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Growth Promoting Rhizobacteria or Dangerous Pathogens?

¿Rizobacterias Promotoras de Crecimiento o Peligrosos Patógenos?

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Resumen

Existen numerosos estudios que han demostrado los beneficios de las rizobacterias promotoras del crecimiento vegetal de las plantas en la agricultura; dentro de éstos se encuentran la producción de hormonas de crecimiento vegetal como el ácido indolacético, giberelinas y citoquininas y la transformación de nutrientes a una forma asimilable por las plantas como el nitrógeno y el fósforo, produciendo sideróforos que actúan como quelantes del hierro. Además, algunas de estas bacterias pueden actuar como antagonistas de algunos microorganismos fitopatógenos. Sin embargo, a pesar de todos los beneficios que ofrecen estas bacterias al actuar principalmente como biofertilizantes y biorremediadores, se sabe poco sobre los posibles efectos negativos que estos microorganismos pueden tener en organismos, especialmente en humanos. Son pocos los estudios de caso de pacientes que han acudido al hospital por una afección causada por diferentes especies de bacterias promotoras del crecimiento de las plantas. Por lo tanto, en esta revisión se describen algunos de los estudios positivos, así como informes negativos de algunas especies de rizobacterias en la última década.

Palabras Clave: *Bacterias, Agricultura, Biofertilizantes, Efectos negativos, Humanos.*

Abstract

There are numerous studies that have shown the benefits of plant growth promoting rhizobacteria (PGPR) in agriculture; within these are the production of plant growth hormones such as indolacetic acid, gibberellins and cytokinins, the transformation of nutrients to a form assimilated by plants such as nitrogen and phosphorus, production of siderophores that act as iron chelators, and also, some of these bacteria can act as antagonists of some pathogenic microorganisms. However, despite all the benefits these bacteria offer by acting mainly as biofertilizers and bioremediation, little is known about the possible negative effects that these microorganisms can have organisms, especially humans. There are a few case studies of patients who have gone to the hospital for a condition caused by different species of plant growth-promoting bacteria. Therefore, in this review some of the positive studies and negative reports of some rhizobacteria species in the last decade are described.

Key words: *agriculture, bacteria, biofertilizers, humans, negative effect.*

INTRODUCTION

Due to the negative effects that fertilizers have caused in agricultural production systems, such as low efficiency, high cost (Lalitha, 2017) and environmental damage (Vejan et al., 2016). Currently, the use of microorganisms as well as plant growth promoting rhizobacteria (PGPR) is gaining importance by acting as biofertilizers increasing plant growth directly by providing nutrients and growth hormones or indirectly by reducing the effects of pathogens (Ramesh et al., 2014) (Figure 1). Among the direct mechanisms are biological processes such as biological nitrogen fixation, solubilization of organic or inorganic complexes, mobilization of iron through the production of siderophores and the production of growth regulating hormones, such as indole acetic acid (IAA), gibberellins and cytokinins (Lugtenberg and Kamilova, 2009) as well as the synthesis of the enzyme 1-aminocyclopropane-1-carboxylic acid (ACC) deaminase aiding to promote the growth of plants as affected by environmental stress (Lalitha, 2017). Indirect growth promotion can occur through antagonism, due to antibiotics and lytic enzyme activity, or through competition for nutrients, niche exclusion and induced systemic resistance in host plants (Zandi and Basu, 2016). hydrogen cyanide produced by many rhizobacteria, which plays an important role in the biological control of pathogens by inhibiting the transport of electrons, causing energy to not be supplied to cells and causing death of organisms (Lalitha, 2017).

In a recent investigation by Ordóñez-Beltrán et al. (2020), the bacterial genera *Enterobacter*, *Chryseobacterium*, *Exiguobacterium*, *Pseudomonas*, *Acinetobacter* and *Bacillus* were isolated from the rhizosphere of *Vitis vinifera* as potential strains to promote growth in this species or others. However, since the possible risks of using these genera are unknown, the purpose of this review was to better know both, the positive and negative effects reported on non-target organisms in the last decade.

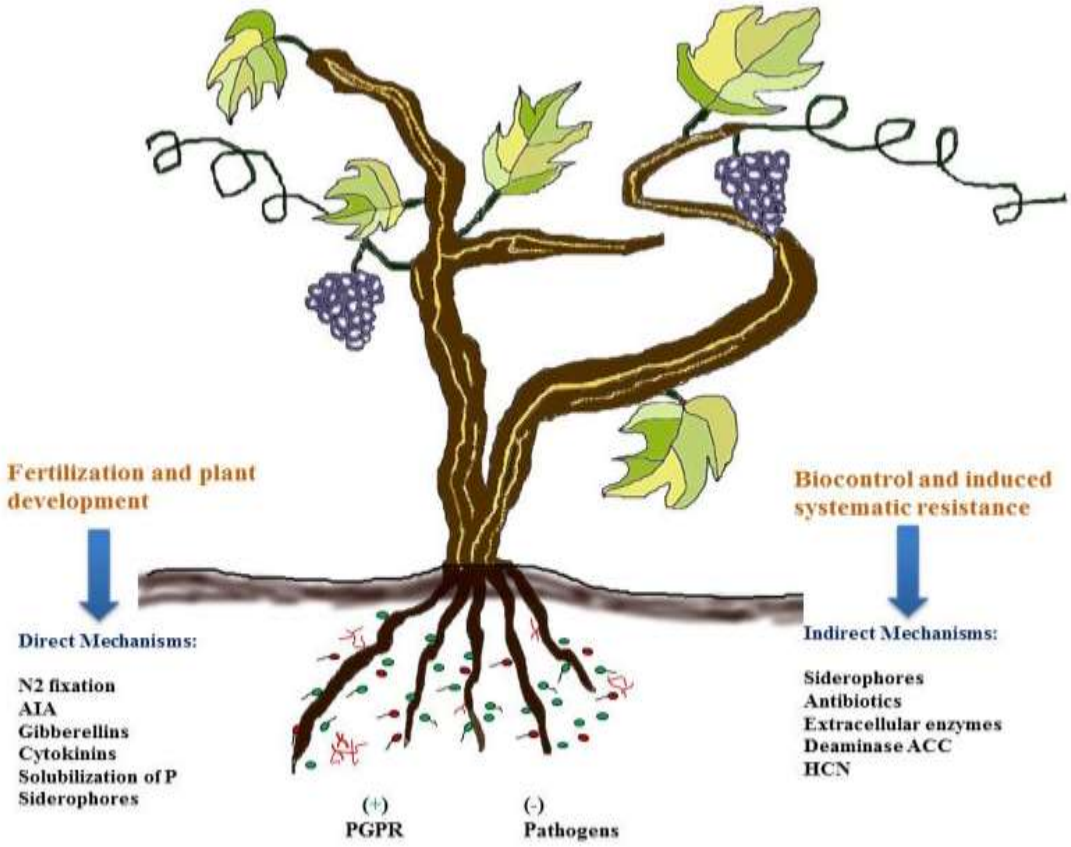


Figure 1. Mechanisms of growth-promoting rhizobacteria.

MATERIALS AND METHODS

The research carried out was a bibliographic review. Relevant information was sought on the genera of bacteria mentioned in this article, regarding their potential to promote growth in plants, as well as other positive effects. At the same time, information was sought about the negative effects of these bacteria on non-target organisms, mainly humans. The search focused mainly on scientific articles and case reports found in search engines and databases such as Google Scholar and Scopus, focusing on publications from the last decade.

RESULTS AND DISCUSSION

The Table 1 shows studies in which the effects as promoters, biocontrollers of pathogens and bioremediators of different bacterial species are reported; while Table 2 shows works in which some negative effects of different bacterial species that promote plant growth have been reported.

Acinetobacter Spp.

In 1974, the genus *Acinetobacter* consisted of one species, *A. calcoaceticus*, which was later subdivided into the subspecies *A. calcoaceticus* v. anitratus and *A. calcoaceticus* v. *lwoffii* (Peleg et al., 2008). Studies have shown the potential of the genus *Acinetobacter* to promote plant growth (Table 1). *Acinetobacter* sp. (RSC7) demonstrated the ability to solubilize phosphorus, production of IAA and siderophores; the inoculation in seeds produced a greater growth of seedlings of *Vigna radiate, Vigna unguiculata, Abelmoschus esculentus, Dolichos lablab* (Prittesh et al., 2017). *Acinetobacter calcoaceticus* (P23) was inoculated in 'duckweed' (*Lemna minor*) and 'lettuce' (*Lactuca sativa*) plants, in which the

chlorophyll content increased (Suzuki et al., 2014). *Acinetobacter harbinensis* and *Acinetobacter johnsonii* (CA1 and NA1, respectively) showed the ability to fix nitrogen, produce siderophores and solubilize phosphorus (Ordóñez-Beltrán et al., 2020).

It has been reported that some *Acinetobacter* species that have beneficial activity in plants are pathogenic for humans. Being this genus *Acinetobacter* one of the main causes of nosocomial infections (Table 2), being associated with the growing appearance of epidemics and has become a widespread concern in hospitals (Almasaudi, 2018). The *A. baumannii* species has been described as an opportunistic nosocomial pathogen and one of the six most important multidrug-resistant microorganisms in hospitals worldwide, responsible for a wide range of infections, ventilator-associated pneumonia, and blood infections, considered to contribute to a mortality rate that can reach up to 35% (Antunes et al., 2014). According to Elhosseiny and Attia (2018), *A. baumannii* has become a nightmare in hospitals in recent years, ranked first in the priority list of pathogens by the World Health Organization (WHO) for the development of new antibiotics.

In a study in Brazil, more than half of a sample of 141 people in hospital, resulted with infections in blood, pneumonia, surgical wound, urinary tract, skin and soft tissues caused by some species of the genus Acinetobacter (Leão et al., 2016).

Table 1. Positive effects of Plant Growth Promoting Rhizobacteria.

Species	Origin	Country	Description	Potential	Reference
Acinetobacter calcoaceticus (P23)	Duckweed surface (*Lemna minor*)	Japan	Duckweed inoculation (*Lemna minor*) and lettuce (*Lactuca sativa*)	Growth promotion	Suzuki et al., (2014)
Acinetobacter sp. (RSC7)	Rhizosphere of sugar cane (*Saccharum officinarum*)	India	Inoculation in seeds of *Vigna radiate, Vigna unguiculata, Abelmoschus esculentus* and *Dolichos lablab*	Growth promotion	Prittesh et al., (2017)
Acinetobacter harbinensis (CA1) and *Acinetobacter johnsonii* (NA1)	Rhizosphere of grape vine (*Vitis vinifera)*	Mexico	*In vitro* evaluation	Growth promotion	Ordóñez-Beltrán et al., (2020)
Bacillus amyloliquefaciens (FZB42)	Rhizosphere of lettuce (*Lactuca sativa*)	Germany	Inoculation in lettuce (*Lactuca sativa*)	Growth promotion and biologic control	Kröber et al., (2014)
Bacillus licheniformis (B017)	Collection of Agrounik d.o.o.	Serbia	Inoculation in tomato (*Solanum lycopersicum*)	Growth promotion	Katsenios et al., (2021)
Bacillus megaterium (R181), *B. safensis* (R173), *B. simplex* (R180) and *Paenibacillus graminis* (R200)	Rhizosphere of Wheat (*Triticum*)	United States	Inoculation in corn (*Zea mays*), soy (*Glycine max*) and wheat (*Triticum*)	Growth promotion	Akinrinlola (2018)
Bacillus pumilus (S2-3-2)	Plant rhizosphere soil	Korea	Inoculation in pepper plants *(Capsicum annuum)*	Growth promotion and suppress plant disease.	Li et al., (2020)
Bacillus solani (CB1)	Rhizosphere of grape vine (*Vitis vinifera)*	Mexico	*In vitro* evaluation	Growth promotion	Ordóñez-Beltrán et al., (2020)

Bacillus subtilis (L2)	Laboratory of Medicinal Plants Genetics and Biotechnology	Uzbekistan	Inoculation of the sterilized Ginger rhizome.	Growth promotion	Jabborova et al., (2021)
Chryseobacterium sp. PYR2	Soil contaminated with pesticides	China	Organochlorine pesticide degradation	Biorremediation	Qu et al., (2015)
Chryseobacterium sp. (PSR10)	Soybean rhizosphere (*Glycine max*)	India	Inoculation into lentil (*Lens culinaris*) seeds	Growth promotion	Singh et al., (2018)
Chryseobacterium indologenes (CC1 and RPC2)	Rhizosphere of grape vine (*Vitis vinifera)*	Mexico	*In vitro* evaluation	Growth promotion	Ordóñez-Beltrán et al., (2020)
Enterobacter sp. (EJ01)	Rhizosphere of Chinese sea rose (*Dianthus japonicus thunb*)	Korea	*Arabidopsis* and in tomato (*Solanum lycopersicum*)	Growth promotion	Kim et al., (2014)
Enterobacter sp. (FD17)	Rhizosphere or corn (*Zea mays)*	Austria	Inoculation in corn plants (*Zea mays*)	Growth promotion	Naveed et al., (2014)
Enterobacter sp. (UPMR18)	Soil of crop fields	Malaysia	Inoculation into okra (*Abelmoschus esculentus*) seedlings	Growth promotion	Habib et al., (2016)
Enterobacter cloacae (MSR1)	Non-nodular alfalfa roots (*Medicago sativa*)	Saudi Arabia	Inoculation in alfalfa (*Medicago sativa*) plants	Growth promotion	Khalifa et al., (2016)
Enterobacter hormaechei (NE1)	Rhizosphere of grape vine (*Vitis vinifera)*	Mexico	*In vitro* evaluation	Growth promotion	Ordóñez-Beltrán et al., (2020)
Exiguobacterium sp. (VSG-1)	Soil	India	Lytic enzyme production	Biocombustible	Vijayalaxmi et al., (2013)
Exiguobacterium mexicanum (PR 10.6)	Soil contaminated by metals	England	Synthesis of silver nanoparticles	Biorremediation	Padman et al., (2014)
Exiguobacterium sp. (EM9)	Mud volcano and limestone caves	India	Inoculation in Chilean seeds (*Capsicum annuum*) and tomato (*Solanum lycopersicum*)	Growth promotion and biologic control	Venkadesaperumal et al., (2014)
Exiguobacterium sp. (PMA)	Contaminated chemical	India	4-chloroindole degradation	Biorremediation	Arora and Bae (2015)
Exiguobacterium sp. (MH3)	Duckweed rhizosphere (*Lemna minor*)	China	Inoculation in duckweed (*Lemna minor*)	Growth promotion and biorremediation	Tang et al., (2015)
Exiguobacterium subiricum (AE1)	Rhizosphere of grape vine (*Vitis vinifera)*	Mexico	*In vitro* evaluation	Growth promotion	Ordóñez-Beltrán et al., (2020)
Pseudomonas sp. y *Pseudomonas fluorescens*	Soil	Uzbekistan	Inoculation in wheat (*Triticum)*	Growth promotion	Egamberdieva (2010)
Pseudomonas pseudoalcaligenes, P.knackmussii P. pseudoalcaligenes, P. mosselii y P. *knackmussii*	Coastal soils	Indonesia	*In vitro* evaluation	Growth promotion	Susilowati et al., (2015)
*Pseudomonas fluorescens (*L111, L228 y L321)	Grass endophytes (*Miscanthus giganteus*)	Ireland	Inoculation in pea (*P. sativum*) plants	Growth promotion	Otieno et al., (2015)

Pseudomonas montelii (CP1)	Rhizosphere of grape vine (*Vitis vinifera)*	Mexico	*In vitro* evaluation	Growth promotion	Ordóñez-Beltrán et al., (2020)

Table 2. Negative effects of Plant Growth Promoting Rhizobacteria on non-target organisms.

Species	Gender	Age	Infection	Country	Reference
Acinetobacter spp.	42 Male and 17 Female	52 on average	Blood, pneumonia, surgery wound, urinary tract, skin and soft tissue and others	Brazil	Leão et al., (2016)
Bacillus licheniformis and *Bacillus subtilis*	Male	71 years	Bacteremia and mediastinitis	Korea	La Jeon et al., (2012)
Bacillus pumilus	1 Female and 1 Male	Neonatal	Sepsis	Greece	Kimouli et al., (2012)
Bacillus licheniformis	Female	41 years	Sepsis and arthralgia	Bulgaria	Haydushka et al., (2012)
Bacillus pumilus	Female	6 years	Septic arthritis	Canada	Shivamurthy et al., (2016)
Bacillus. subtilis var. natto	Female	70 years	Bacteremia	Japon	Kato et al., (2022)
Chryseobacterium indologenes	Male	66 years	Pneumonia	United States	Monteen et al., (2013)
Chryseobacterium indologenes	Female	6 years	Neonatal meningitis	India	Eshwara et al., (2014)
Chryseobacterium indologenes	Male	1 year	Central Nervous System	Spain	Olbrich et al., (2014)
Chryseobacterium indologenes	Female	3 months	Pneumonia	Turkey	Atıcı et al., 2016
Chryseobacterium indologenes	Female	3 months	Pneumonia	India	Das et al., (2017)
Chryseobacterium indologenes	5 Female and 3 Male	49-72 years	Tracheobronchitis and pneumonia	Spain	González-Castro et al., (2017)
Chryseobacterium indologenes	Male	10 days	Pneumonia	Brazil	Antonello et al., (2017)
Chryseobacterium indologenes	Male	58 years	Covid-19 associated bacteremia	Taiwan	Yeh et al., (2022)
Enterobacter cloacae	Male	60 years	Cholecystitis	Spain	Isasti et al., (2009)
Enterobacter cloacae	Male	82 years	Pulmonary edema and symptomatic pericardial effusion	United Kingdom	Blundell and Mason (2015)
Exiguobacterium sibiricum	Male	66 years	Cutaneous	Spain	Tena et al., (2014)
Exiguobacterium spp.	Male	51 years	Pneumonia and bacteremia	China	Chen et al., (2017)
Exiguobacterium profundum and *Nocardia terpenica*	Female	53 years	Nocardiosis cerebral	China	Hu et al., (2018)
Pseudomonas aeruginosa	Male	49 years	Infectious Endocarditis	Costa Rica	Dimadi et al., (2023)

Bacillus Spp.

The genus Bacillus was first reported by Cohn (1872) and has been described as the most abundant genus of bacteria in the rhizosphere. Some species of this genus have been recognized for years for their activity as growth promoters (Susilowati et al., 2015); (Table 1). *B. amyloliquefaciens* (FZB42), showed an increase in the growth of 'lettuce' (*Lactuca sativa*) and contributed to health by reducing the severity of the disease caused by the phytopathogenic fungus *Rhizoctonia solani*, through the production of lipopeptides and polypeptides (Kröber et al., 2014). *B. megaterium* (R181), *B. safensis* (R173), *B. simplex* (R180) and *Paenibacillus graminis*

(R200), increased the growth of ‘corn’ (*Zea mays*), ‘soybean’ (*Glycine max*) and ‘wheat’ (*Triticum*) (Akinrinlola, 2018). *Bacillus pumilus* (S2-3-2) helped increase weight, chlorophyll content and root growth, and helped suppress bacterial spot disease (Li et al., 2020). *Bacillus solani* (CB1) demonstrated the ability to fix nitrogen and solubilize phosphorus (Ordóñez-Beltrán et al., 2020). *Bacillus subtilis* (L2) increased plant height, length, and number and width of leaves in the ginger crop (*Zingiber officinale Roscoe*) (Jabborova et al., 2021). *Bacillus licheniformis* (B017) increased the dry weight of tomato (*Solanum lycopersicum*) plants by 39% and the yield per plant by 51.94% (Katsenios et al., 2021).

Regarding health risks, most species of the genus *Bacillus* are not considered pathogenic for humans. However, infections by some species have been reported (Table 2). In Korea, an unusual bacteremia and mediastinitis due to co-infection with *B. subtilis* and *B. licheniformis* occurred in a patient with esophageal perforation (La Jeon et al., 2012). A case report in Canada revealed septic arthritis caused by *B. pumilus* and it is presumed that the infection was acquired on a trip to Africa. Despite, this organism rarely causes serious infections and has only been described in newborns and immunocompromised individuals or as a skin infection (Shivamurthy et al., 2016). Another case report in Greece revealed infection caused by this same species in two newborns, one in a female baby without any factors that predispose her to infection and the other in a male child who required mechanical ventilation and an intravenous catheter, demonstrating the potential of *B. pumilus* as a bloodstream pathogen during childhood (Kimouli et al., 2012). A case of Sepsis and arthralgia in an immunocompetent patient was reported in Bulgaria, caused by the species *B. licheniformis*, recognized as a human pathogen that causes infections (Haydushka et al., 2012). Another case of bacteremia was reported in Japan by *B. subtilis* var. natto, in a patient with a severe immunosuppressed condition (Kato et al., 2022).

Regarding pathogenicity in animals, a study in China found that the *B. subtilis* strain (HFBF-B11) is an opportunistic pathogen of ducklings when co-infecting with the bacterium *Riemerella anatipestifer*. The animals demonstrated liver injury and blood-brain barrier disorders that led to infections and brain damage with a 100% mortality rate (Zhu et al., 2017).

Chryseobacterium Spp.

The genus *Chryseobacterium* was originally described in 1994 by Vandamme et al., (Cools et al., 2019). Species of this genus have been found in various environments, including freshwater, soil, rhizosphere, phyllosphere, sludge, fish, insect intestine, dairy products, raw chicken, industrial plants and clinical samples (Cho et al., 2010).

This bacterium has shown to promote growth and bioremediation (Table 1). *Chryseobacterium* sp. (PSR 10), when inoculated in lentil seeds (*Lens culinaris*), increased significantly plant growth, chlorophyll content, nitrate reductase activity, phosphorus and crop yield, compared to control plants (Singh et al., 2018). In addition to growth promotion, *Chryseobacterium* has demonstrated its potential in bioremediation and biological control. According to Qu et al., (2015) *Chryseobacterium* sp. (PYR2) was able to degrade several organochlorine pesticides, using them as a carbon source for their development. Regarding the potential to promote plant growth *Chryseobacterium indologenes* (CC1 and RPC2) showed a higher ability to fix nitrogen and a higher production of siderophores compared to other

bacteria in that study (Ordóñez-Beltrán et al., 2020).

On the other hand, there are also case reports that show the pathogenicity of this bacterium in humans (Table 2). Although *Ch. indologenes* has been described as a microorganism that rarely causes disease in humans (Olbrich et al., 2014), some cases have been reported by these species. In India, a case study reported the association of this bacterium with pneumonia (Das et al., 2017). Besides, cases of ventilator-associated pneumonia have been documented in Brazil, Spain, Turkey, and the United States (Monteen et al., 2013; Atıcı et al., 2016; Antonello et al., 2017; González-Castro et al., 2017); as well as a case of neonatal meningitis in India (Eshwara et al., 2014). In Spain, the first case of infection on the central nervous system by this bacterium in a newborn was reported (Olbrich et al., 2014). Another case study in Taiwan reported the cause of Covid-19-associated bacteremia by *Chryseobacterium indologenes* (Yeh et al., 2022).

Enterobacter Spp.

The genus Enterobacter was first described in 1960 by Hormaeche and Edwards (Davin-Regli, 2015). Since then, it has been isolated from the soil, rhizosphere and the root zone of various crops and some studies have shown its potential to promote plant growth (Table 1). *E. cloacae* (MSR1) showed ability to solubilize phosphorus, production of phytohormones and bioactive compounds, where the inoculated plants showed greater length and dry weight in alfalfa (Medicago sativa), compared to the control (Khalifa et al., 2016). *Enterobacter*. sp. (EJ01), showed ability to produce ACC deaminase and AIA. Also, the strain has shown to be able to colonize the rhizosphere and endosphere of *Arabidopsis* roots, increasing both the fresh and dry weights, as well as plant height, with similar results in tomato (*Solanum lycopersicum*), under normal and high salinity conditions. *Enterobacter* sp. (UPMR18), improved seed germination and seedling growth of okra (*Abelmoschus esculentus*) under salinity stress, compared to *Bacillus megaterium* and with a control treatment (Habib et al., 2016). *Enterobacter hormaechei* (NE1) solubilized phosphate, showed the ability to fix nitrogen and it was able to produce siderophores (Ordóñez-Beltrán et al., 2020).

Some other studies, show that species of this genus, have been reported as pathogenic for humans (Table 2). *E. cloacae* and *E. hormaechei* are the most frequently isolated from clinical specimens (Davin-Regli, 2015). In the last three decades, *E. aerogenes* and *E. cloacae* were reported as opportunistic pathogenic bacteria in hospitals of Europe during outbreaks of infection, being isolated from the respiratory, urinary, blood and gastrointestinal tracts (Langley et al., 2001). A report of pulmonary edema caused by the species *E. cloacae* was reported in the United Kingdom (Blundell & Mason, 2015). In Spain, another case study reported gallbladder inflammation caused by the same species (Isasti et al., 2009).

Exiguobacterium Spp.

The bacterial genus *Exiguobacterium* was first described by (Collins et al., 1983), and *Exiguobacterium* species have been isolated from a wide variety of samples, such as soils, sediments, seawater, permafrost, glaciers, industrial effluents, and hydrothermal vents (Vishnivetskaya et al., 2009), as well as legume root nodules, demonstrating their endophytic capacity (De Meyer et al., 2015).

The distinctive feature of the isolates of this genus is their ability to grow under extreme environmental conditions, with temperatures

ranging from 12 to 55 °C in nutrient-limiting conditions (Vishnivetskaya et al., 2009).

Researchers have exploited this genus with attributes for growth promotion as well as bioremediation (Table 1). *Exiguobacterium* sp. (EM9) showed ability to IAA production, hydrogen cyanide (HCN), phosphorus solubilization, siderophore production, and hydrolytic enzymes *in vitro*. In the manner inoculation of seeds (*Capsicum annuum*) and (*Solanum lycopersicum*), resulted in a higher percentage of seedling emergence, root length and weight of the plants. In addition, the co-inoculation with the bacterium *Pantoea agglomerans* gave a more pronounced effect on the emergence of the seedlings, number of secondary roots, the length of the primary root and length of the stem, demonstrating the potential of the use of microbial consortia (Venkadesaperumal et al., 2014). *Exiguobacterium* sp. (MH3) decreased stress levels by preventing excessive chromium absorption in "duckweed" (*Lemna minor)* and increased the number of fronds in the same plant. (Tang et al., 2015). In addition to its ability to promote growth, the genus *Exiguobacterium* has shown other applications. *E. mexicanum* (PR 10.6) has been used for the synthesis of silver nanoparticles (Padman et al., 2014). *Exiguobacterium* sp. (VSG-1) used to produce bioethanol from ''sugarcane bagasse (*Saccharum officinarum*) and some lytic enzymes such as cellulase, pectinase, mannanase, xylanase and tannase (Vijayalaxmi et al., 2013). *Exiguobacterium* sp. (VSG-1) demonstrated its potential for bioremediation by degrading 4-chloroindole from contaminated sites and use it as its sole carbon and energy source (Arora & Bae, 2015). *Exiguobacterium subiricum* (AE1) showed the ability to fix nitrogen, produce IAA, and solubilize phosphorus, its results were lower than other bacteria in the study (Ordóñez-Beltrán et al., 2020).

Bacterial species of this genus are rarely associated with infections in humans, however, there are studies that show the opposite (Table 2). In China, it was reported the first case of an adult man with pneumonia and bacteremia caused by *Exiguobacterium* spp. (Chen et al., 2017). In Spain, a case of skin infection was reported by *E. sibiricum* (Tena et al., 2014). Despite the fact that in recent years there have been few cases of bacteremia in the central nervous system caused by *Exiguobacterium*, the first report was presented in patient with symptoms of this infection caused by *E. profundum* together with the bacterium *Nocardia terpenica* in China (Hu et al., 2018).

Pseudomonas Spp.

The genus *Pseudomonas* was described by Migula in 1984 (Slabbinck et al., 2010). This genus can be found in agricultural soils and they have been used as biofertilizers, as they are capable of improving crop yield through direct and indirect mechanisms (Walsh et al., 2001), being *P. fluorescens* the species that has been described as most effective in promoting plant growth (Susilowati et al., 2015) (Table 1). The bacterial strains *Pseudomonas* sp. (NUU1) and *P. fluorescens* (NUU2) stimulated sprouting, increased root length and dry weight when inoculated on 'wheat' (*Triticum*) (Egamberdieva, 2010). Studies have reported that. *P. pseudoalcaligenes, P. knackmussii, P. pseudoalcaligenes, P. mosselii, P. knackmussii, P. pseudoalcaligenes and P. mosselii*, promote plant development by their ability to promote nitrogen fixation and phosphate solubilization (Susilowati et al., 2015). *P. fluorescens* (L111, L228 y L321) showed ability to phosphate solubilization, and when inoculated in pea plants (*Pisum sativum*), they had effects of growth promotion (Otieno et al., 2015). *Pseudomonas montelii* (CP1) showed high

capacity to produce IAA and solubilize phosphorus (Ordóñez-Beltrán et al., 2020).

On the other hand, the *P. fluorescens* species area not generally considered a bacterial pathogen in humans. However, studies have identified it at low levels in various parts of the body (Table 2). *P. fluorescens* has been found to cause bacteremia in humans, and the majority of reported cases can be attributed to the transfusion of contaminated blood products or the use of contaminated equipment associated with intravenous infusions. Although it is not considered to be an etiological agent of lung disease, there are several reports that identify it in respiratory samples.

It is also suspected to be related to Crohn's disease, since approximately 50% of patients with this disease develop serum antibodies against *P. fluorescens* (Scales et al., 2014). Another species also called an opportunistic pathogen is *P. aeruginosa*, capable of infecting humans with compromised defenses and causing severe lung disease, being one of the main pathogens associated with nosocomial infections (Alhazmi, 2015). Another case study showed that Pseudomonas aeruginosa caused endocarditis in an immunosuppressed adult (Dimadi et al., 2023).

CONCLUSIONS

There is no doubt about the multiple benefits that plant growth promoting rhizobacteria (PGPR) provide to plants and the soil. However, it is important to note that these microorganisms can also be pathogenic for other non-target organisms, including humans. The vast majority of studies and case reports published about the negative effects of this type of bacteria show their action as infectious agents in immunosuppressed people, who go to the hospital for other primary pathologies. Pointing out that these bacteria act opportunistically. In recent years, the presence of some of these genera of bacteria in patients with Covid-19 has been reported, corroborating their opportunistic presence and that they can interact with other infectious agents. Despite the fact that their presence mostly occurs in hospitals, the risk of infection cannot be ruled out when working with them in agricultural crops. Therefore, it is important to always use the right equipment when handling them. More research is recommended on the effects of these bacteria not only on human health, but also on other non-target organisms, since in this area the research is almost non-existent, and beneficial native organisms must be included in the place where they are intended to be applied.

AUTHOR CONTRIBUTIONS

Supervision and review: M.N.F.M and G.I.O.O. Investigation, writing and editing: V.O.B. Review: M.J.A.D. All authors read and approved the final manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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