

Review

Bioformulations based on plant growth promoting rhizobacteria for sustainable agriculture: Biofertilizer or Biostimulant?

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Integrated production in sustainable agriculture aims to improve the efficiency of biological inputs through plant-based bioformulations or microorganisms, which are an excellent source of natural fertilisers. A variety of plant stimulants are increasingly used in crop production for environmentally sustainable agriculture. These products have different names and the designations are confusing. The aim of this work is to clarify what is meant by biofertilizer and biostimulant. A biofertilizer is a bacterial or fungal inoculant applied to plants with the aim of increasing the availability of nutrients and their use by plants, regardless of the nutrient content of the inoculant itself. A plant biostimulant is substance or microorganism applied to plants for the purpose of improving the nutritional efficiency, abiotic stress tolerance and/or quality characteristics of crops, regardless of its nutrient content. By extension, plant biostimulants also refer to commercial products containing mixtures of these substances and/or microorganisms. Plant Growth Promoting Rhizobacteria (PGPR) can be called biofertilisers or biostimulants; PGPR formulations are biostimulants. It can be noted that biofertilisers are included in biostimulants.

Key words: Biostimulant, biofertilizer, Plant Growth Promoting Rhizobacteria (PGPR), bioformulation, sustainable agriculture.

INTRODUCTION

The uncontrolled and excessive use of chemical inputs to increase agricultural productivity is argued by some to be degrading the soil and endangering the ecosystem, which is further argued to pose a serious threat to human health (Nellemann et al., 2009). It is therefore imperative to

move towards modern agriculture and to look for new biotechnological advances that allow a reduction in the use of chemical inputs without affecting crop yields and farmers' income (Chbani et al., 2013). Recent efforts have been devoted to the production of high quality,

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nutrient-rich food in a sustainable manner to ensure biosecurity (Raja, 2013). Consumption of organic food is associated with health beliefs and subjective well-being, leading to increased values and market demand (Apaolaza et al., 2018). Recent studies highlight that organic food has significant human and environmental health benefits (Gomiero, 2018). Moreover, in the coming years, agriculture will be pushed to become more sustainable as a global response to climate change. This significant growth in organic farming is not only due to agricultural change, but also represents the implementation of important changes in society and their relationship with agriculture (Lobley et al., 2009). Nowadays, there are several biological products to manage and improve crops (Benfatto et al., 2015). Among these products, we have biostimulants and biofertilisers. These two terms are often misused. In view of the confusion surrounding biofertilisers and biostimulants, it was necessary to look for objectively available information in the literature to clarify these two concepts. The aim of this review is to clarify the notions of biofertilisers, biostimulants and to find a correct name for Plant Growth Promoting Rhizobacteria (PGPR) and PGPR formulations. This review gives an overview of the definition of the concepts of plant biofertilisers and biostimulants, as well as their mode of action. It will also briefly describe the benefits and some interesting results of biofertilisers and biostimulants and present some biofertilisers and/or biostimulants products currently on the market. At the end, we will clarify the relationship between the two concepts and specify the appropriate name for PGPR and PGPR formulations.

CONCEPTS CLARIFICATION

Biofertilisers

Definition and modes of action

Biofertilizer can be interpreted in different ways (El-Ghamry et al., 2018). A biofertilizer is a bacterial or fungal inoculant applied to plants with the aim of increasing the availability of nutrients and their utilisation by plants, regardless of the nutrient content of the inoculant itself. Biofertilizer is a substance containing living microorganisms that, when applied to the seed, plant surface or soil, colonise the rhizosphere or plant interior, promoting growth, yield and increasing the supply or availability of primary nutrients to the host plant.

Biofertilizer is a product that is not chemically synthesised, biodegradable and can be used as a fertiliser containing live phosphate solubilising and nitrogen fixing microorganisms PGPR (Roychowdhury et al., 2014). They promote plant growth by increasing nutrient supply (Adjanohoun et al., 2012), increasing the root biomass or root area (Vessey, 2003). Some

biofertilisers are able to produce sufficient growth-promoting phytohormones (IAA) and substances that control pathogen proliferation (HCN) (Noumavo et al., 2015). Biofertilisers add nutrients through natural nitrogen fixation processes, solubilising phosphorus and stimulating plant growth through the synthesis of growth-promoting substances (Agbodjato et al., 2018; Nilabja Ghosh, 2007). They provide environmentally friendly organic agricultural inputs and may be more cost-effective than chemical fertilisers, and can associate symbiotically with plant roots. The microorganisms involved can easily and safely convert complex organic materials into simple compounds, so that plants can easily assimilate them.

Benefits and some interesting results

The main role of biofertilisers application is to increase plant growth and yield without deleterious environmental side effects (Mishra et al., 2013). They maintain the natural soil habitat, and stimulate plant growth. Microbial biofertilisers play a crucial role in maintaining soil fertility at the appropriate level and improving soil structure by influencing the aggregation of soil particles (Rashid et al., 2015). They also may contribute to a better plant-water relationship (Xiang et al., 2012), provide protection against drought, make plants less prone to certain soil-borne diseases, mycotoxin-producing fungi (Simarmata et al., 2016) and reduce the incidence of insect pests (Dey et al., 2014). Biofertilisation is a practice to restore the functionality of soils destroyed by chemical inputs. Biofertilisers are most commonly used in maize, wheat, rice, sugarcane and sorghum crops in different soils and regions. Today, their use has been extended to species as different as pine, alfalfa, cactus, lettuce, strawberry, etc. (Singh and Singh, 2018; Mehnaz, 2015). According to a study by Schütz et al. (2018), inoculation with biofertilisers increased average crop yields by 16.2% compared to controls. Similarly, Amogou et al. (2021) obtained increases in height, leaf area, fresh biomass and yield of maize of 27.19, 32.23, 47.89 and 46.98% respectively after the use of microbial biofertilisers combined with 25% of the recommended dose of NPK-Urea in Benin.

Biostimulants

Definition and modes of action

Biostimulants are products, other than fertilisers, that promote plant growth if applied in small quantities (Du Jardin, 2015; Kauffman et al., 2007). They are products that have a stimulating effect on the growth and development of the plant, likely to provoke a defence reaction from the latter. Other authors consider

Table 1. Overview of some biofertilisers and/or biostimulants products available on the French market.

Supplier	Product	Fungi	Bacteria
Actura	Resid MG	<i>Champignons endomycorhizogènes</i>	
Agrifutur	Nitrogen		<i>Bradyrhizobium japonicum</i>
Agrostar	Baci Start M4		<i>Bacillus amyloliquefaciens</i>
BASF	Rhizoflo soja		<i>Bradyrhizobium japonicum</i>
Biovitis	Cérés Carpoes Heles	<i>Trichoderma harzianum</i> <i>Trichoderma harzianum</i>	<i>Pseudomonas fluorescens</i> <i>Bacillus methylotrophicus</i>
Cybele Agro Care	Bacteriolis Rhizobacteriolis		<i>Pseudomonas fulva</i> <i>Pseudomonas fulva</i> + <i>Pseudomonas fluorescens</i>
Compo expert	Agrosil turf Argin		<i>Bacillus amyloliquefaciens</i>
De Sangosse	Rizoliq Top		<i>Bradyrhizobium japonicum</i>
FCA	Mycosol	<i>Coniothyrium minitans</i> + <i>Trichoderma asperellum</i>	<i>Pseudomonas fluorescens</i> + <i>Pseudomonas putida</i>
Fertemis	Fertevie Rhiz		<i>Bacillus amyloliquefaciens</i>
Elephant vert	Ovalis rhizofertil		<i>Pseudomonas putida</i>
Gaiago SAS	Free PK		<i>Bacillus mucilaginosus</i>
Lallemant Plant Care	Rhizocell		<i>Bacillus amyloliquefaciens</i> sp
Plantworks	Root grow	<i>Champignons endomycorhizogènes</i>	
Premier Tech GHA	Myke Pro	<i>Champignon endomycorhizogène</i>	

Alabouvette and Cordier (2018).

biostimulants as stimulators of natural defences, and focus only on the phytoprotective aspect of these products (Lambert, 2006). According to Yakhin et al. (2017), a biostimulant is a biologically derived product that improves plant productivity as a result of emergent properties caused by constituent complexes, and not as a sole consequence of the presence of essential nutrients, plant growth regulators or plant protective compounds. Biostimulants can be microorganisms (PGPR, Arbuscular Mycorrhizal Fungi (AMF)), natural or naturally occurring substances (humic acids, amino acids, algae extract, plant extract), and synthetic substances (chitosan) (Katiyar et al., 2015; Hadwiger, 2013). They can be used alone, in the soil or in the growing medium, by spraying on plants or by coating seeds (EBIC, 2014). Biostimulants are products that promote or improve water uptake, nutrient uptake, bioavailability and nutrient assimilation efficiency, tolerance to abiotic stresses, crop quality, crop yield, maintenance of growth and production levels, under optimal conditions, stimulation and fortification of plants (Yakhin et al., 2017; Faessel et al., 2014).

Biostimulants are not considered fertilisers, as such, because they do not provide a sufficient amount of nutrients. Biostimulants are materials, other than fertilisers, that promote plant growth when applied in small quantities (Kauffman et al., 2007). However, they are classified as a fertiliser from a regulatory point of view for marketing.

Benefits and some interesting results

Biostimulants have a very positive impact on the environment and the preservation of resources by promoting a better use of nutrients by plants (EBIC, 2012). They contribute to the reduction of greenhouse gas emissions (through a better use of nitrogen). Biostimulants contribute to the preservation of unrenovable resources through better absorption of certain nutrients. According to Calvo et al. (2014), biostimulants enhance the uptake of water and nutrients from the soil, increase root growth and make plants more resistant to water and heat stress and excessive salinity, all of which reduce the need for pesticides (Childs and Beeson, 2000). The height, stem diameter, leaf area, above-ground biomass and below-ground biomass of maize under the influence of biostimulants were improved by 83.06, 44.57, 102.94, 86.84 and 42.68% respectively, compared to the control under greenhouse conditions (Adoko et al., 2021).

Biofertilisers and/or biostimulants currently on the market

Table 1 gives an overview of some products available on the French market. From Table 1 the biofertilisers and/or biostimulants found on the French market can be grouped into five categories. Biofertilisers and/or

biostimulants formulated with a single strain of fungi; a single strain of bacteria; a combination of fungi; a combination of bacteria and a combination of fungi and bacteria (Alabouvette and Cordier, 2018).

RELATIONSHIP BETWEEN BIOFERTILISERS AND BIOSTIMULANTS

Biostimulants are classified according to the origin and nature of the resources used for their manufacture, their function, their use or the type of effects observed. According to Torre et al. (2016), there are five groups of biostimulants. Humic substances, algae extract, protein and amino acid hydrolysates, inorganic salts and microorganisms (beneficial bacteria and fungi). According to Yakhin et al. (2017), humic substances and PGPR are classified as biofertilisers, phytostimulants and biopesticides. Du Jardin et al. (2015) consider biofertilisers as a subcategory of biostimulants. Algae extracts and microorganisms are considered by other authors as biofertilisers (Torre et al., 2016; Roychowdhury et al., 2014).

WHAT IS THE CORRECT TERM FOR PGPR AND PGPR FORMULATION?

PGPR are soil microorganisms that naturally stimulate plant growth and yield. They play their roles either by solubilising and assisting in nutrient acquisition or by releasing phytohormones or biocontrol agents to protect the plant from various pathogens (Glick, 2012). The rhizobacteria solubilise metals such as phosphorus (P), zinc (Zn), iron (Fe), potassium (K), into soluble forms that are available to plants. These soluble forms of metals significantly improve plant nutrition and growth (Kamran et al., 2018; Gupta et al., 2015). Also, the phytase produced by some PGPR allows the release of phosphorus associated with organic compounds. In addition, they produce organic acids to reduce metal toxicity (Ahemad, 2015).

There are several categories of PGPR depending on their modes of action. Somers et al. (2004) classified PGPR into four subgroups: biofertilisers (increase in nutrient availability to the plant), phyto-stimulators (increase in plant growth, ability to produce phytohormones), rhizo-remediators (degradation of organic pollutants) and finally biopesticides (control of diseases, production of fungicidal and antibiotic metabolites). Du Jardin et al. (2015) consider all categories of PGPR as biostimulants. PGPR can be called biofertilisers or biostimulants.

In addition to rhizobacteria, PGPR formulations contain binders and other organic and mineral substances. Formulations based on Plant Growth Promoting Rhizobacteria (PGPR) are then called biostimulants.

CONCLUSION

In recent years there has been an increase in the number of natural products that stimulate plant growth and yield. A biofertilizer is any bacterial or fungal inoculant that increases the availability of nutrients and their use by plants, regardless of its nutrient content. Biofertilisers are microbial biostimulants. Biofertilizer is a product that is not chemically synthesised, biodegradable and can be used as a fertiliser containing living microorganisms. Biostimulants are products, other than fertilisers, that promote plant growth if applied in small quantities. Biostimulants are substances or microorganisms that function to stimulate natural processes to increase nutrient uptake and efficiency, tolerance to abiotic stresses and crop quality independent of nutrient content. Biostimulants are broader than biofertilisers. Biofertilisers are included in biostimulants. They are therefore microbial biostimulants. PGPR can be called biofertilisers or biostimulants; PGPR formulations are biostimulants.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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