Bacterial Plant Biostimulants

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Plant biostimulants are an important tool for modern agriculture as part of an integrated crop management (ICM) system, helping make agriculture more sustainable and resilient. Plant biostimulants contain substance(s) and/or microorganisms whose function when applied to plants or the rhizosphere is to stimulate natural processes to enhance plant nutrient uptake, nutrient use efficiency, tolerance to abiotic stress, biocontrol, and crop quality.

Keywords: abiotic stress ; ethylene ; jasomic acid

1. Introduction

The global environment is changing continuously and the incidence of global warming caused by extreme climatic events is also on the rise, consequently disturbing the world ecosystems, including agro-ecosystems [1]. Such extreme changes in climate can affect the quality and quantity of crops severely by inducing various environmental stresses to crops, threatening food security worldwide [2]. An increase in global temperature, atmospheric CO_2 level, tropospheric O_3, and acid rains can cause multifarious chronic stresses to plants, reducing their capability to respond in case of pathogen attacks [3]. Among these stresses, drought, water scarcity, and soil salinization are the most problematic and complicated factors of agricultural losses resulting from human-induced climate changes [4]. Fluctuations in temperature and rainfall variations are key indicators of environmental stresses [5]. Elevated temperatures lead to an amplification of the rates of respiration and evapotranspiration in crops, a higher infestation of pests, shifts in weed flora patterns, and reduction in crop duration [6]. Water scarcity is also considered one of the prime global issues that have direct effects on agricultural systems and according to climate projections, its severity will increase in the future [7]. Water scarcity piercingly influences a crop's gaseous exchange capacity, causing the closure of stomata [8]. This leads to the impairment of the evapotranspiration and photosynthetic activities of plants, affecting overall biomass production [9]. Impaired evapotranspiration reductions also affect the nutrient uptake ability of plants [8]. In semi-arid and arid climatic zones where rainfalls are already less intense and sporadic, the damages caused by drought stress can be exacerbated due to excessive accumulation of salts in soil [10].

Furthermore, the liberal use of inorganic fertilizers and pesticides to increase crop productivity and meet the food requirement of the ever-growing human population, which is projected to reach 9.7 billion by 2050, has severely affected the health of agro-ecosystems and human beings. Confrontational challenges of improving agriculture production with limited arable land rely on sustainable technologies. Several technical advances have been suggested in the past three decades to increase the productivity of agricultural production processes by reducing toxic agrochemical substances such as pesticides and fertilizers. An emerging technology tackling these critical problems includes the creation of novel plant biostimulants and successful methods for their application [11][12][13][14][15]. Plant biostimulants differ from other agricultural inputs such as fertilizers and plant protection products because they utilize different mechanisms and work regardless of the presence of nutrients in the products. They also do not take any direct action against pests or diseases and therefore complement the use of fertilizers and plant protection products. According to the latest European Regulation (EU 2019/1009), a biostimulant is an EU fertilizer that seeks to promote processes for plant feeding, regardless of the product's nutrient quality, solely to boost the following plant or plant rhizosphere characteristics: (i) increased nutrient utilization efficiency, (ii) abiotic stress alleviation/tolerance, (iii) quality traits, and (iv) soil or rhizosphere supply of stored nutrients [16][17]. Over the past decade, microbiome research has changed our understanding of the complexity and composition of microbial communities. The intense interest of industry and academics in biostimulants based on live microbes has increased due to the reason that the growth and development of a plant can be improved under field conditions more effortlessly than other biostimulants [18][19]. Biostimulants are not nutrients, but encourage the utilization of nutrients or help foster plant growth or plants' resistance/tolerance to various types of stresses [9][20]. Beneficial plant fungi and bacteria can be considered the most promising microbial biostimulants [21]. The recent trend has underscored the fact that plants are not autonomous agents in their environments but are associated with bacterial and fungal microorganisms, and that many external and internal microbial interactions respond to biotic and abiotic stresses [22][23]. Therefore, biostimulants are gradually being incorporated into production systems to alter physiological processes in plants to maximize productivity [24].

Bacterial plant biostimulants (BPBs) comprise a major category of plant biostimulants. Plant growth-promoting rhizobacteria (PGPR) that colonize the plant rhizosphere are the most prominent group in this category [24]. These PGPR improve plant growth, control plant pathogens, improve nutrient and mineral uptake in plants, and increase plants' resistance to various types of biotic stresses and tolerance towards abiotic stresses (Figure 1). The representative beneficial groups of PGPR-based BPBs include nitrogen-fixing *Rhizobium*, *Azotobacter* spp., *Azospirillum* spp., *Pseudomonas* spp., and *Bacillus* spp. [25][26].

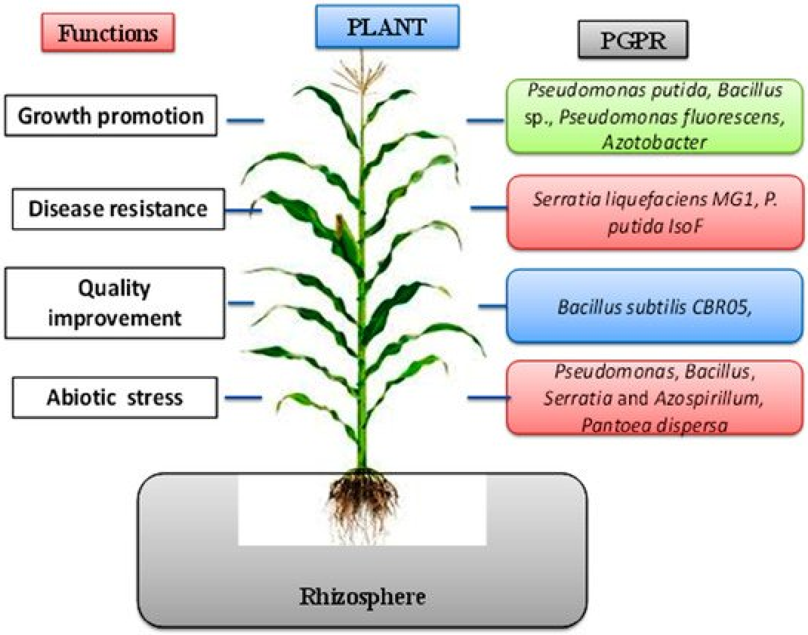

Figure 1. The beneficial influence of PGPR on crop plants.

2. Global Market for PGPR-Based Biostimulants

Biostimulants are emerging as an essential component in sustainable agricultural practices. Instances of environmental hazards and soil contamination from injudicious and excessive application of chemical-based products on crops have been a key issue for the industry in recent times. The global biostimulants market size was estimated at USD 1.74 billion in 2016, and projected to expand at a Compound Annual Growth Rate (CAGR) of 10.2% from 2017 to 2025. A rising focus on enhanced productivity, coupled with rapid soil degradation, is likely to drive the market over the forecast period. The global biostimulants market size was estimated at USD 2.30 billion in 2019 and is expected to reach USD 2.53 billion in 2020. The global biostimulants market is expected to grow at a compound annual growth rate of 10.2% from 2017 to 2025 to reach USD 4.14 billion by 2025 [27]. Although not all biostimulants are biological in nature [28], the bacteria are ancestral companions of a plant in all conditions. Moreover, according to the currently available literature, less than 25% of the commercial products of biostimulants are microbial based [9]. Table 1 provides a list of some popular PGPR-based commercial biostimulants [29][30][31]. Although some formulations contain fungal associations, the preparations are mainly based on PGPR.

Table 1. Examples of commercial PGPR-based plant biostimulants [29][30][31].

Commercial Products (Manufacturer)	PGPR Strains	Target Crops for Use	Target of Function
FZB24®fl Rhizovital 42® (ABiTEP GmbH, Germany)	***Bacillus amyloliquefaciens* and *B. amyloliquefaciens* sp. *plantarum***	**Ornamentals, vegetable field crops**	**Phosphate availability and protection against pathogens**

Commercial Products (Manufacturer)	PGPR Strains	Target Crops for Use	Target of Function
Inomix® Biostimulant, Inomix® phosphore, and Inomix® Biofertilisant (IAB (Iabiotec), Spain)	*B. subtilis* (IAB/BS/F1) and *B. polymyxa* (IAB/BP/01); *Saccharomyces cerevisiae; B. megaterium* and *P. fluorescens*; and *Rhizobium leguminosarum*, *Azotobacter vinelandii*, *B. megaterium*, and *Saccharomyces cerevisiae*	Cereals	Plant growth promotion increases root and shoot weight, strong root system
BactoFil B10® (AGRO.bio Hungary Kft., Hungary)	*Azotobacter vinelandii, Azospirillum lipoferum*, *P. fluorescens*, *B. circulans*, *B. megaterium*, and *B. subtilis*	Dicotyledons (potato, sunflower, rapeseed)	Soil amelioration; produce plant growth-promoting hormones auxin, gibberellins, and kinetin; N_2 fixation; a biocontrol agent
Bio-Gold (BioPower, Sri Lanka)	*Pseudomonas fluorescens* and *Azotobacter chroococcum*	All agricultural and horticultural crops	Growth promotion via nitrogen fixation, drought tolerance, control of root rot and wilt diseases, phosphorus solubilization
Cedomon® (Lantmannen BioAgri AB, Sweden)	*P. chlororaphis*	Barley and oats	Highly effective against various types of seed-borne diseases
Rhizosum N Liquid PSA (Mapleton Agri Biotec Pty Limited, Australia)	*Azotoformans* (N_2-fixing bacteria) and *Pseudomonas sp.*	Wheat	Phosphate availability, N_2 fixation, plant growth promotion
BactoFil A10® (AGRO.bio Hungary Kft., Hungary)	*Azotobacter vinelandii*, *Azospirillum brasilense*, *P. fluorescens*, *B. polymyxa*, and *B. megaterium*	Monocotyledons (cereals)	Increased soil nutrient content that results in plant growth promotion
Micosat F® Uno; Micosat F® Cereali (CCS Aosta Srl, Italy)	*Agrobacterium radiobacter* AR 39, *Streptomyces* sp. SB 14, and *B. subtilis* BA 41	Fruits, vegetables, and flowers	Increased nutrient and water absorption, increases stress tolerance and enhances ISR
	Paenibacillus durus PD 76, *B. subtilis* BR 62, and *Streptomyces* spp. ST 60	Cereals, soybeans, beet, tomatoes, and sunflowers	
Bioscrop BT16 (Motivos Campestres, Portugal)	*Bacillus thuringiensis* var. *kurstaki*	Deciduous fruit trees, horticultural brassicas, cotton, citrus, cauliflower, olives, pepper, banana, and tomato	Protection against pests (beetles)
Amase® (Lantmannen Bioagri, Sweden)	*Rhizobium*, *Azotobacter*, *Pseudomonas*, *Bacillus*, and *Chaetomium*	Cucumber, lettuce, tomato, pepper, eggplant, cabbage, and broccoli	Growth promotion, quick production of the large and strong root system, and increases stress tolerance
PGA® (Organica technologies, USA)	*Bacillus* sp.	Fruits and vegetables	Improved biomass accumulation, stress tolerance
Nitroguard®	*Azorhizobium caulinodens* NAB38, *Azospirillum brasilense* NAB317, *Azoarcus indigens* NAB04, and *Bacillus* sp.	Cereals, rapeseed, and sugar	Growth promotion via nitrogen fixation
TwinN® (Mapleton Agri Biotec Pty Ltd. Australia)	*Azospirillum brasilense* NAB317, *Azoarcus indigens* NAB04, and *A. caulinodens* NAB38	Beet, sugarcane, and vegetables	Helps with nitrogen fixation and phosphorus solubilization and produces growth-promoting hormones
Symbion®-N, Symbion®-P, and Symbion®-K (T. Stanes & Company Ltd., India)	*Rhizobium*, *Azotobacter*, *Azospirillum*, *Acetobacter*; *B. megaterium* var. *phosphaticum*; and *Frateuria aurantia*		Promotion of plant growth, improved root and shoot weight, and a stronger root system

Commercial Products (Manufacturer)	PGPR Strains	Target Crops for Use	Target of Function
Ceres® (Biovitis, France)	***Pseudomonas fluorescens***	**Field and horticultural crops**	**Biocontrol agent against pathogens**
Gmax® PGPR (Greenmax AgroTech, India)	***P. fluorescens*, *Azotobacter*, and *phosphobacteria***	**Field crops**	**Nitrogen and phosphatic nutrition, disease prevention and helps in plant growth promotion.**

References

1. Ebert, A.W.; Engels, J.M. Plant Biodiversity and Genetic Resources Matter! Plants 2020, 9, 1706.
2. Shahzad, A.; Ullah, S.; Dar, A.A.; Sardar, M.F.; Mehmood, T.; Tufail, M.A.; Shakoor, A.; Haris, M. Nexus on climate change: Agriculture and possible solution to cope future climate change stresses. Environ. Sci. Pollut. Res. 2021, 7, 1–22.
3. Sangiorgio, D.; Cellini, A.; Donati, I.; Pastore, C.; Onofrietti, C.; Spinelli, F. Facing climate change: Application of microbial biostimulants to mitigate stress in horticultural crops. Agronomy 2020, 10, 794.
4. Del Buono, D. Can biostimulants be used to mitigate the effect of anthropogenic climate change on agriculture? It is time to respond. Sci. Total. Environ. 2020, 751, 141763.
5. Raza, A.; Razzaq, A.; Mehmood, S.S.; Zou, X.; Zhang, X.; Lv, Y.; Xu, J. Impact of climate change on crops adaptation and strategies to tackle its outcome: A review. Plants 2019, 8, 34.
6. Malhi, G.S.; Kaur, M.; Kaushik, P. Impact of Climate Change on Agriculture and Its Mitigation Strategies: A Review. Sustainability 2021, 13, 1318.
7. Mancosu, N.; Snyder, R.L.; Kyriakakis, G.; Spano, D. Water scarcity and future challenges for food production. Water 2015, 7, 975–992.
8. Kałużewicz, A.; Bosiacki, M.; Spiżewski, T. Influence of biostimulants on the content of macro-and micronutrients in broccoli plants exposed to drought stress. J. Elem. 2018, 23, 287–296.
9. Bulgari, R.; Franzoni, G.; Ferrante, A. Biostimulants application in horticultural crops under abiotic stress conditions. Agronomy 2019, 9, 306.
10. Daneshmand, H.; Alaghmand, S.; Camporese, M.; Talei, A.; Yeh, P.J.F.; Daly, E. Long-term impacts of partial afforestation on water and salt dynamics of an intermittent catchment under climate change. Water 2020, 12, 1067.
11. Bulgari, R.; Cocetta, G.; Trivellini, A.; Vernieri, P.; Ferrante, A. Biostimulants and crop responses: A review. Biol. Agric. Hort. 2015, 31, 1–17.
12. Colla, G.; Rouphael, Y. Biostimulants in horticulture. Sci. Hortic. 2015, 196, 1–2.
13. Yakhin, O.I.; Lubyanov, A.A.; Yakhin, I.A.; Brown, P.H. Biostimulants in plant science: A global perspective. Front. Plant Sci. 2017, 7, 2049.
14. Rouphael, Y.; Colla, G. Synergistic biostimulatory action: Designing the next generation of plant biostimulants for sustainable agriculture. Front. Plant Sci. 2018, 9, 1655.
15. Chiaiese, P.; Corrado, G.; Colla, G.; Kyriacou, M.C.; Rouphael, Y. Renewable sources of plant biostimulation: Microalgae as a sustainable means to improve crop performance. Front. Plant Sci. 2018, 9, 1782.
16. Rouphael, Y.; Colla, G. Toward sustainable agriculture through plant biostimulants: From experimental data to practical applications. Agronomy 2020, 10, 1461.
17. E.U. Regulation of the European Parliament and the Council Laying Down Rules on the Making Available on the Market of EU Fertilising Products and Amending Regulations (EC) No 1069/2009 and (EC) No. 1107/2009 and Repealing Regulation (EC) No 2003/2003. 2019. Available online: (accessed on 11 January 2021).
18. Szczałba, M.; Kopta, T.; Gąstoł, M.; Sękara, A. Comprehensive insight into arbuscular mycorrhizal fu ngi, Trichoderma spp. and plant multilevel interactions with emphasis on biostimulation of horticultural crops. J. Appl. Microbiol. 2019, 127, 630–647.
19. Wozniak, E.; Blaszczak, A.; Wiatrak, P.; Canady, M. Biostimulant Mode of Action: Impact of Biostimulant on Whole-Plant Level. In The Chemical Biology of Plant Biostimulants; Geelan, D., Xu, L., Eds.; Wiley Online Library: Hoboken, NJ, USA, 2020; pp. 205–227.
20. Brown, P.; Saa, S. Biostimulants in agriculture. Front. Plant Sci. 2015, 6, 671.

21. Ruzzi, M.; Aroca, R. Plant growth-promoting rhizobacteria act as biostimulants in horticulture. Sci. Hort. 2015, 196, 124–134.

22. Vandenkoornhuyse, P.; Quaiser, A.; Le Van Duhamel, M.; Dufresne, A. The importance of the microbiome of the plant holobiont. New Phytol. 2015, 206, 1196–1206.

23. Ratiu, I.A.; Al-Suod, H.; Ligor, M.; Monedeiro, F.; Buszewski, B. Effects of growth conditions and cultivability on the content of cyclitols in Medicago sativa. Int. J. Environ. Sci. Technol. 2020, 18, 33–48.

24. Du Jardin, P. Plant biostimulants: Definition, concept, main categories and regulation. Sci. Hort. 2015, 196, 3–14.

25. Lugtenberg, B. Principles of Plant-Microbe Interactions: Microbes for Sustainable Agriculture; Lugtenberg, B., Ed.; Springer: Cham, Switzerland, 2015; pp. 1–15.

26. Rouphael, Y.; Colla, G. Biostimulants in Agriculture. Front. Plant Sci. 2020, 11, 40.

27. Dunhamtrimmer.com. 2018. Available online: (accessed on 11 January 2021).

28. Woo, S.L.; Pepe, O. Microbial consortia: Promising probiotics as plant biostimulants for sustainable agriculture. Front. Plant Sci. 2018, 9, 1801.

29. Le Mire, G.; Nguyen, M.; Fassotte, B.; du Jardin, P.; Verheggen, F.; Delaplace, P.; Jijakli, H. Implementing biostimulants and biocontrol strategies in the agroecological management of cultivated ecosystems. Biotechnol. Agron. Société Environ. 2016, 20, 1–15.

30. Aamir, M.; Rai, K.K.; Zehra, A.; Dubey, M.K.; Kumar, S.; Shukla, V.; Upadhyay, R.S. Microbial bioformulation-based plant biostimulants: A plausible approach toward next generation of sustainable agriculture. In Microbial Endophytes; Woodhead Publishing: Cambridge, UK, 2020; pp. 195–225.

31. Mishra, J.; Arora, N.K. Bioformulations for plant growth promotion and combating phytopathogens: A sustainable approach. In Bioformulations: For Sustainable Agriculture; Springer: New Delhi, India, 2016; pp. 3–33.