suggests a consumer preference for organically grown plants, the economic viability of organic ornamental plant production requires careful consideration of production costs and market demand. With the increasing demand for sustainable agricultural practices, the application of plant biostimulants, particularly those derived from microalgae, presents a promising opportunity to enhance productivity, improve soil health, address environmental issues, and overcome challenges posed by new regulations in the European Union related to the use of plant protection products.

**Keywords:** biostimulant, horticulture, ornamental plants, organic fertilisers, microalgae

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## PRESENTATION AND EVALUATION OF DOMESTIC AND FOREIGN LITERATURE

Ornamental plants are widely used for landscaping and interior and exterior decoration, and are remarkably effective in shading technology, especially in warm seasons. The demand for such plants is increasing rapidly, which leads to the use of different methods to improve their growth and development. According to Somogyi et al (2022), biostimulants are one of the methods that can enhance the growth and development of the plant naturally. Microalgae are one of the biostimulants that have been studied extensively for their potential to enhance plant growth and development. To examine future possibilities, we have to understand the positive effects of biostimulants. In addition to their ecological significance in generating oxygen and serving as the foundation of aquatic food chains, algae are economically important as a valuable source of crude oil, food and numerous pharmaceutical and industrial products for human use (Somogyi et al, 2013). Algae exhibit a wide range of sizes that span seven orders of magnitude. Some algae are composed of a single cell, while the largest algae can consist of millions of cells. Microalgae are unicellular or multicellular photosynthetic microorganisms that are found in marine and freshwater environments. In macroscopic algae, various groups of cells are specialised to perform specific functions, including anchorage, transport, photosynthesis, and reproduction. It is worth noting that algae taxonomy is a subject of ongoing debate and is susceptible to rapid changes as new molecular information emerges (Horváth, Molnár, & Ördög, 2016). Algae are found almost everywhere around the world and can be classified ecologically according to their habitats. Planktonic algae are microscopic, thrive in the water column, while neustonic algae grow on the surface of the water and can be either micro- or macroscopic. Cryophilic algae are found in snow and ice, as seen in phenomena such as red snow, while thermophilic algae inhabit hot springs. Edaphic algae live in or in the soil, epizoic algae grow in animals such as turtles and sloths, and epiphytic algae grow in fungi, land plants, or other algae. Corticolous algae thrive on the bark of trees, epilithic algae inhabit rocks, and endolithic algae live within porous rocks or coral. Some algae even live within other organisms (Pradeep & Maulin, 2021). Under certain advantageous circumstances, such as nutrient enrichment, elevated temperature, pH, water column stability, and increased exposure to sunlight, they can quickly reproduce and multiply. They form so-called blooms, which have the potential to pose a threat to the environment, animals, and human health. Certain bloom-forming cyanobacteria also produce secondary toxic metabolites such as cyanotoxins (Graham, Graham, & Wilcox, 2009). This article will explore the use of biostimulant microalgae to influence the growth and development of ornamental plants.

## WHAT ARE BIOSTIMULANTS?

A plant biostimulant refers to any substance or microorganism used in plants to enhance their nutrient efficiency, tolerance to abiotic stress, and / or overall quality attributes, without regard to its actual nutrient composition (Chiaiese et al, 2018). Biostimulants can be defined as small amounts of organic or inorganic substances that promote plant growth and development in ways that plants would not be able to do without the addition of these compounds. They can also be called "positive

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growth regulators" or "metabolic enhancers" (Schmidt, Ervin, & Zhang, 2003). Biostimulants can be applied to plants as foliar sprays, soil drenches, or seed treatments. They are composed of a wide range of substances, such as amino acids, carbohydrates, vitamins, enzymes, and microorganisms. Zhang & Schmidt (1997) first used the term ‘plant biostimulant’ and the industry based on it has evolved, as have the materials and technologies used. In 2014, Calvo, Nelson, & Kloepper (2014) defined all substances and microorganisms that are beneficial to plants as biostimulants. A year later, in 2015, Du Jardin (2015) noted that the definition of biostimulants is based on what is not a biostimulant rather than what it is. For example, fertilisers and pesticides increase plant productivity but are not biostimulants (Zhang & Schmidt, 1997). Biostimulants are also defined as non-plant nutrients and therefore cannot be characterised by nutrient composition claims. In the United States, the Coalition of Biostimulants defines biostimulants as substances, including microorganisms, that when applied to the plant, seed, soil, or growing medium, enhance the capacity to absorb nutrients of plants and have a beneficial effect on plant growth (Ördög et al, 2013). Although they affect growth and development, they also increase resistance to abiotic stresses (Colla et al, 2016). In 2016, the European Commission classified biostimulants as CE (*conformité européenne)*, which means that they are fertilisers that promote plant growth and development regardless of the amount applied (Plaza, Gómez-Serrano, Acién-Fernández, & Jiménez-Becker, 2018). In 2018, the *Council of the* European Union amended the definition to include, in addition to the above, one of the following effects on the rhizosphere directly at the root of the plant:

- More efficient use of nutrients
- Tolerance to abiotic stress
- The Impact on Plant Quality
- The availability of limited nutrients in the soil or rhizosphere (Biostimulant Coalition, 2023 and European Commission, 2016).

Biostimulants belong to three main groups.

- Humic Substances
- Algae Extract
- Products containing amino acids (Mutale-joan et al, 2020).

They are used in various applications such as food, feed, biofuels, and pharmaceuticals. Microalgae are rich in bioactive compounds such as polysaccharides, proteins, amino acids, vitamins, and antioxidants that have the potential to enhance plant growth and development. Furthermore, microalgae are well-known for their application in bioremediation, particularly in wastewater treatment, because of their exceptional ability to capture atmospheric carbon dioxide. They are also used as raw materials due to the wide range of bioactive compounds they contain, which form the building blocks of microalgae (Du Jardin, 2015). In addition to this, the presence of specific algae species in wetlands or water tanks can indicate potential health hazards and water safety problems. The use of microalgae is becoming increasingly important in the pharmaceutical and beauty industries as well as in food substitutes, and further experiments are underway in the energy industry (Pavlova, Stoyneva, Babica, Kohoutek, & Bratanova, 2007).

According to Abbott et al (2018) biological modifiers can be classified into the following three main types:

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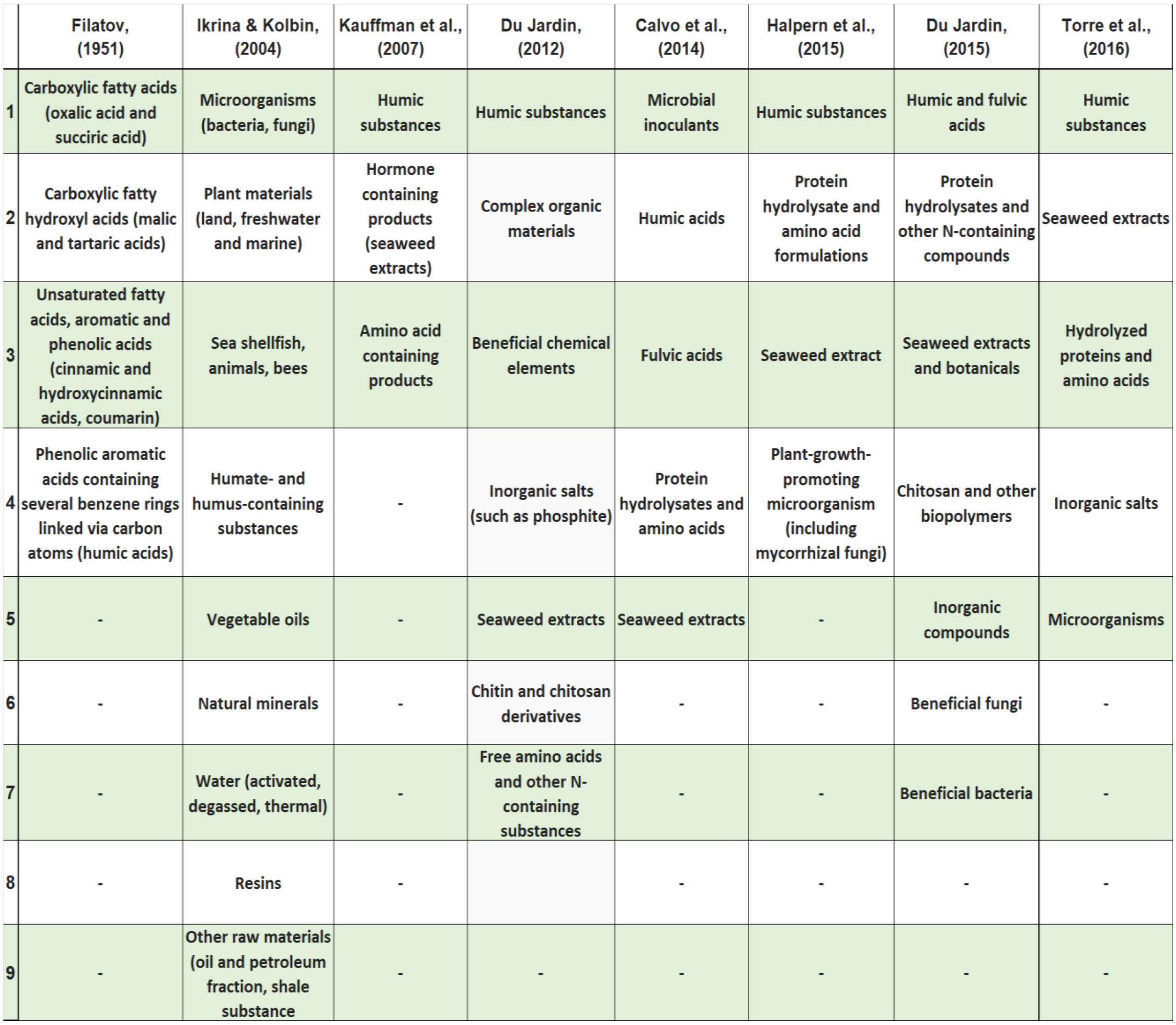
- Biostimulants,
- Organic materials, and
- Microbial inoculants.

Within this classification system (see *Table 1.* Abbott et al, 2018) biostimulants include amino acids, chitosan, seaweed extracts and humic substances. The mechanism of action of biostimulants is largely unknown, and they can only be used after their safety and efficacy have been proved through extensive tests.

*Table 1* Proposed biostimulant categories
(The numbering of the columns represents the 9 categories.)



| | Filatov, (1951) | Ikrina & Kolbin, (2004) | Kauffman et al., (2007) | Du Jardin, (2012) | Calvo et al., (2014) | Halpern et al., (2015) | Du Jardin, (2015) | Torre et al., (2016) |
|---|---|---|---|---|---|---|---|---|
| 1 | Carboxylic fatty acids (oxalic acid and succiric acid) | Microorganisms (bacteria, fungi) | Humic substances | Humic substances | Microbial inoculants | Humic substances | Humic and fulvic acids | Humic substances |
| 2 | Carboxylic fatty hydroxyl acids (malic and tartaric acids) | Plant materials (land, freshwater and marine) | Hormone containing products (seaweed extracts) | Complex organic materials | Humic acids | Protein hydrolysate and amino acid formulations | Protein hydrolysates and other N-containing compounds | Seaweed extracts |
| 3 | Unsaturated fatty acids, aromatic and phenolic acids (cinnamic and hydroxycinnamic acids, coumarin) | Sea shellfish, animals, bees | Amino acid containing products | Beneficial chemical elements | Fulvic acids | Seaweed extract | Seaweed extracts and botanicals | Hydrolyzed proteins and amino acids |
| 4 | Phenolic aromatic acids containing several benzene rings linked via carbon atoms (humic acids) | Humate- and humus-containing substances | - | Inorganic salts (such as phosphite) | Protein hydrolysates and amino acids | Plant-growth-promoting microorganism (including mycorrhizal fungi) | Chitosan and other biopolymers | Inorganic salts |
| 5 | - | Vegetable oils | - | Seaweed extracts | Seaweed extracts | - | Inorganic compounds | Microorganisms |
| 6 | - | Natural minerals | - | Chitin and chitosan derivatives | - | - | Beneficial fungi | - |
| 7 | - | Water (activated, degassed, thermal) | - | Free amino acids and other N-containing substances | - | - | Beneficial bacteria | - |
| 8 | - | Resins | - | | - | - | - | - |
| 9 | - | Other raw materials (oil and petroleum fraction, shale substance | - | - | - | - | - | - |

## PRACTICAL HORTICULTURAL APPLICATION

The decrease in societal acceptance of synthetic pesticides and pharmaceuticals in recent times has given impetus to the research of naturally derived active compounds, which is also supported by the European Union. Algae are valuable to agriculture mainly due to their regulatory and plant-protective effects (Ördög, 2015). As global demand for edible and ornamental plants is expected to double by 2050 (Singh, 2017), it is extremely important to find alternatives to increase plant cultivation productivity. Our planet's climate is set to undergo significant changes in the coming decades due to various environmental factors. As a consequence, the agricultural industry is going to face new challenges (Khare et al, 2023). Environmentally friendly farming and horticulture are receiving increasing attention, where the use of different plant conditioning agents can enhance the resistance of plants. Marine algae extract and microalgae preparations positively impact plant life processes, thus increasing both the quantity and quality of harvest (Khan, Rayirath, & Subramanian, 2009).

The use of plant biostimulants is increasing significantly in modern agriculture. Due to their diversity, microalgae, which are composed of eukaryotic and prokaryotic cyanobacteria (blue-green algae), have attracted great interest from researchers, plant growers, and various industrial segments. This is mainly due to its simple single-celled structure, high photosynthetic efficiency, heterotrophic growth potential, and valuable by-product production (Chiaiese et al, 2018). The development of innovative technologies based on biological resources, including plant biostimulants, has proven to be an effective method for improving the performance of crop and plant cultivation (Mutale-joan et al, 2020). Microalgae are classified primarily based on pigmentation, life cycle, and cell structure. The microalgae species available in commerce include the following species: *Sprinulla spp, Isochrysis spp; Chaetoceros spp; Chlorella spp, Arthrospira spp; Dunaliella spp*. From this list, the most commonly used species are *Arthrospira spp*. and *Chlorella spp.* (Ördög et al, 2013).

Microalgae are microscopic plants that contain potential bioactive substances in the form of proteins, lipids, glycerin, carotenes, and vitamins (Singh, Gupta, Guldhe, Rawat, & Bux, 2015). The potential of these microorganisms as a source of bioactive compounds can be attributed to their remarkable ability to synthesise useful products, such as polysaccharides, proteins, polyunsaturated fatty acids, lipids, and other bioactive metabolites, from atmospheric $CO_2$ (Mutale-joan et al, 2020). The presence of certain amino acids in microalgae extracts is expected to significantly increase the growth and yield of cultivated plants, as these microorganisms are metabolic precursors of various phytohormones (Colla et al, 2016). According to Katona, Horváth, Molnár, & Ördög, (2018), certain strains of MACC (microalgae consortia culture) produce valuable extracellular polysaccharides (EPS), which can serve as ingredients for soil conditioning products.

The hormone production of algae strains in Mosonmagyaróvár has been studied for nearly two decades at the Department of Plant Science. Through biotests and analytical methods, it has become apparent that both microalgae and macroscopic marine algae produce plant hormones (Ördög et al, 2013), making them suitable for special plant treatments. They affect, among other things, the reduction of transpiration, the increase in fruit set, the increase in the chlorophyll content of leaves, the protein content of fruit, as well as the development of roots and shoot

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development (Ördög & Pulz, 1996). Numerous studies have reported the positive effects of microalgae on plant growth. Foliar fertilisation with hydrolysed microalgae has been shown to accelerate plant development, resulting in stronger root mass growth, leaf and shoot development, as well as more intense flowering (Plaza, Gómez-Serrano, Acién-Fernández, & Jiménez-Becker, 2018). It is also important to mention that biostimulants added to the soil will soon be subjected to microbial degradation.

The agricultural sector is facing the challenge of increasing productivity to meet the ever-increasing demands of the growing world population, primarily by increasing the efficiency of resources. Plant growers are under immense pressure to boost their production. In recent years, the agricultural use of fertilisers and pesticides has greatly enhanced the food supply. However, this has resulted in severe consequences, such as environmental pollution and even substantial impacts on human health. Therefore, there is a gradual need to replace fertilisers and pesticides with environmentally friendly solutions that improve plant productivity, crop yield, and nutritional value (Gitau, Farkas, Ördög, & Maróti, 2022). Due to the harmful effects on ecosystems and human health, it is becoming increasingly important to reduce the use of synthetic fertilisers. One way to increase the uptake of plant nutrients in both agricultural and horticultural practices is through the use of biostimulants (Zulfiqar, Younis, Finnegan, & Ferrante, 2020; Van Oosten, Pepe, De Pascale, Silletti, & Maggio*,* 2017).

Microalgae-derived polysaccharides, protein hydrolysates, peptides, and free amino acids have been shown to increase plant productivity (Kapoore, Wood, & Llewellyn, 2021). These hydrolyses and amino acids primarily facilitate the mobilisation of nutrients in plants through the complexation and chelation of essential minerals, as indicated by Du Jardin (2015). Furthermore, certain amino acids such as glycine, betaine, and proline act as osmoprotectants and antioxidants, helping plants cope with abiotic stressors such as heavy metals and salinity (Bulgari et al, 2015). Furthermore, the application of amino acids and protein hydrolysates promotes the growth of plant-promoting bacteria by providing a reduced nitrogen source to the microflora, thus promoting a healthy soil microbiome (Colla et al, 2016; Lee & Ryu, 2021). Microalgae and cyanobacteria boast a high protein content, ranging from 63%, with amino acids comprising 40% to 48% of total proteins (Hempel et al, 2012). Specific amino acids such as arginine and tryptophan, abundant in species such as *Spirulina platensis*, make them particularly attractive for biostimulant applications, since they serve as precursors for polyamines and auxins, respectively (Bulgari, Franzoni, & Ferrante, 2019). Studies have demonstrated the positive effects of foliar applications of protein-rich extracts from *Spirulina platensis* on different plant species. For example, red beet, increased hypocotyl growth, chlorophyll content, and nutrient composition (Mógor, Ördög, Lima, Molnár, & Mógor, 2018). Similarly, in *Petunia × hybrida*, the application resulted in a higher flower number, fresh flower weight and dry weight (Plaza, Gómez-Serrano, Acién-Fernández, & Jiménez-Becker, 2018). Another study reported that green microalgae amino acid rich extracts improved solids content, total organic content, and capsaicinoids, which showed improved solids content, total organic content, and capsaicinoids levels in three varieties of hot pepper (*Capsicum spp.)* (Zamljen, Hudina, & Veberič, 2021). However, the study highlighted that the results were specific to each plant variety in response to biostimulatory treatments, according to Zamljen, Hudina, & Veberič (2021). In a broader sense, materials classified as biofertilizers or biopesticides also belong to this category. The term

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"biostimulants" often includes natural stimulants, including phenols, salicylic acid, humic acids, and fulvic acids or protein hydrolysates (Du Jardin, 2015). Their positive effect on horticultural production is mainly due to bioactive compounds that promote plant growth, such as phytohormones, amino acids, and nutrients (Zhang & Schmidt, 1997). Biostimulant preparations can be single or multicomponent, but the combined effect of several different components has also been observed. Biostimulants have been classified into several groups based on their application method (soil, foliar), raw materials used in their production (plant, animal), or the process by which they are formed (hydrolysis, fermentation, extraction) (Drobek, Frąc, & Cybulska, 2019). The development of new molecular biotechnological methods will soon help to understand the mechanisms and possible modes of action of biostimulants (Yakhin, Lubyanov, Yakhin, & Brown, 2017). Some studies have shown that biostimulators do not harm the environment or human health, as their biological toxicity is low, they rapidly decompose in the environment, and their mobility in food is low. Their use can be very important in improving the sustainability of agriculture, as they can promote increased production with less environmental impact (Yakhin, Lubyanov, Yakhin, & Brown, 2017; Caradonia et al, 2018). Research and application of biostimulants is developing rapidly. The demand for sustainable agricultural practices is increasing, with the exclusion of synthetic fertilisers and pesticides (Graham, Graham, & Wilcox, 2009) currently the laws in the European Union also limit the use of mineral fertilisers and pesticides. This forces a reduction in the use of chemicals, either through parallel application or partial replacement with products that can increase the effectiveness of traditional treatments. The new EU regulations have forced member states to modify or withdraw permits for products used in plant protection that contain active ingredients such as auxins (indole-3-acetic acid, IBA) (Singhal et al, 2022).

## METHODS OF APPLICATION OF MICROALGAE-BASED BIOFERTILIZERS AND BIOSTIMULANTS

Plants treated with suspensions of hormone-producing algae show improvement in several aspects (e.g., increased shoot and root length, increased leaf area and higher nutritional contents, protection against biotic and abiotic factors, etc.) (Gonçalves, 2021).

The application of microalgae-based biofertilizers and biostimulants varies according to their form and intended purpose. Live or dried biomass from cyanobacteria and microalgae can be mixed directly with the soil or used as seed sprigs by dipping seeds in cellular extracts of microalgae. Root drenching is another common method in which biofertilizers or biostimulants are mixed proportionately during sowing to enhance plant growth and nutrient absorption (Lee & Ryu, 2021). The choice of application method depends on the specific needs of the plant, such as nutrient supplementation, micronutrient enrichment, or disease suppression, and also whether the plant is seeded directly or grown in nurseries and then transplanted (Renuka, Guldhe, Prasanna, Singh, & Bux, 2018).

Roots serve as the crucial interface between soil and plants, sustaining plant growth by facilitating nutrient mobilisation, responding to external stimuli, and initiating defence mechanisms against stressors (Ma et al, 2022). The soil, on the other hand, is a finite and non-renewable resource that forms the foundation of agriculture. Ensuring the health of both the roots and the soil is essential for sustainable agriculture, achieved through the application of soil conditioners and fertilisers that replenish the health of the soil and provide nutrients to the roots. However, intensive agricultural practices relying on chemical fertilisers and conditioners have led to issues such as soil compaction, acidification, decreased fertility, and imbalances in soil microflora, which exacerbate soil diseases (Ye et al, 2020). As a result, there is a need to transition towards biodegradable and less harmful soil conditioners and fertilisers. Soil drenching is a technique that involves mixing biofertilizers or biostimulants proportionately during sowing to enhance plant growth. The mechanism of action of biostimulants / biofertilizers through soil drenching involves the agglomeration of soil particles with organic molecules such as polysaccharides, promoting the biological mineralisation of complex nutrients and restoring the soil microflora (Karthikeyan et al, 2009; Alvarez et al, 2021).

Plants require seventeen essential mineral elements, classified as macro and micronutrients, to support their proper growth and functioning. In addition to these, certain elements such as cerium (Ce), cobalt (Co), iodine (I), aluminium (Al), selenium (Se), sodium (Na), lanthanum (La), silicon (Si), titanium (Ti), and vanadium (V) are emerging as pivotal biostimulants, contributing to plant growth and stress tolerance. Although these elements are not universally required by all plants, their supplementation has been found to positively promote plant growth and improve tolerance to various abiotic and biotic stresses. Despite their crucial role in plant growth, the uptake, transport, and molecular understanding of these elements remain somewhat obscure compared to the well-known macro and micronutrients (Singhal et al, 2022).

Plants rely heavily on oxygen, an essential element, to fuel their cell organelles, such as chloroplasts and mitochondria, enabling the generation of sufficient energy for their growth. During plant metabolism, reactive oxygen species (ROS), such as hydrogen peroxide ($H_2O_2$), are produced as inherent by-products. These ROS play a crucial role in signal transduction and are produced in various cell compartments, including mitochondria, apoplast, endoplasmic reticulum, chloroplasts, and peroxisomes (Gill & Tuteja, 2010). Plants growing in natural environments are exposed to both biotic and abiotic stresses, which can lead to various molecular, biochemical, physiological, and morphological changes. One consequence of such stresses is the increased production of ROS, such as $H_2O_2$, causing oxidative stress that results in the degradation of cell membranes, proteins, nucleic acids, and lipids (Bajguz & Hayat, 2009). To counteract this, plants have developed various biochemicals and strategies to regulate physiological ROS production and cope with elevated ROS levels during stress (Apel and Hirt, 2004). Antioxidants, which can be enzymatic or non-enzymatic, play a vital role in this process and are present in almost all cell organelles, working together in a well-organised scheme (Gill & Tuteja, 2010; Szőllősi, 2014). Plant hormones known as brassinosteroids (BRs) can help alleviate stress by optimising antioxidant systems, including enzymatic ones, and scavenging free radicals (Rajewska, Talarek, & Bajguz, 2016; Soares et al, 2016). When applied to microalgae, BRs have been shown to enhance their growth, increase the accumulation of valuable bioproducts, and improve their resistance to various stresses. Additionally, the effects of BRs on the physiology of green algae have been previously reported (Piotrowska & Bajguz, 2011; Bajguz & Czerpak, 1998; Yu et al, 2015).

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## THE IMPACT OF BIOSTIMULANTS AND THEIR APPLICATION METHODS ON PLANT METABOLISM

As previously mentioned, the method of applying biostimulants depends primarily on the type of ornamental or edible plant and its specific needs, such as the enhancement of nutrients or tolerance to biotic and abiotic stresses. The application method and timing significantly impact the response of the plant to biostimulants. For example, a study with lettuce showed that the response to *Chlorella vulgaris* extracts differed between root drenching and foliar spray applications (Puglisi et al, 2022). When using root drenching, the microalgae extract had a significant influence on carbon metabolism, leading to increased activities of malate dehydrogenase and citrate synthase, key enzymes involved in carbon fixation (Krebs cycle). This was supported by an increase in carbon content in biomass, as well as an increase in root and shoot weight (Puglisi et al, 2022). On the other hand, both root drenching and foliar spray influenced nitrogen metabolism, as evidenced by increased activity of enzymes such as glutamate synthase and glutamine synthetase, resulting in enhanced protein content in the shoot, increased leaf pigments and biomass weight (Puglisi et al, 2022). Similar observations were made with the foliar application of *Scendesmus quadricauda* extracts in lettuce and commercial algae-based biostimulants in spinach, indicating enhanced nitrogen metabolism and increased nitrogen content of the shoot and root and biomass protein (Fan, LiGonzal, & Miguez-MachoGonzalo, 2013; Ronga et al, 2019; Puglisi et al, 2020).

In addition to supporting plant growth, biostimulant application activates secondary metabolism, promoting stress tolerance in plants. Many reports have shown enhanced tolerance to abiotic/biotic stress, which can be attributed to the increased activity of the enzyme PAL (Phenylalanine ammonia lyase) involved in the phenylpropanoid pathway responsible for synthesising phenolics and flavonoids, acting as defense molecules for plants (Dehghanian et al, 2022). Extracts derived from *Chlorella vulgaris* and *Scenedesmus quadricauda microalgae* significantly increased PAL activity in crops such as lettuce and sugar beet (Barone et al, 2018; Puglisi et al, 2020; Puglisi et al, 2022). Among the different application methods, foliar spray resulted in an instant increase in enzymatic activity compared to soil drenching, the PAL enzyme showing an immediate increase in activity after foliar spray and delayed expression in root drenched samples, indicating differences in physiological response time according to the application method (Puglisi et al, 2022). The faster physiological response to foliar spray could be attributed to the faster absorption rate through the stomata compared to root cells (Hong et al, 2021; Arahou et al, 2022). This has been supported by previous findings with nanofertiliser applications of micronutrients, where the foliar application of minerals resulted in better and faster modulation of plant growth compared to soil application (Alshaal & El-Ramady, 2017). For commercial and large-scale applications, root drenching and foliar spraying are often preferred methods of biostimulant application. However, for a faster physiological response in plants, foliar spray of biostimulants is generally preferred. It is essential to reiterate that the mode of application of biostimulants depends on the specific case and varies according to the plant's requirements (Priyanka, Raman, Yograj, & Vidyashankar, 2023).

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## APPLICATION OF ORGANIC FERTILISERS IN POTTED PLANTS

Potted ornamental plants are grown in greenhouses and include various types, including ornamental / bedding plants, herbs/lettuce, and vegetable transplants. The use of organic fertilisers in these potted plants presents challenges due to the limited volume of growing media available in the pots. This limitation restricts both the total application of suitable fertilisers for plants and the volume available to the microbial community responsible for the mineralisation of the organic fertilisers. It has been noted that there is a general lack of knowledge regarding organic production in pots (Treadwell et al, 2007).
Foliar feeding represents a method used to nourish plants by administering essential nutrients through the application of a liquid solution directly to their leaves. This process involves spraying an aqueous solution containing vital nutrients, which are then absorbed by the plants through specialised openings called stomata and the protective outer layer known as cuticles present on the surface of the leaf. Through these microscopic openings, the plant efficiently takes in the necessary nutrients, supporting its growth, development, and overall health (Fageria, Filho, Moreira, & Guimarães, 2015). The use of foliar spray can serve as a beneficial strategy when plants exhibit deficiencies in specific nutrients; however, it should not be considered a replacement for maintaining nutrient-rich and healthy soil. Furthermore, one notable advantage of employing foliar spray is its ability to bypass potential nutrient leaching from the soil, as the nutrients are directly applied to the plant's foliage. This method triggers a swift and targeted response within the plant, facilitating rapid uptake of essential elements, thereby aiding in the correction of deficiencies and supporting the plant's overall vitality (Waraich, Ahmad, Ahmad, Saifullah, & Ashraf, 2015).

Contrary to foliar spray application, the soil drenching technique involves administering diluted products directly at the plant's base, ensuring the solution permeates the soil around its root system. This method operates at a slower pace than foliar spraying due to the necessity for the chemicals applied to the branches to be absorbed by the roots. Once absorbed, these substances need time to traverse through the plant's vascular system, gradually making their way up the stems and branches, and ultimately reaching the leaves. Consequently, the impact of soil drenching unfolds gradually over time, as plants gradually assimilate and distribute the nutrients or substances introduced at their base, supporting sustained growth and development (Suchithra et al, 2021).
Utilising microalgae through application methods such as foliar spraying and soil drenching presents a promising avenue for strengthening the growth of examined plants, especially when subjected to alkaline stress. These microorganisms, rich in essential nutrients and growth-promoting hormones, have exhibited remarkable efficacy in improving the plant resilience against alkaline conditions. Their application has proven instrumental in modulating soil properties, maintaining nutrient balance, and improving the efficiency of photosynthesis, for example, in chia plants under stress (Youssef, El-Serafy, Ghanem, Elhakem, & Abdel Aal, 2022). Moreover, the introduction of microalgae via different application methods has shown substantial potential to significantly augment both seed and oil production while optimising the plant composition. This optimisation includes increasing the content of total protein and carbohydrate, enriching non-enzymatic compounds such

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as phenolics and flavonoids, and influencing the activity of DPPH (2, 2-diphenyl-1-picrylhydrazyl) activity. Additionally, these applications have been found to influence and alter the fatty acid profiles within chia plants (Atteya et al, 2022). Consequently, the diverse application of various microalgae strains by spraying foliar or soil drenching emerges as a promising and environmentally friendly approach to increase agricultural productivity, particularly in alkaline environments. The findings strongly suggest the potential efficacy of using *Arthrospira platensis*, commonly known as Spirulina, through soil drenching techniques for future applications aimed at improving plant growth and productivity, especially in conditions characterised by alkaline soil (Suchithra et al, 2021).

## QUALITY OF POTTED PLANTS AND POTENTIAL ECONOMIC IMPACT

The appearance of plants depends on factors such as shape, size, colour, and the turnover of flowers and leaves. Potted plants encompass a wide variety of species, each having distinct ornamental characteristics that make them highly attractive. For flowering potted plants, key quality parameters include colour and flower number (Noordergraaf*,* 1994), while for foliage plants, leaf shape, size, and greenness are important factors (Wang, Chen, Stamps, & Li, 2005). In the United States, market research has been conducted to gauge consumer interest in organic container-grown plants. Hawkins et al (2010) reported that consumers showed significant interest in organically grown vegetable/herb and ornamental container plants. It would be valuable to gather more international economic and marketing data for growers in the future. In addition, it is becoming more and more common for people to use edible plants as ornamental plants, for example, basil, tomatoes, or blueberry plants. According to Hawkins et al (2010), consumers indicated a willingness to pay 10 to 15% more for organically grown container plants compared to conventional ones. However, when it comes to organically grown vegetables, consumers are willing to pay an even higher price of 25% more (Rippy et al, 2004). If the 10% to 15% increase in premium does not cover the higher production costs of container-grown plants, it can be challenging to justify the adoption of organic production techniques in this context.

## CONCLUSIONS

In conclusion, biostimulants play an important role in modern agriculture by improving plant growth, improving nutrient efficiency, and increasing stress tolerance. They are composed of various organic and inorganic substances, including amino acids, carbohydrates, vitamins, enzymes, and microorganisms. Biostimulants belong to three main groups: humic substances, algae extracts, and products containing amino acids. They are applied by methods such as foliar sprays, soil drenches, or seed treatments, and their impact on plant metabolism varies depending on the application method and timing.

Microalgae, with their diverse bioactive compounds, have gained attention as potential biostimulants due to their positive effects on plant growth and development. The use of microalgae-based biostimulants is expanding in various agricultural practices, driven by the need for sustainable and environmentally friendly alternatives to synthetic fertilisers. These biostimulants contribute to improved nutrient mobilisation, stress tolerance, and overall plant quality. Biostimulant application methods, whether through root drenching or foliar sprays, have a profound impact on plant metabolism. Different methods lead to varied responses in terms of carbon and nitrogen metabolism, antioxidant systems, and secondary metabolite production. The choice of application method depends on the specific needs of the crop and the desired physiological responses. Furthermore, the use of biostimulants is gaining attention in the cultivation of potted plants, both ornamental and edible plants. Organic fertilisers are being explored as alternatives to conventional methods, although challenges related to limited substrate volume and economic viability need to be addressed. Consumer interest in organically grown potted plants presents opportunities for growers to tap into new markets with potentially better and premium prices.

In the face of increasing global demands for both edible and ornamental plants, limited resources, and environmental concerns, the research and application of biostimulants, including microalgae-based solutions, offer promising avenues for sustainable agriculture. As the agricultural industry seeks alternatives to synthetic input, biostimulants have the potential to contribute to increased productivity, improved plant quality, and reduced environmental impact. Continued research and innovation in this field are essential to unlock the full potential of biostimulants in shaping the future of agriculture.

# A BIOSTIMULÁNS MIKROALGÁK DÍSZNÖVÉNYEK NÖVEKEDÉSÉNEK ÉS FEJLŐDÉSÉNEK BEFOLYÁSOLÁSÁRA TÖRTÉNŐ FELHASZNÁLÁSÁNAK ÁTTEKINTÉSE

## ÖSSZEFOGLALÁS

A növény biostimulánsok koncepciója olyan anyagokra vagy mikroorganizmusokra utal, amelyeket a növény tápanyagfelvételének hatékonyságát, stressztűrésének és általános minőségének javítása érdekében használnak. A biostimulánsok közül a mikroalgák kivonatai gazdag bioaktív tartalmuk miatt keltenek egyre nagyobb figyelmet. A mikroalgák új lehetőségeket kínálnak a mezőgazdaságban, a szennyvízkezelésben, a gyógyszeriparban stb. Ezek az apró élőlények a szén-dioxid-leválasztásban, a bioremediációban és az értékes vegyületek előállításában betöltött szerepükről ismertek. A biostimulánsok különféle mechanizmusokon keresztül hatnak a növényekre, elősegítve a növekedést, a tápanyag-mobilizációt és a stresszrezisztenciát. A mikroalgákban bővelkedő aminosavak és fehérje-hidrolizátumok fokozzák a tápanyagfelvételt, és ozmoprotektánsként hatnak az olyan stresszel szemben, mint a nehézfémek és a sótartalom. A cserepes dísznövények vizuális megjelenése döntő szerepet játszik minőségük meghatározásában. Habár kutatások szerint a vásárlók preferálják a biotermesztésű növényeket, a dísznövények biotermelésének gazdasági életképessége megköveteli a termelési költségek és a piaci kereslet alapos mérlegelését. A fenntartható mezőgazdasági gyakorlatok iránti kereslet növekedésével a növényi biostimulánsok, különösen a mikroalgákból származó biostimulánsok alkalmazása ígéretes lehetőséget jelent a termelékenység növelésére, a talaj egészségének javítására és a környezeti problémák kezelésére, valamint az új Európai Uniós, növényvédő szerek alkalmazhatóságával kapcsolatos szabályzások által támasztott kihívások leküzdésére.

**Kulcsszavak**: abiotikus stressztűrés, biostimuláns, kertészet, dísznövények, organikus trágyák, mikroalgák

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