Chapter

Biostimulants as Plant Growth Stimulators in Modernized Agriculture and Environmental Sustainability

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Abstract

Plant growth stimulators (growth regulators + biostimulants; PGS) are chemical substances (organic/inorganic), helpful in plant growth and development. These are not considered as the replacement of fertilizers but can help in improved crop and soil quality. Both compounds can amplify the root biomass, nutrients translocation, enzymatic activities, crop yield, physiology, and nutrient uptake. Biostimulants are rich in minerals, vitamins, plant hormones, oligosaccharides, and amino acids. These compounds have a serious role to improve soil health, fertility, sorption, and desorption of nutrients. Hence, have a vital character in nutrients cycling, abiotic stress control, heavy metals bioavailability, and greenhouse gaseous emission. This chapter focuses on the discussions about the influence of plant growth regulators and biostimulants in crop production, soil health, heavy metal cycling, greenhouse gases emission with environmental sustainability. Whereas, the impact of biostimulants on greenhouse gases is a research gap.

Keywords: PGR, Biostimulants, Sustainable agriculture, sustainability

1. Introduction

Modernized agricultural practices are focusing on sustainable environmental systems. The major challenges for agriculture scientists and experts are to improve the crop quality and yield with minimum inputs focusing on environmental sustainability. To fulfill this aim, various breeding programs are introduced but it is a time-consuming and species-specific method. Apart from this, a less time-consuming and cheaper method identification is a vital need, as the use of an organic substance can stimulate healthy plant metabolism and improve their growth and development functions [1].

In addition to increasing population, food security, and environmental pressure, modern agriculture is also facing the challenges of soil degradation and reduction of arable lands. About 24 billion tons of fertile soil has been depleted worldwide due to inadequate agriculture practices and erosion. In addition, drought stress, salinization of cultivated lands, and natural disasters have poorly impacted agriculture. Approximately, 60–70% yield gap is due to abiotic stresses specifically salinity, heat stress, drought, nutrient deficiency, and hypoxia [2].

Biostimulant is a material, which when applied in minute quantity promotes plant growth. Here, the word "minute" describes how the biostimulants are different from soil amendments and nutrients that perform a similar task but are applied in higher amounts [3]. Do not confuse biostimulants with fertilizers because they do not supply nutrients directly to the plants. But facilitate the plant and soil metabolic processes to improve nutrient availability [4]. According to the new regulation (EU; 2019/1009), biostimulant is a fertilizing product that improves the plant's nutritional processes independent of its own nutrient content. Moreover, its goal is to achieve one or more following [2] characteristics of the plant and/or the plant rhizosphere.

i. nutrient use efficiency

ii. tolerance resistance to (a) biotic stress

iii. quality characteristics

iv. availability of confined nutrients in the soil or rhizosphere

Initially, plant biostimulants were used for organic production but as its benefits explored, it is now being adopted in sustainable agricultural practices and integrated cropping systems [2]. Biostimulants are the extracts derived from organic raw substances containing bioactive compounds. The common components of biostimulants are humic substances, mineral elements, amino acids, chitin, chitosan, vitamins, poly-, and oligosaccharides [1]. Biostimulants vary in their formulation and ingredients, but the major classification is on the basis of source and content (includes: hormone-containing products, amino acid-containing products), and humic substances [3].

Various substances such as enzymes, micronutrients, proteins, amino acids, phenols, humic and fulvic acid, salicylic acid, protein hydrolases, and other compounds are sources as biostimulants. Moreover, living organisms i.e., bacteria and fungi that can induce changes among the organism present in plant or soil system are included in the group of biostimulants. Biostimulants are applied via soil application in the forms of granules, powders, capsules, or solutions, or as foliar sprays. Moreover, it can be also applied via fertigation through irrigation systems and foliar application [4]. Different substances are included under the term PGS. **Table 1** summarizes the definition and examples of PGS discussed.

Terminology	Definition	Examples
Biostimulant	It is a fertilizing substance when applied in minute amount improves the plant's growth and nutrition	Seaweed extract, Protein hydrolysates.
Plant growth regulators	It is a synthetic substance that has the potential to improve plant growth and alter biological processes in plants.	Abscisic acid, Cytokinins.
Plant growth hormones	Plant growth regulators when naturally produced by and inside the plant are termed as plant hormones.	-do-

Table 1.
Concept of different plant growth stimulators.

In this chapter, we have focused on the plant growth stimulators (PGS) which comprise both plant biostimulants and growth regulators. The chapter consists of 8 sections, which describes the introduction and significance of the plant growth stimulators (Section 1), the influence of PGS on crop productivity (Section 2), the role of PGS in abiotic stress conditions (Section 3), the efficacy of PGS in soil health (Section 4), the role of PGS in heavy metals cycling (Section 5), its impact on greenhouse gas emission (Section 6), the constraints, challenges and future aspects (Section 7), and the conclusion of the chapter (Section 8), respectively.

2. Influencing the crop productivity with PGS

Plant-derived biostimulants have been reported as an innovative tool to cope with agriculture challenges and environmental sustainability. Moreover, it has been reported that plant biostimulants impact plant growth hormones that improve the plant metabolic activities and ultimately enhance crop productivity [5]. Moreover, it is reported that plant biostimulants improve chlorophyll synthesis, the mineral status, and also synthesis and accumulate antioxidant metabolites. These antioxidants reactivate photosynthetic activity and improve plant growth [2].

Biostimulants are also responsible to increase the leaf chlorophyll content. Its application to vegetables and floriculture crops has been reported to build tolerance against biotic and abiotic stresses by improving the internal and external quality. Moreover, it also reduces the fertilizer requirement thereby is recognized as a step towards environmental sustainability [1, 6]. In addition, biostimulants also enhance the thiamine levels of green beans in proportion to the thiamine content it contains [7]. Furthermore, biostimulants also influence the mechanical properties of fruits and vegetables such as firmness. It might be due to the stiffness of the cell wall that results in extensibility reduction. Biostimulants also significantly improve the cell wall flexibility that helps increase the shelf life of fruits and vegetables, thus facilitate transportation and storage processes [4].

Non-microbial and microbial plant biostimulants also have a positive impact on crop productivity. It increases plant growth and development, nutrient uptake, and translocation consequently increases the yield and biomass production in horticulture and agronomic crops. Moreover, it improves nutrient soil solubilization (both macro and micronutrients), the plant root system architecture, and enhances soil exploration. Thus, it has also been shown to influence nutrient use efficiency specifically nitrogen in plants [2]. Plant biostimulants are also responsible to improve nutrient assimilation by improving the gene expression of functioning in the plant metabolism or due to the improved nutrient uptake and transport [8].

Biostimulants based on chitosan positively impact strawberry pulp firmness and improves the shelf-life by increasing the concentration of the phenolic compound in plants [9]. Moreover, it has been demonstrated that the application of biostimulants in the absence of fertilizers improves the radish shoot and root biomass [6]. Whereas the foliar application of seaweed extract influenced the growth of soybean possibly due to the identified minerals and plant growth regulators present in the biostimulant [10]. Moreover, seaweed is also reported to improve plant water and nutrient use efficiency due to the phytohormones involved. Furthermore, the potential outcomes of seaweed to minimized abiotic stresses and nutrient deficiencies can be expected [11]. Biostimulants have a promising role in improving plant growth, metabolic activities, better stress resistance, and reduction in fertilizer use [12]. Furthermore, **Table 2** summarizes the role of PGS and plants responses respectively.

Crop	PGS	Group	Plant Response	Reference
Zea mays L. (Hydroponics)	Biostimulant	Protein Hydrolysates	Mitigate abiotic stress and regulates the transcription of the gene involved in nitrate transport	[13]
Solanum lycopersicum L.	Biostimulant	Microbe-based	Improve uptake of macro-and microelements (potassium, sodium, and manganese)	[14]
Ocimum basilicum L., *Solanum lycopersicum* L., and *Chrysanthemum indicum* L.	Biostimulant	Vegetable derived protein	Enhances Adventitious Rooting	[5]
Glycine max L.	Biostimulant	Seaweed Extract	Altered the nutraceutical and antioxidative potential and improved the growth and yield	[10]
Crocus sativus L. (Soil less condition)	Biostimulant	Arbuscular mycorrhizal fungi	Increased the polyphenol content	[15]
Lactuca sativa L.	Biostimulant	Amino Acids	Improves the Growth and Yield, Enhance Photosynthetic Assimilation and Nutrient Availability	[16]
Zea mays L.	Biostimulant	Humates and lignosulfonates	Increase root growth, enhance photosynthesis and stimulate N metabolism	[17]
Strawberry tray plants (*Fragaria × ananassa* Duch.)	Biostimulant	10 different biostimulants	Increased pulp firmness, high nutritional value, and yield and fruit quality	[9]
Trifolium pratense L. and *Lolium perenne* L.	Biostimulant (Seed coating)	Soy flour, diatomaceous earth, micronized and concentrated vermicompost	Enhance seedling growth, increased the integrity and compressive strength of seeds.	[18]
Lactuca sativa L.	Biostimulant	Seaweed extract, legume-derived protein hydrolysate and tropical plant extract	Increase leafy vegetable productivity in low fertility soils, better physiological and biochemical status	[19]
Raphanus sativus L.	Biostimulant	Biostimulant, Vitamin B12, and CoQ10	Improved root and shoot biomass	[6]

Table 2.
Plant growth stimulators and plant responses in different crops.

3. Limiting the abiotic stress by PGS

Plants face multiple stressful events throughout their lifecycle. Stresses are classified based on the nature of the trigger factor as biotic and abiotic stresses. Biotic stresses are caused by a living organism such as insects microorganisms, weeds, etc. that impact plant growth, and productivity. However, the latter one is general associated with different environmental components that negatively impact plant development and survival. Drought, non-optimal temperatures, low soil fertility, and salinity are the most common abiotic stresses that limit agriculture production globally. Whereas, in the developing countries where the life of the majority depends on the agriculture sector, drought and nutrient deficiencies major issues [20].

Besides this, the rapid increase in population leading to urbanization and increases soil erosion has poorly impacted the prime cropland. Therefore, it is the need for time to utilize the less productive soils and enhance the crop yield and productivity [16]. Biostimulants ensure a promising role to improve the productivity of vegetables and also develop tolerance against stresses. Moreover, it positively impacts the plant metabolic activities in optimal and sub-optimal environmental conditions. In addition, it is very crucial to identify the proper timing for the application of biostimulants. It depends on the critical stages of development and crop species. To avoid unexpected results, minimize production cost and wastage of products, it is good to determine the exact dose and application time of biostimulants [20].

Diverse changes in temperature and precipitation have been reported due to climate change, this has resulted in severe drought conditions [16]. Drought has adverse effects on the plant gas exchange and causes changes in transpiration and photosynthetic rates, which ultimately results in yield losses. Biostimulants can be used to overcome water stress as it is effective to improve water use efficiency in plants [20]. It is reported that the micro-algal-biostimulants minimized the drought damaging effects on tomatoes and improve plant growth. It might be due to the presence of plant growth hormones, like abscisic acid that regulates transpiration and reduce water losses, present in biostimulant [21]. Microalgae improve the total flavonoid and phenolic content in plants which also increase the enzymatic activities of antioxidants such as catalase, superoxide dismutase, ascorbate peroxidase that consequently mitigate drought-induced oxidative damage [22].

Furthermore, biostimulants are also useful against nutrient deficiency. The results have shown that the application of biostimulants cannot replace fertilizers but it can contribute to overcoming nutrient deficiency and imbalanced conditions. It is responsible for improving plant root morphology which ultimately improves nutrient uptake, translocation, and assimilation [23]. Cold stress or low temperatures adversely affect plant metabolism and delay physiological processes. It also damages the cell membrane by destabilizing phospholipid layers. Biostimulants also help to stimulate biosynthetic pathways that increase the osmotic molecule accumulation, membrane thermostability, and overcome chilling injury. Moreover, the seed priming with chitosan also improved germination and plant growth under temperature stress [24].

The most abundant environmental stress is a salinity that adversely impacts plant metabolism and growth. With the application of biostimulants to salt stress environmental conditions, the damage can be minimized as it induces the accumulation of osmolytes to increase the osmotic potential of plant cells and enhance the level of protective molecules against oxidative stress [25]. Moreover, it has been reported that the protein hydrolysates-based biostimulant significantly mitigates single as well as multiple stresses (nutrient stress + hypoxia or nutrient stress + salinity) in maize under hydroponic conditions [2].

Plant growth regulators also play a constructive role to mitigate the abiotic stress damages and improve plant development. Such as, salicylic acid is effective against drought as it increases the restoration process in plants. Moreover, putrescine fights against oxidative, drought, and salinity stress probably due to its acid-neutralizing abilities. Thus, plant growth regulators, plant growth-promoting rhizobacteria, and biostimulants could play a significant performance against environmental stresses [16].

4. Efficacy of PGS in soil health

Plant growth regulators also effectively influence the soil properties and ultimately give a huge benefit to agriculture management. As describes earlier, plant biostimulants improve nutrient availability, uptake, translocation, and assimilation, which is beneficial to organic farming. In addition, incredible results can be obtained with the integrated application of biostimulants with chemical fertilizers in soil [26]. It contributes to improving the cation exchange capacity of the soil and enhances the solubility of the nutrients in soil solution which subsequently increases the nutrient availability for plant uptake [8]. Whereas, biostimulants are not nutrients and has no direct impact on nutrients bioavailability but they have a potential to reduce the application of mineral nutrients [6].

Protein hydrolysates, an important plant biostimulant is prepared using protein sources by the process of partial hydrolysis. It comprises amino acids, mixtures of poly- peptides, and oligopeptides. When applied as foliar spray or in the soil/root system, protein hydrolysates improve the microbial biomass and activity, soil respiration by providing a rich source of C and N to microbes. Moreover, it forms complexes and chelates with soil micronutrients (i.e., Zn, Mn, Fe, and Cu), improves nutrient availability, and ultimately improves plant nutritional status [8].

Another well-known plant biostimulant is "seaweed extracts". Due to its complex biochemical composition (minerals, antioxidants, polysaccharides, hormones, vitamins, pigments, fats, oils, acids), it is highly difficult to understand its mechanism. Likewise, protein hydrolysates, seaweed extract can be applied to soil as well as plants (foliar spray). It is responsible for improving soil retention, soil microflora as well as soil remediation. Moreover, it can be a rich source of nutrients and probably have hormonal effects. Whereas, multidisciplinary approaches are required to understand the complex interaction between bioactive compounds present in the extract [11].

5. Role of PGS in heavy metals cycling

The increase in anthropogenic activities including industrial and mining activities, urbanization, use of chemicals in agriculture has potentially increased the concentration of toxic elements in soil throughout the globe [27]. Moreover, wastewater mishandling also contributes to heavy metal contamination and induces toxic effects on plant metabolic activities, soil environment, groundwater, and ultimately human health [28]. One of the most toxic trace elements is chromium (Cr). It is harmful to the soil microbes as it depresses their microbial and enzymatic activities, as well as humans if enters the food chain [29]. Therefore, it is important to minimize or treat the negative impacts of Cr. Plant growth stimulators can also play a significant role in this regard.

The application of micronutrient-amino acid is responsible to reduce the Cr stress in plants. It is reported that iron-lysine (Felys) application significantly improved plant growth and biomass. Additionally, with the increased nutrient uptake, gaseous exchange parameters also increased whereas it contributes to form complexes that reduce oxidative stress in plants. Therefore, the Cr toxicity caused due to contaminated water can be treated using Felys. Whereas, the mechanism behind the Felys attributes needs to be explored [30].

The foliar application of Zinc-lysine (Znlys) also improved rice growth and contributed to stimulating the anti-oxidant defense system, decrease oxidative stress, increase Zinc (Zn) uptake, and decreases Cr concentration in plants. Whereas, further studies are required to explore the mechanism of Znlys in mitigating Cr level in plants [31]. Moreover, Znlys is also effective to reduce cadmium (Cd) concentration in wheat along with improving Zn contents and plant growth in Zn deficient and Cd contaminated soil. It is useful to protect people from Cd risk and Zn deficiency [32].

Apart from biostimulants, plant growth regulators also contribute to phytoremediation. Plant growth regulators can be defined as the substance that can impact plant growth and is capable of altering biological processes in plants. Such compounds when produced inside the plant are known as plant hormones but when used as synthetic compounds to play a similar role are termed as plant growth regulators [33]. Auxins perform various biochemical changes in plant cells and their membranes which reduces the toxicity of metal ions [34]. Different hypotheses report that auxins cause changes in the cell membrane and alter its properties against toxic elements [33]. It also improves the rate of transpiration and ultimately heavy metal adsorption.

The use of cytokinins on *Alyssum murale* also improves the plant aerial biomass and transpiration due to the adsorption of heavy metals in soil solution. Likewise, the application of cytokinin on *Helianthus annuus* is helpful in the adsorption of Zn and lead (Pb). Studies reported that the usage of salicylic acid helps reduce the negative impacts of copper (Cu) and Pb in plants. Thus the use of plant growth stimulators is significant in heavy metal recycling [33].

6. Greenhouse gases emission and PGS

Greenhouse gases (GHGs) are defined as the gases that obtain heat energy from the sunlight and limit the backward movement of radiations from the earth's crust thus resulting in global warming. The agriculture sector contributes a lot in this aspect by the emission of methane (CH4), nitrous oxide (N_2O), and carbon dioxide (CO_2). One of the major sources of GHGs emissions is paddy systems [35]. Moreover, the long-term application of manures also increases GHGs emissions [36].

With the increase in population, the demand for food has also increased. To fulfill this challenge, the farmers tend to apply more fertilizer to attain more yield. However, field fertilization is supposed to be a major source of GHGs emissions. It is reported that agriculture produces about 90% N_2O and 20% CO_2 worldwide. Depending upon the global warming potential, carbon dioxide and nitrous oxide are two important GHGs. Moreover, after CH_4, and CO_2, N_2O is an important GHG that contributes about 6–8% of global warming [36]. Therefore, it is the need of today to introduce such agriculture practices that ensure high yield with minimum negative impacts on global warming and climate change.

Microbes-biostimulants specifically N-fixing microorganisms are responsible to increase N_2O emission. Whereas few pieces of research have been reported in this regard. Further studies need to be conducted to explore the impacts of different types of biostimulants on agro-ecosystems [37]. Additionally, the foliar application of plant growth regulators (abscisic acid and kinetin) has been shown to mitigate the N_2O emission and also manipulate plant growth and development processes in the wheat cropping system. It is possibly due to the manipulation of anatomical and physiological processes. Thus, the application of plant growth regulators might be an effective tool for modernized agriculture and environmental sustainability [38]. Apart from this, there is a huge gap to study PGS for GHG emission and reduced agro-environmental pollution, especially from non-point sources.

7. Constraints, challenges, and future aspects

Agriculture production is facing multiple challenges including food security, climate change, soil restoration, and environmental sustainability. Plant growth stimulators have the potential to overcome the biotic and abiotic stresses, improve crop productivity, better soil nutrient cycling, mitigation of heavy metal uptake, and GHGs emission. Due to the complex composition of biostimulants, their potential role and mechanism are still not clear. Therefore, further studies about the possible use of biostimulants to minimize GHGs emission needs to be studied.

Biostimulants are also expected to increase NUE, therefore, careful monitoring, climatic aspects, and related modeling need to be studied. Limited literature related to the impacts of biostimulants under sub-optimal nitrogen regimens is available. Further studies can bring huge benefits to modern agriculture. Moreover, open field studies should also be carried out in the future, which then moves back to the lab for further elucidation. Few field-based research using biostimulants has been reported which is a major constraint to adopt its application in farming. Furthermore, the farming community should be introduced with the product along with the cost–benefit analysis, thus moving towards environment sustainability.

Currently, biostimulants are gaining popularity in the market. Variety of biostimulants with different active ingredients (humic substances, seaweed extracts, microbial amendments, and amino acids) are estimated to account for $2.6 billion and will reach about $5 billion by 2025 [2]. Therefore, it is time to introduce new and beneficial biostimulants that have practical application and yield benefits for sustainable agriculture. Integration of plant biostimulants and growth regulators with nutrients and waste organics for different regions can be introduced with also helps in minimizing pollution and waste recycling.

8. Conclusion

A sustainable agriculture management system needs to be adopted for dealing the adverse climatic conditions. Plant growth stimulators have positively contributed towards modern agriculture and have the potential to improve crop yield, plant growth, and development, handle biotic and abiotic stresses, minimize heavy metal translocation, and contribute to mitigating GHGs emissions. Biostimulants are rich in multi-nutrients but cannot replace fertilizers. Although it has a potential to improve soil quality and plant productivity even under stress conditions. Whereas, few researches regarding GHGs emission using biostimulants has been reported. It is a huge research gap. Whereas, different mechanisms need to be studied further to develop a better understanding and introducing useful products.

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References

[1] Bulgari, R.; Cocetta, G.; Trivellini, A.; Vernieri, P.; Ferrante, A. Biostimulants and crop responses: A review. Biol. Agric. Hortic. 2015, *31*, 1-17.

[2] Rouphael, Y.; Colla, G. Toward a sustainable agriculture through plant biostimulants: From experimental data to practical applications. Agronomy **2020**, *10*, doi:10.3390/agronomy10101461.

[3] du Jardin, P. Plant biostimulants: Definition, concept, main categories and regulation. Sci. Hortic. (Amsterdam). **2015**, *196*, 3-14, doi:10.1016/j.scienta.2015.09.021.

[4] Drobek, M.; Frąc, M.; Cybulska, J. Plant biostimulants: Importance of the quality and yield of horticultural crops and the improvement of plant tolerance to abiotic stress-a review. Agronomy **2019**, *9*, 335, doi:10.3390/agronomy9060335.

[5] Kim, H.J.; Ku, K.M.; Choi, S.; Cardarelli, M. Vegetal-derived biostimulant enhances adventitious rooting in cuttings of Basil, tomato, and chrysanthemum via brassinosteroid-mediated processes. Agronomy **2019**, *9*, doi:10.3390/agronomy9020074.

[6] Rehim, A.; Amjad Bashir, M.; Raza, Q.-U.-A.; Gallagher, K.; Berlyn, G.P. Yield Enhancement of Biostimulants, Vitamin B12, and CoQ10 Compared to Inorganic Fertilizer in Radish. Agronomy **2021**, *11*, 697, doi:10.3390/agronomy11040697.

[7] Russo, R.O.; Berlyn, G.P. Vitamin-Humic-Algal Root Biostimulant Increases Yield of Green Bean. *HortScience* **1992**, *27*, 847, doi:10.21273/hortsci.27.7.847.

[8] De Pascale, S.; Rouphael, Y.; Colla, G. Plant biostimulants: Innovative tool for enhancing plant nutrition in organic farming. *Eur. J. Hortic. Sci.* **2017**, *82*, 277-285, doi:10.17660/eJHS.2017/82.6.2.

[9] Soppelsa, S.; Kelderer, M.; Casera, C.; Bassi, M.; Robatscher, P.; Matteazzi, A.; Andreotti, C. Foliar applications of biostimulants promote growth, yield and fruit quality of strawberry plants grown under nutrient limitation. Agronomy **2019**, *9*, 483, doi:10.3390/agronomy9090483.

[10] Kocira, S.; Szparaga, A.; Kuboń, M.; Czerwińska, E.; Piskier, T. Morphological and biochemical responses of Glycine max (L.) Merr. To the use of seaweed extract. Agronomy **2019**, *9*, 1-23, doi:10.3390/agronomy9020093.

[11] El Boukhari, M.E.M.; Barakate, M.; Bouhia, Y.; Lyamlouli, K. Trends in seaweed extract based biostimulants: Manufacturing process and beneficial effect on soil-plant systems. Plants **2020**, *9*, doi:10.3390/plants9030359.

[12] Russo, R.O.; Berlyn, G.P. The use of organic biostimulants to help low input sustainable agriculture. J. Sustain. Agric. **1990**, *1*, 19-42.

[13] Trevisan, S.; Manoli, A.; Quaggiotti, S. A novel biostimulant, belonging to protein hydrolysates, mitigates abiotic stress effects on maize seedlings grown in hydroponics. Agronomy **2019**, *9*, 1-15, doi:10.3390/agronomy9010028.

[14] Allaga, H.; Bóka, B.; Poór, P.; Nagy, V.D.; Szucs, A.; Stankovics, I.; Takó, M.; Manczinger, L.; Vágvölgyi, C.; Kredics, L.; et al. A composite bioinoculant based on the combined application of beneficial bacteria and fungi. Agronomy **2020**, *10*, doi:10.3390/agronomy10020220.

[15] Caser, M.; Victorino, Í.M.M.; Demasi, S.; Berruti, A.; Donno, D.;

Lumini, E.; Bianciotto, V.; Scariot, V. Saffron cultivation in marginal alpine environments: How AMF inoculation modulates yield and bioactive compounds. Agronomy **2019**, *9*, 1-14, doi:10.3390/agronomy9010012.

[16] Khan, N.; Bano, A.M.D.; Babar, A. *Impacts of plant growth promoters and plant growth regulators on rainfed agriculture*; 2020; Vol. 15; ISBN 1111111111.

[17] Ertani, A.; Nardi, S.; Francioso, O.; Pizzeghello, D.; Tinti, A.; Schiavon, M. Metabolite targeted analysis and physiological traits of zea mays L. In response to application of a leonardite-humate and lignosulfonate-based products for their evaluation as potential biostimulants. Agronomy **2019**, *9*, 1-19, doi:10.3390/agronomy9080445.

[18] Qiu, Y.; Amirkhani, M.; Mayton, H.; Chen, Z.; Taylor, A.G. Biostimulant seed coating treatments to improve cover crop germination and seedling growth. Agronomy **2020**, *10*, 1-14, doi:10.3390/agronomy10020154.

[19] Mola, I. Di; Cozzolino, E.; Ottaiano, L.; Giordano, M.; Rouphael, Y.; Colla, G.; Mori, M. Effect of vegetal- And seaweed extract-based biostimulants on agronomical and leaf quality traits of plastic tunnel-grown baby lettuce under four regimes of nitrogen fertilization. Agronomy **2019**, *9*, doi:10.3390/agronomy9100571.

[20] Bulgari, R.; Franzoni, G.; Ferrante, A. Biostimulants application in horticultural crops under abiotic stress conditions. Agronomy 2019, *9*.

[21] Oancea, F.; Velea, S.; Fatu, V. Micro-algae based plant biostimulant and its effect on water stressed tomato plants. Rom. J. Plant Prot. **2013**, *6*, 104-117.

[22] Kusvuran, S. Microalgae (Chlorella vulgaris Beijerinck) Alleviates Drought Stress of Broccoli Plants by Improving Nutrient Uptake, Secondary Metabolites, and Antioxidative Defense System. Hortic. Plant J. **2021**, doi:10.1016/j.hpj.2021.03.007.

[23] Toscano, S.; Romano, D.; Massa, D.; Bulgari, R.; Franzoni, G.; Ferrante, A. Biostimulant applications in low input horticultural cultivation systems. *Italus Hortus* **2018**, *25*, 27-36, doi:10.26353/J.ITAHORT/2018.1.2736.

[24] Ashraf, M.A.; Akbar, A.; Askari, S.H.; Iqbal, M.; Rasheed, R.; Hussain, I. Recent advances in abiotic stress tolerance of plants through chemical priming: An overview. Adv. Seed Priming **2018**, 51-79, doi:10.1007/978-981-13-0032-5_4.

[25] Semida, W.M.; Abd El-Mageed, T.A.; Hemida, K.; Rady, M.M. Natural bee-honey based biostimulants confer salt tolerance in onion via modulation of the antioxidant defence system. J. Hortic. Sci. Biotechnol. **2019**, *94*, 632-642, doi:10.1080/14620316.2019.1592711.

[26] Nephali, L.; Piater, L.A.; Dubery, I.A.; Patterson, V.; Huyser, J.; Burgess, K.; Tugizimana, F. Biostimulants for plant growth and mitigation of abiotic stresses: A metabolomics perspective. Metabolites **2020**, *10*, 1-26, doi:10.3390/metabo10120505.

[27] Visconti, D.; Caporale, A.G.; Pontoni, L.; Ventorino, V.; Fagnano, M.; Adamo, P.; Pepe, O.; Woo, S.L.; Fiorentino, N. Securing of an industrial soil using turfgrass assisted by biostimulants and compost amendment. Agronomy **2020**, *10*, 1-25, doi:10.3390/agronomy10091310.

[28] Bashir, M.A.; Rehim, A.; Liu, J.; Imran, M.; Liu, H.; Suleman, M.; Naveed, S. Soil survey techniques determine nutrient status in soil profile and metal retention by calcium carbonate. Catena **2019**, *173*, 141-149, doi:10.1016/j.catena.2018.10.015.

[29] Hassan, Z.; Ali, S.; Farid, M. Effect of Chromium (Cr) on the Microbial and Enzymatic Activities in the Soil : A Review. In *Biodiversity conservation in changing climate*; 2017; pp. 1-20 ISBN 9789385995033.

[30] Zaheer, I.E.; Ali, S.; Saleem, M.H.; Imran, M.; Alnusairi, G.S.H.; Alharbi, B.M.; Riaz, M.; Abbas, Z.; Rizwan, M.; Soliman, M.H. Role of iron–lysine on morpho-physiological traits and combating chromium toxicity in rapeseed (*Brassica napus* L.) plants irrigated with different levels of tannery wastewater. *Plant Physiol. Biochem.* **2020**, *155*, 70-84, doi:10.1016/j.plaphy.2020.07.034.

[31] Hussain, A.; Ali, S.; Rizwan, M.; Zia ur Rehman, M.; Hameed, A.; Hafeez, F.; Alamri, S.A.; Alyemeni, M.N.; Wijaya, L. Role of Zinc–Lysine on Growth and Chromium Uptake in Rice Plants under Cr Stress. *J. Plant Growth Regul.* **2018**, *37*, 1413-1422, doi:10.1007/s00344-018-9831-x.

[32] Rizwan, M.; Ali, S.; Hussain, A.; Ali, Q.; Shakoor, M.B.; Zia-ur-Rehman, M.; Farid, M.; Asma, M. Effect of zinc-lysine on growth, yield and cadmium uptake in wheat (Triticum aestivum L.) and health risk assessment. Chemosphere **2017**, *187*, 35-42, doi:10.1016/j.chemosphere.2017.08.071.

[33] Rostami, S.; Azhdarpoor, A. The application of plant growth regulators to improve phytoremediation of contaminated soils: A review. Chemosphere **2019**, *220*, 818-827, doi:10.1016/j.chemosphere.2018.12.203.

[34] Hac-Wydro, K.; Sroka, A.; Jabłońska, K. The impact of auxins used in assisted phytoextraction of metals from the contaminated environment on the alterations caused by lead(II) ions in the organization of model lipid membranes. Colloids Surfaces B Biointerfaces **2016**, *143*, 124-130, doi:10.1016/j.colsurfb.2016.03.018.

[35] Bashir, M.A.; Liu, J.; Geng, Y.; Wang, H.; Pan, J.; Zhang, D.; Rehim, A.; Aon, M.; Liu, H. Co-culture of rice and aquatic animals: An integrated system to achieve production and environmental sustainability. J. Clean. Prod. 2020, *249*, 119310.

[36] Zhang, T.; Liu, H.; Luo, J.; Wang, H.; Zhai, L.; Geng, Y.; Zhang, Y.; Li, J.; Lei, Q.; Bashir, M.A.; et al. Long-term manure application increased greenhouse gas emissions but had no effect on ammonia volatilization in a Northern China upland field. Sci. Total Environ. **2018**, *633*, 230-239, doi:10.1016/j.scitotenv.2018.03.069.

[37] Souza, E.F.C.; Rosen, C.J.; Venterea, R.T. Contrasting effects of inhibitors and biostimulants on agronomic performance and reactive nitrogen losses during irrigated potato production. F. Crop. Res. **2019**, *240*, 143-153, doi:10.1016/j.fcr.2019.05.001.

[38] Bordoloi, N.; Baruah, K.K.; Thakur, A.J. Effectiveness of plant growth regulators on emission reduction of greenhouse gas (Nitrous oxide): An approach for cleaner environment. J. Clean. Prod. **2018**, *171*, 333-344, doi:10.1016/j.jclepro.2017.09.284.