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NEWS AND VIEWS

PROPOSAL FOR THE DIVISION OF PLANT GROWTH-PROMOTING RHIZOBACTERIA INTO TWO CLASSIFICATIONS: BIOCONTROL-PGPB (PLANT GROWTH-PROMOTING BACTERIA) AND PGPB

YOAV BASHAN* and GINA HOLGUIN

Department of Microbiology, The Center for Biological Research of the Northwest (CIB). P.O. Box 128. La Paz. B.C.S.. 230(X) Mexico

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Bacteria that can increase plant growth and productivity have been known for over a century (Brown, 1974). Prominent among these organisms are species of the genus *Rhizobium* (Dejordjevic *et* al., 1987) whose potential and practical use in agriculture is beyond doubt (O'Gara *et al.,* 1995). Although other bacterial species associated with plants, but, without creating symbiosis like *Rhizobium. were* discovered early in this century (Beijerinck. 1925), the fact that many of them were able to promote plant growth was not widely recognized. The breakthrough in this field occurred in the mid 1970s with (i) the discovery that some bacteria, mainly pseudomonads, are capable of controlling soil-borne pathogens to indirectly enhance plant growth (Kloepper and Schroth, 1978, Kloepper *et al.,* 1980), and (ii) the re-discovery (Döbereiner and Day, 1976) of *Azospirillum spp.* (Beijerinck, 1925) which directly affect plant metabolism and consequent growth. These findings established two research approaches to bacterial inoculation (i) the biocontrol of plant pathogens (Kloepper *et al.,* 1989), and (ii) *Azospirillum*-related organisms (Bashan and Levanony, 1990). Most bacteria in both groups are root associated, free living in soil or the phyllosphere and unlike *Rhizobium* or *Agrobacterium* form no apparent structural association with plant roots (Kloepper *et al.,* 1989; Bashan and Levanony, 1990). Curiously, the two fields have developed almost independently of one another, yielding only few cross-citations (Glick, 1995; Institute for Scientific Information (Philadelphia) citation search, 1996 done by the authors) in papers with subjects in common such as migration towards the plant, survival in soil and effects on plant growth. The primary barriers between these two fields have been of both taxonomic and functional nature.

When Kloepper and Schroth (1978) and Kloepper *et al.* (1980) coined the term Plant Growth-Promoting *Rhizobacteria* (PGPR), it was originally used to describe the biocontrol group. This term is used appropriately by many scientists, and is almost universally accepted to describe this research field. The other bacterial group has no particular name and is vaguely referred to by different terms depending on the research group.

During the last decade, close to 4000 publications have appeared in the field of Plant GrowthPromoting Bacteria (Life Science data base; Cambridge Scientific abstracts). Many of these studies characterized new bacterial strains which had not belonged to any previously defined group, thus contributing to the confusion in classification and terminology. The numerous terms currently being used to describe plant growth-enhancing bacteria (Table 1 and Appendix) foster incorrect and confusing communication between scientists and unnecessary hardship in extracting data from databases. We believe that an accurate, accepted terminology is fundamental for biological precision, scientific cooperation, and understanding between various researchers.

We propose two new terms for general scientific use; "biocontrol plant growth-promoting bacteria" (Biocontrol-PGPB) and "plant growth-promoting bacteria" (PGPB). These terms would seem to encompass all the plant beneficial bacteria according to their particular role as understood today.

*Author for correspondence.

Table 1. Currently used terms for Plant Growth-Promoting Bacteria (PGPB) and their limitations

Term	Where used?	Major drawbacks	Selected reference
PGPR (plant growth-promoting rhizobacteria; rhizosphere bacteria)	This term covers all bacteria of rhizosphere origin that promote plant growth. It has been used solely in the field of bacterial biocontrol. These bacteria suppress disease development by either producing pathogen-inhibiting substances or by increasing plant resistance.	(1) The term does not cover non-rhizosphere interactions like biocontrol in the phyllosphere; (2) This term was coined when this field was relatively small (in number of publications). At that time, its broad reference was an advantage. Today, the term is too general and non specific.	Brown *et al.*, 1990; Keel *et al.*, 1991; Casida and Lukezic, 1992; Bushan *et al.*, 1993; Chanway and Holl, 1994a; Tuzun and Kloepper, 1994
Plant-beneficial bacteria (PBB)	This term covers all, experimentally proven, bacteria exhibiting positive effects on plants. The common term for non-biocontrol type of bacteria.	(1) This term does not appropriately differentiate between bacteria that are beneficial to plants (i.e., increase plant growth) and bacteria that may have one beneficial characteristic (e.g. nitrogen fixation, phosphate solubilization or plant-hormone production) among other non-beneficial characteristics. For example, can the nitrogen-fixing, tumor-producing *Agrobacterium tumefaciens* be considered beneficial bacteria? (2) Term is too broad and does not precisely delineate the nature of the bacteria.	Kanvinde and Sastry, 1990; Bashan and Holguin, 1994; Chanway and Holl, 1994b.
Direct and Indirect PGPR	"Indirect" refers to biocontrol PGPR and "direct" refers to all other PGPB. While these two classifiers distinguish the nature of bacterial effects, they are rarely found in the literature.	The term "direct" excludes non-biocontrol bacteria that indirectly affect plant growth by their metabolic products like phosphate solubilization, sulfur oxidation, nitrogen fixation by cyanobacteria or ethylene production.	Gaind and Gaur, 1991; Grayston and Germida, 1991; Glick *et al.*, 1994; Ryder *et al.*, 1994; Toledo *et al.*, 1995

A classification scheme for plant enhancing bacteria should: (i) accurately describe its primary nature: capacity to increase plant growth or yield. (ü) cover as many of the bacteria as possible that are known at the time. (iii) allow for accumulating data afterwards with only minor modification, (iv) be clear and encompassing, (v) describe each group of bacteria by their unique features and not by their lack of features, and (vi) if more than one term is used, they should not be contradictory.

We therefore propose that the common descriptor Plant Growth-Promoting Rhizobacteria (Kloepper *et al.*, 1980) be updated to accommodate new knowledge in the field. We believe that this term best describes the nature of many beneficial bacteria and is already widely accepted by the scientific community. Since many beneficial bacteria are not rhizosphere bacteria, we propose replacing "rhizobacteria" with "bacteria", creating the modified term Plant Growth-promoting Bacteria (PGPB). When this term is used to describe bacteria that suppress a plant pathogen (by either producing inhibitory substances or by increasing the natural resistance of the plant), the word "Biocontrol" will combine to produce the new term Biocontrol PGPB.The term PGPB is applicable where the bacteria affect plants by means other than the suppression of other microorganisms. They can do this through their own metabolism [phosphate solubilization, hormone production. N_2-fixation (Dejordjevic *et* al., 1987; Leinhos. 1994; Strzelczyk *et al*, 1994), directly affect the plant metabolism [enhance water and mineral uptake (Bashan et al.. 1990), improve root development (Okon and Kapulnik, 1986), enhance plant enzyme activity (Ferreira et al., 1987)] or affect the plant by "helping" another beneficial microorganism to function better [e.g. *Azospirillum* increasing modulation of legumes by rhizobia (Yahalom *et al*., 1987), or enhancing mycorrhizal phosphate solubilization (Barea *et* al., 1983) or mycorrhizal infection (Li *et al*.. 1992; Garbaye, 1994)].

These terms could be used regardless of the bacterial genus or species. However, in some cases different strains of the same species might be biocontrol PGPB or PGPB. In rare cases, these different functional features could be found in the same strain (Oberhänsli *et al*., 1991). The new terms proposed include, to the best of our knowledge, all the plant growth-enhancing bacteria known today, including rhizobia. Adoption of these terms would allow scientists to communicate more accurately on a global basis, and will standardize this field of biology. At the same time, the old terms should be abandoned.

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APPENDIX

Terms In Use Describing Habitat

Root associative bacteria. The original term for the *Azospirillum*-like organisms. This term covers all bacteria which live in the rhizosphere and rhizoplane. Major drawbacks: (1) Not appropriate for endophytic organisms such as *Acetobacter diazotrophycus,* rhizobia living in stem and leave nodules, phyllosphere bacteria and many other endophytic bacteria whether root residents or introduced biocontrol agents. (2) The term is too general to be meaningfully related to the nature of the bacteria. (Döbereiner and Day, 1976; Lindow, 1987; Misaghi and Donndelinger, 1990; McInroy and Kloepper. 1991; James *et al*., 1994; Ladha and So. 1994).

Rhizosphere bacteria (rhizobacteria). Like the term "root associative bacteria", it covers all bacteria living in the rhizosphere. These include numerous species and strains, either pathogenic or saprophytic. Major drawback: the term refers to the location from which the bacteria were isolated rather than the effect these bacteria have on plants (Bazin et al., 1990; de Freitas and Germida, 1990; Chanway and Holl, 1994b).

Endorhizosphere bacteria. This term is supposed to describe bacteria living in the "inner" parts of the rhizosphere (Lynch, 1982: You and Zhou, 1989: van Peer *et al*., 1990). Major drawback: a semantically incorrect term that should not be used for the arguments presented by Kloepper *et al.* (1992).

Special Use Terms (Sub-division Of PGPB)

Biofertilizer. The term is favored by the inoculation industry. !t is believed that the term "biofertilizer" facilitates the registration process of new bacterial products in industrialized countries. In developing countries. it is also easier to sell a product with a name that reminds the farmer of "fertilizer" rather than "bacteria", which connotates human and animal diseases. Major drawback: Despite its popularity, this term is inappropriate because it excludes all bacterial strains which do not contribute to plant growth via mineral uptake and microbial extraction of minerals from rocks like Biocontrol-PGPB (Bashan, *1993)*.

Yield increasing bacteria. The term was originated in China and is exclusively being used there. Major drawback: the term is incomplete. It wrongly assumes that all PGPB increase plant yield. This is not true in plants which have no defined yield like cactus. There, the entire plant simply grows more vigorously (Puente and Bashan, 1993*:* Tang, 1994).

Azospirillum-related microorganisms. Currently in use in the non-biocontrol field. Major drawbacks: it has a limited scope (referring only to *Azospirillum*-type bacteria) and does not properly define which are the "related microorganisms" and by what criteria a bacterium should be considered "*Azospirillum*-related" (Del Gallo and Fendrik, *1992;* Fendrik et *al.*, 1995).

Non-biocontrol PGPR. The term has been used to define non-biocontrol PGPB. Major drawback: it is inappropriate to define an organism by what it does not do rather than by what it does (Bashan, 1995)

Other Used Term

Biocontrol Agent. Used solely in the biocontrol field. Major drawback: the term does not differentiate between bacteria, fungi, and other organisms that have biological control capacity over pathogens and thus. it is non-specific (Dupler and Baker, 1984).