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Section I: Agricultural and Animal Biotechnology

Mini Review

Interacciones bacteria-planta: un valor añadido de la inoculación microbiana

Bacteria-Plant interactions: an added value of microbial inoculation

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Abstract

High world population and the increase in global food demands results in an indiscriminate use of chemical fertilizers by farmers, causing soil deterioration and other environmental problems. In recent years there has been a collective concern to preserve the environment through sustainable and environmentally friendly techniques. Plant growth-promoting bacteria (PGPB) are widely known to benefit plants in a sustainable manner, reducing chemical fertilizers application. Many studies have shown that these bacteria not only improve crop yields but also its quality, increasing certain nutrients and molecules that are important for human health such as aminoacids, proteins, vitamins, flavonoids, antioxidants, essential oils, among others. This work compiles recent information of PGPB as an alternative of chemical fertilizer for improving crop yields and plant metabolites production.

Resumen

El incremento acelerado de la población mundial que conlleva al aumento en la demanda de alimentos; ha ocasionado el uso indiscriminado de fertilizantes químicos por parte de los agricultores, provocando así el deterioro del suelo y con ello los subsecuentes problemas ambientales. En los últimos años ha surgido la preocupación colectiva de preservar el medioambiente a través del uso de técnicas sostenibles y ambientalmente amigables. Las bacterias promotoras de crecimiento vegetal (PGPB) son ampliamente conocidas por incrementar el crecimiento y desarrollo de las plantas de manera sostenible permitiendo así la reducción de la aplicación de fertilizantes químicos. Muchos estudios han demostrado que estas bacterias no solo mejoran el rendimiento de los cultivos sino también la calidad de estos, aumentando ciertos nutrientes y moléculas que son importantes para la salud del ser humano que los consume como aminoácidos, proteínas, vitaminas, flavonoides, antioxidantes, aceites esenciales, entre otros. Este trabajo recopila información reciente de las PGPB como alternativa a los fertilizantes químicos para la mejora en el rendimiento de los cultivos y la producción de metabolitos en las plantas.

Palabras clave:

PGPB; biofertilizantes; agricultura sostenible; interacciones; principios activos en plantas.

Keywords:

PGPB; biofertilizers; sustainable agriculture; interactions; active principles of plants.

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Introduction

The current world population is growing by 1.10 percent per year and is projected to increase to more than one billion people over the next 13 years, reaching 9.8 billion in 2050 (United Nations 2017). Limitations in the world's supply of natural resources for food production, coupled with environmental degeneration of lands, present a great challenge for agriculture (Dash & Gupta 2011). In order to feed this large population, food production must increase by 70 percent (Population Reference Bureu 2009). Intensive agriculture with chemical fertilization has been used to improve plant growth and nutrient requirements within a short period of time to get faster results (Han et al. 2016), although this kind of practice is costly and has high pollution effects (Orhan et al. 2006).

Due to the harmful effects of this type of agriculture on the environment and on consumer's health, there has recently been an interest to adopt more environmentally friendly agricultural practices (Jiménez-Gómez et al. 2017a). Plant growth-promoter bacteria (PGPB) have emerged as an alternative to chemical fertilization (De la Torre-Ruiz et al. 2016) and have been widely studied for its positive effects on crops yield (Umesha et al. 2018, Zhu et al. 2016, Flores-Félix et al. 2015). There are also recent studies that highlight the effects of PGPB in crops quality by increasing certain metabolites, which are beneficial to human health (Jimenez-Gómez et al. 2017b). This review highlights PGPB not only as a biofertilizer for crops yield improvement, but also as plant probiotic enhancer.

Microbe-plant interaction

Numerous studies have shown the enormous richness and abundance of varying microorganisms in different habitats such as soil, sediments, plants and even animals. Coevolution of different species resulted in a large variety of relationships (Faust & Raes 2012). Microorganisms-plant associations existed millions of years ago, since the land colonization of plants. Plant organs interact with microorganisms during all its phenological development, sculpting complex microbial assemblages within plant's phyllosphere, rhizosphere, and endosphere (Hassani et al. 2018). These interactions have undergone selection pressure over the years, which has effectively shaped, not only plant's microbial communities, but also plant's fitness (Hassani et al. 2018, Thrall et al. 2007) and metabolism.These kinds of interactions are fundamental for terrestrial ecosystems (Wu et al. 2009), since they define plant´s growth, stress tolerance (Schiarwski et al. 2018) and metabolite production (Agrawal et al. 2018). Moreover, bacteria may affect plants in a beneficial, harmful or neutral way (Brimecombe et al. 2007). However, the effect that a particular bacterium has on a plant may change depending on the environmental conditions. Sometimes the prevalence of certain bacterial population may have an impact on soil communities. Determination of soil microbial communities, isolation and application of their cultivable representatives would induce changes in soil microbial composition (Trabelsi & Mhamdi 2013). A bacterial inoculum could then be used at field level to increase plant yields and metabolite production

Biofertilizers

In recent years there has been a need for food production to increase due to the rise in growth population, generating a permanent concern for farmers to maintain soil fertility (Kundan et al. 2015). To satisfy the food demand, farmers have adopted an indiscriminate use of chemical products that endanger public and environmental health (Alori et al. 2017). Biofertilizers are a natural alternative substance for chemical fertilizers that were used to increase the growth of plants. They contain a series of microorganisms that through different mechanisms improve the availability of nutrients in the plant, increasing the effective assimilation of them (Verssey 2003). Biofertilizers are versatile, since they can be applied in the soil or as foliar fertilizers on the plant itself. They have recently gained popularity because people have started to realize the environmental contamination in both soil and water. Additionally, chemical fertilizers are quite expensive due to the rising costs of petroleum. The advantage of using biofertilizers is unquestionable, however there are many problems that must be solved related to regulations of its use and the establishment of a quality control system that ensures its safety (Jiménez-Gómez et al. 2017). Nowadays, nitrogenous biofertilizers are the most studied and commercialized, especially for legumes. The current market of formally constituted biofertilizers represents about 5% of the total market of chemical fertilizers, which is an indicator that there is still much to do to impulse this sector (Timmusk et al. 2017).

Plant-growth promotion

Plant–microbe interactions have been extensively used to improve plant growth for food production and recently for biofuel and secondary metabolites production too (Wu et al. 2009). Within these associations, PGPB are mainly reported to improve plant growth and based on their colonizing strategy could be defined as epiphytic, endophytic or rhizospheric (Eida et al. 2018). This last group is widely studied as a vast number of them have been found in a wide range of plants (Nihorimbere 2011). PGPB are beneficial microorganisms that include cyanobacteria, free-living, symbiotic and endophytic bacteria (Glick 2012). They can affect plant growth through direct and indirect mechanisms (Ngoma et al. 2012). Direct mechanisms are related with a forward and a direct promotion of plant growth (Kudan et al. 2015); while indirect involves the ability of PGPB to diminish negative effects of phytopathogens (Grobelak et al. 2014, Zúñiga et al. 2019). These include bacteria assistance for plant nutrient acquisition, modulation of phytohormones levels, production of antimicrobial compounds against phytopathogenic microorganisms, induction of systemic resistance against pathogens and competition ability, among others (Eida et al. 2018). These mechanisms do not work independently of one another; but they work interrelated, since plant growth is a physiologycally complex process. Several studies clearly demonstrated that these mechanisms have had beneficial effects on plant growth (Kumar et al. 2014, Ortiz-Ojeda et al. 2017, Ogata-Gutiérrez et al. 2017, Akinrinlola et al. 2018). Moreover, beneficial effects of bacteria depend on different factors too, including if bacteria are inoculated individually or in a consortium, their competitiveness, plant variety, type of sustrate and environmental conditions such as those provided by the laboratory, greenhouse or field. Only about 2–5% of rhizobacterial that are reintroduced in a soil containing competitive microflora, exerted a beneficial effect on plant growth (Ahemad & Kibret 2014). That is why results of controlled experiments varies among those executed in the field.

Impact of PGPB on plants metabolites production

Plants, as well as all organisms, are highly influenced by their accompanying microbiota. Many of these microorganisms may protrude or displace certain microbial populations depending on the environmental conditions. Within that microbiota, plant growth promoting bacteria interact with plants, activating certain metabolic pathways that in turn, induces the overproduction of some molecules that are important for human health; thus improving plant quality (Jimenez-Gómez et al. 2017). In that context, quality is defined as plant overproduction of certain metabolites (primary or secondary) increasing its nutritional or medical values. Some authors reported that PGPR are found to increase micronutrients (Esitken et al. 2010; Bona et al. 2014), proteins (Pandey et al. 2018), fatty acids (Habibi et al. 2011), vitamin C (Flores-Félix et al. 2015), volatile compounds (Oordookhani 2011, Banchio et al. 2008) and antioxidants (Ochoa-Velasco et al. 2016, Silva et al. 2014, Oordookhani 2011, Ordokhani et al. 2010, Grajek et al. 2005) in plants. For example, Flores-Félix et al. (2015) showed that not only the bacteria is important to induce the production of ascorbic acid in fruits; but also the type of colonization, such as biofilm formation. In their work, they demonstrated that biofilm formation in the rhizosphere duplicated vitamin C content in strawberries. A study in *Physalis peruviana* also showed a significant increase of this vitamin in fruits of plants inoculated with PGPR (Ogata-Gutiérrez & Zúñiga-Dávila 2013). Another study showed an overproduction of glucosinolates in inoculated maca plants compared to uninoculated control (Zúñiga-Dávila 2010). Glucosinolates are glycosides, precursors of isothiocyanates which is widely appreciated for its anticancer properties. Many of these metabolites are not synthesized by humans itself and have to be incorporated into their diet.

Scientific research has shown that secondary metabolites generated by the plant for its own defense result in the overproduction of certain molecules that have nutritional and pharmacological properties important to human health. These days, people prefer to consume organic and healthy food. Consequently, the induction of these types of molecules by PGPR is important to improve the human diet. In turn, it shows economical potential of plants to be commercialized as functional and medicinal foods. Nowadays, consumers are greatly concerned about the food they are incorporating into their diet.

While plant growth promoting bacteria is recently becoming important both in food and nutraceutical industries; this must be accompanied by the generation of quality control policies and regulations in the use of biofertilizers. It is necessary to have a better knowledge of the identity of the isolated bacteria before inoculating, to avoid the pathogenic ones, ensuring food safety.

Conclusions

Authors show the importance of microorganism-plant interactions, focusing on bacterial inoculants as a biofertilization alternative for increasing crop growth and productivity in an eco-friendly manner reducing the overuse of chemical fertilizers and ensuring food quality. In addition, it explores the effects of these interactions on the production of plant metabolites that are important for human health. This field of study still has a long way to go, but the evidence determines a new role for bacteria inoculums since it has an interesting commercial potential. However, further studies that involve metabolomic approaches are necessary to understand the mechanisms involved in these physiological processes.

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