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Bacteria-Soil-Plant Interaction: This Relationship to Generate can Inputs and New Products for the Food Industry

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Abstract

A thorough study of microbial communities that inhabit aquatic agro-ecosystems is crucial to a better understanding of what happens in the soil, since these microorganisms play important roles for the maintenance of the habitat. Irrigated rice culture is very common in Brazil. However, the incorrect use of these environments can affect the soil and cause damage. The bacteria-soil-plant interaction has been used in order to support biotechnology, as the rhizosphere possesses a different microbial ecology from the rest of the soil. Microorganisms from this region are directly related to plant growth. Bacterial diversity in soil is extremely diverse, with its population changed rapidly as new nutrients are made available or the existing ones are exhausted. The bacteria that live there receive both the plant nutrients and antimicrobial agents, which are selective and inhibit certain undesirable microorganisms. Aiming at this data, this article has an objective to review existing literature on the interaction between microorganisms and their relationship with the plants, which can be transmitted to food through minerals and/or enzymes, thus enabling the generation of inputs or new products.

Keywords: Bacteria; Soil plant; Food microbial comunity

Introduction

Rice is one of the most consumed foods in the world, being one of the most important grains in global economic terms. It is also an important product in the economy of many Latin American countries because it is a staple in the diet of the population [1].

Brazil is among the 10 countries with the highest production of rice, reaching the significant amount of 13 million tons per year, representing about 82% of production in the Mercosul bloc. Rio Grande do Sul is the largest producing state in Brazil, accounting for 61% of total production. Along with the state of Santa Catarina, the southern region accounts for 70% of total production in the country, ensuring the supply of this grain to the entire population of Brazil. The average consumption in the country is 45 kg per person per year [2].

The irrigated rice culture is the largest agricultural user of water worldwide. It is believed that it may cause environmental impacts and this not completely known. Some of the possible impacts of rice culture may be linked to phytosanitary treatments, water, and culture management in a general way [3]. New rice varieties were introduced in the second half of the 20th century that provided increased yields, and these yield gains were almost doubled when synthetic fertilizers were used [4]. Therefore, anthropogenic activities, such as the expansion of cities, pesticides and pollution may directly affect the microbiota of water and soil. However, little is known about how these factors may influence the action of these microorganisms in the ecosystems [5].

The key aspect of this review is to obtain answers to the following questions; (I) how the literature shows the interaction between soil, plant and bacteria; and (II) how the bibliography relates microorganisms with the generation of inputs for the food industry.

Rice

Rice is a plant of the genus *Oryza* belonging to the Gramineae family, who most cultivated species are *O. sativa* (Asian rice) and *O. glaberima* (African rice). The rice domestication happened about 10,000 years ago in Asia and, in Brazil, the plant came through Portuguese colonization [2].

Rice is an annual monocot and can be planted in wetland or highland ecosystems, but has variations in its yield, since the plant needs to adapt to the environment [6]. The plant grows in a period of 100 to 140 days, depending on the chosen crop [7]. The rice development cycle is separated into three phases: the vegetative stage; the reproductive phase; and the grain filling stage [8].

Because it is a culture of easy adaptation, which develops in many soils and climate conditions, the rice is being cultivated more, as the world population is in broad expansion and demand in food production should continually increase to meet the daily nutritional needs of the people, since rice is a mandatory component in the Brazilian meal [9]. The soil microbiota helps in the development of the rice plant. Such as the establishment of plant-microorganism association in the root system that is critical to the chemotactic response of the endophyte to root exudates.

The rice is a cereal that is recommended to people with coeliac disease for its lack of gluten, which is the element of some flour that gives softness to the food. Brown rice is a food that, for each 100 g, consists of 79.3 g of starch, 6.61 g mg of protein and some mg of vitamins such as vitamin B1, B2, B6, niacin, phosphorus, magnesium, iron, potassium and zinc [10,11].

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The rice grain is divided into three parts: Bark, containing the embryo, the endosperm and a fiber complex; - Bran, a thin layer of differentiated tissues such as fibers, proteins, fats, and vitamin B; - Embryo, containing starch, amylose and amylopectin [2].

Wet Lands

Irrigated agriculture shows significant growth in Brazil [12]. The rice fields may be considered wetlands because, according to Maltchik et al. [13], wetlands are environments created by men that help promote the proliferation of microorganism populations on substrates such as sand, gravel or other material in association with plants.

Each cultivation system also presents a different demand of irrigation water. Minimum tillage and no-till systems have similar methods of irrigation [14]. The pre-germinated system presents a different irrigation system of soil, with a flooding prior to their preparation, remaining for 20 days before sowing.

Soil

The soil is a complex mixture of chemicals, including inorganic such as minerals, and the changes taking place in its composition are called biogeochemical transformations. The rate of mineralization grade depends on the availability of oxygen. Compared with the anaerobic metabolism, aerobic is more versatile. Many organic materials are mineralized only if there is oxygen. When the soil is dry and loose, oxygen penetrates more easily, up to about 30 cm depth. Yet, small soil particles are anaerobic, since microorganisms that use oxygen consume it quickly. The mineralization happens slowly in flooded soils because of this oxygen deficit. Soil fertility depends on adequate supply of oxygen, nitrogen, phosphorus and potassium whereas the inorganic forms of these minerals are produced by microorganisms as they mineralize organic material. Natural fertilizers are added to enrich the soil with these elements [15,16]. Necessary the maintain of vegetation, because it avoids the loss of soil nutrients and contamination, and the rational use of pesticides, as it preserves the food chain and also prevents contamination of water resources in the region. It also requires soil analysis before planting to make proper fertilization, since the answer will be different because the cultivation system chosen requires specific conditions [17]. Other important aspects are associated with the use of agrochemicals, once they can quickly reach surface water sources through surface drainage, lateral seepage, surface and subsurface draining, drift, volatilization and also reaching underground water sources by leaching and facilitated flow, reaching non-target organisms and causing environmental contamination [17].

The most widespread cropping systems for irrigated rice are: no-till, conventional, pre-germinated and minimum tillage. Each system is characterized by different types of soil management and of culture itself. In conventional cultivation, soil preparation is done with plowing, in other words, occurs very intense movement of topsoil. For no-till, there is little soil movement, which is held far in advance of planting period, in order to use an herbicide of total action against competing plants that germinate in the period between soil preparation and planting. The pre-germinated planting is characterized by the sowing of pre-germinated seeds in soil flooded beforehand. The soil preparation is done with machinery and implements, by working within the fully flooded plantation frame. Minimum tillage cultivation uses less soil mobilization. When compared to the conventional system, the seeding is performed directly on the vegetation cover previously desiccated with herbicide without soil disturbance [2].

In paddy fields, the first fertilization occurs with nitrogen coverage in a dry ground. After the development of 3 or 4 leaves in the plants, irrigation starts. Another detail that should be noted is that early irrigation, up to two days after herbicide application, results in greater weed control [2]. Knowing how to handle the soil to preserve or even improve their characteristics in sustainable systems is one of the challenges to the current agriculture [18]. Agricultural practices affect physical and chemical characteristics of the soil, influencing diverse populations and bacterial communities [19]. The frequent use of the soil, over time, tends to lead to a reduction of its heterogeneity [20], resulting in the decrease of nutrients available to the microorganisms and consequently the plants. In addition to the common use of soil, the use of chemicals may also have antimicrobial effects [21].

The continuous use of the soil, through the planting of rice, can cause loss of important resources for maintaining this culture, like any other culture that uses it, and the loss of nutrients ends up being inevitable. The soil microbiota promotes important processes for their maintenance and less impacted soil have positive influence on crop development and demand for fewer inputs, which represent costs in the production of grain [22].

Microorganisms

In the soil, it is possible to find various types of microorganisms, such as fungi, protozoa, bacteria and yeasts, which live in symbiosis with others. Some of these relationships are mutualistic, also with plants [23]. The bacteria are differentiated by size and cell structure, and may be spherical, rod-shaped, helical and others. Some obtain energy by processing organic compounds (food), others get nutrients from the environment where they live, using intermediates of glycolysis and other degradation routes [24]. Microorganisms have great importance in biochemical and geochemical cycles and have a great chemical and molecular arsenal. In the context of rice cultivation, bacterial abundance can be considered wide by its variety of microhabitats, caused by constant irrigation, resulting in complex bacterial communities [25].

Because it is a heterogeneous environment, the soil system may harbor the development of many important groups (diazotrophs, nitrifying bacteria, decomposer fungi and antagonists) that can be affected by several factors such as physical disturbances, use of fertilizers and plant species [26]. Most bacteria in the rhizosphere are highly dependent on associations with plants. Therefore, the bacterial diversity plays a key role in the agricultural environment. The result set shows that the irrigated rice culture influences the bacterial density present in water samples used for soil irrigation [27].

From an ecological point of view, decomposer organisms are the most important, which act degrading organic molecules and turning them into inorganic, so that can be used by plants. They are also protagonists in nitrogen and sulfur cycles [28]. Microorganisms are also of great importance in biotechnology, such as the use of bacteria in the bioremediation of pollutants and toxic wastes generated by the industry. Some bacteria are able to use pollutants as energy sources or to convert toxins into less harmful substances. The effect of these bacteria in the environment is highly positive, since the toxins may be removed from different environments, thus being possible their use in oil spills and locations with the presence of toxic waste. Microbial communities are particularly affected by the management and impact in the ground. Agricultural practices such as soil alterations during preparation and irrigation can modify bacterial communities. Water stress is a physiological state of the bacterial community. This stress induces osmotic shock that may result in cell lysis and release of intracellular solutes. Therefore, bacteria can survive under water since

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they remain in soil particles adhered to the roots, and thus can provide the ideal moisture to the roots to keep them alive [1]. There are groups of microorganisms that produce endospores, which stay dormant and viable in the environment for years, remaining so during adverse situations waiting for a favorable environment for their development, when they return to active form. Some organisms use the energy of chemical interactions, others are even able to photosynthesize and produce their own energy [29]. Most studies of microbial communities in irrigated rice are focused on mass of populations from soil experimentally developed, as many microorganisms are closely linked to the ground by removing nutrients and interfering in its composition [30].

Diazotrophic Bacteria

The endophytic bacteria play a fundamental role in plants and do not cause disease symptoms in which they are associated. These species are able to invade the internal tissues providing a systemic dissemination. The population of viable endophytic diazotrophs in cultivated rice varies with the type of soil, the growth phase of rice culture, and plant tissue. In general, bacterial populations are larger in the roots, compared with stems and leaves [30]. The rice roots harbor endophytes equivalent to 10^8 cultivable nitrogen-fixing bacteria by root gram of dry weight, and an even larger number of non-cultivable bacteria [31]. Nitrogen is one of the most important nutrients for achieving high productivity of annual crops due to high demand of the plant for this nutrient. Therefore, the low availability of this nutrient limits the productivity of the crop. Most of the nitrogen fixation from air takes place through diazotrophs such as *Azospirilium*, *Herbaspirilium* and *Burlkoderia* [32]. The diazotrophs, which are inserted in nitrogen utilization in the soil, are important organisms that can be used as an alternative to nitrogen fertilization [33].

The fact of being able to process organic and inorganic substrates successfully, bacterias become critical for the dynamics of aquatic ecosystems. The interaction between plant and microorganism is little explored in agriculture, despite having global and local importance in the dynamic equilibrium of ecosystems.

The plant and microorganism association in the root system is essential for the chemotactic response of the endophyte to root exudates. In the colonization process, several stages occur, beginning with the displacement of the microorganism into the root system, clinging and distributing through roots [34].

The endophytic bacteria, in order to penetrate the roots, first need the formation of intra and intercellular microcolonies. The different associations of endophytic bacteria can cause changes in plant colonization processes. Accordingly, the microorganisms migrate to the rhizosphere in response to root exudates, which are rich in amino acids, organic acids, sugars, vitamins, purines/pyrimidines, among others. In addition to providing nutritious substances, the plants can also eliminate secretions that facilitate colonization of specific groups of bacteria [35,36]. Microorganisms allow the recycling of nutrients such as lost carbon that can be reintroduced into the food web. Aquatic environments differ in physical and chemical aspects as there are microbial differences. Fungi and bacteria are mainly responsible for the decomposition process in aquatic ecosystems by converting organic matter into inorganic substances. Rainfall, when high, appears to contribute to the high bacterial rates [37].

Heterotrophic Bacteria

Bacteria that inhabit the rhizosphere promote the growth of host plants through the production of phytohormones such as auxins, the phosphate solubilization, the production of iron chelators (siderophores), the release of antimicrobial metabolites and for competition for nutrients [38]. The bacteria found in soil are highly diversified. In hot soils, for example, there is the presence of thermophilic microorganisms and microbial population changes very quickly as the available nutrients are modified [39].

The soil has great spatial variability composed of many micro habitats that may differ in their physicochemical properties [40], (Figure 1). These characteristics provide a diverse composition of microorganisms, which accomplish the primary decomposition, cycling and regulation of nutrients and minerals retention. Bacteria

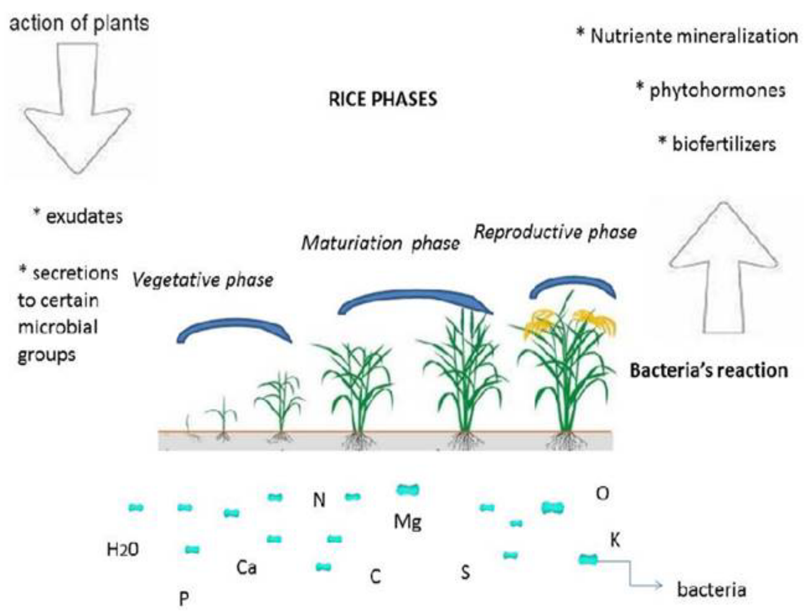

Figure 1: Interactions between bacteria and the rice plants in their different development stages.

also secrete various enzymes such as catalase, urease, cellulose, among others [41], also important for the plants. The cultivars and also the stage of the irrigated rice crop development can influence the microbial populations associated with these agro-ecosystems [17], as well as the different soil management systems, the application of pesticides and the fertilizers used for better development of this culture (Figure 1).

The composition of a community hardly will remain static, so any change in the habitat can cause changes in the composition of populations. Species such as *Bacillus thuringiensis*, *B. subtilis*, *B. cereus* and *Lysinibacillus sphaericus* may have insecticidal activity to different orders of insects [42] and are widely used in biological pest control. Some species are also associated with plant roots, aiding in the absorption and retention of nutrients in the soil.

They also have biotechnological applications and produce antibiotics [43], among other important functions. Therefore, understanding the impact of different rice cultivation systems in the bacterial community in the soil is important for the knowledge of lower environmental impact soil technologies and, eventually, the ones that can contribute positively to the improvement of ecological interactions that take place under sunshine [39]. Cosmopolitan microorganisms isolated from soil, water and vegetables such as bacteria of the Enterobacteriaceae family can also be found in the digestive tract of animals and humans, although it is also possible to find them in transient or normal microbiota. Among them include: *Escherichia* spp., *Klebsiella* spp., *Salmonella* spp., *Enterobacter* spp., *Serratia* spp., *Hafnia* spp., *Citrobacter* spp., *Yersinia* spp., *Proteus* spp., *Rhanella* ssp., *Providencia* spp., *Morganella* spp., *Shigella* spp., *Edwarsiella* spp., *Ewingella* ssp., *Budvicia* ssp., *Tatumella* spp., *Erwinia* spp., *Koserella* ssp., *Kluyvera* ssp., *Hoganella* ssp., *Moellenella* ssp., *Leminorella* ssp., *Buttiauxella* spp. and *Pantoea* spp. They can be pathogenic or opportunistic, occasionally forming components with physicochemical and biological properties beneficial to humans and the environment in which they operate [44]. Pereira et al. [45] points out that there is a wide variety of bacteria in the soil that, when associated with plant hosts, stimulate their growth, such as the rhizobacteria [46]. Stimulation in plants growth is mainly due to increased availability of mineral nutrients [47] and production of growth hormones such as gibberellins and auxin (induced resistance to disease and suppression of harmful microorganisms from the rhizosphere of plants). These direct effects provide a high gain to producers, allowing them to lower their use of inputs in farming or monoculture, reducing costs and also potential environmental problems such as contamination of soil and water sources, caused by the use of chemicals for pest control [48].

Pseudomonas fluorescens, *P. putida*, *Azospirillum brasiliense*, *Serratia marcecens*, *Bacillus subtilis*, *B .megaterium*, *Rizobium* sp., *Bradyrhizobium* sp., *Arthrobacter* sp., *Enterobacter* sp., *Azotobacter* sp. among others are heterotrophic bacteria genres most cited in the literature [49]. Microorganisms that inhabit the soil, along with biological processes, have been investigated as indicators of the sustainability of agriculture and / or soil quality [18]. They also influence the biological quality of products and the productivity achieved [19].

Food

Many diseases that affect plants and impair food production in crops can be caused by bacteria. Some examples well known for rice farmers are the brown spot and the stem rot caused by the plant pathogens *Helminthosporium oryzae* and *Sclerotium oryzae*, respectively [2]. However, besides being studied by the negative aspects, recent scientific research has given great importance to microorganisms for other functions. As an example in the food industry, the fermentation, this allows the manufacture of cheeses, dairy products, breads, meat products, alcoholic beverages and plants. Microorganisms present in the soil can influence the nutrients the food provides being ingested by humans, thus being able to bring beneficial changes to health. Most food is chemically stable, rotting only when contaminated by microorganisms. Factors such as pH, temperature, water availability and addition of chemical substances help in the preservation of food [24].

In the case of rice, its processing ensures quality control. It undergoes different processes leading to each type of rice: whole, parboiled, polished and white rice. White rice is polished and the starch is what predominantly stays in the grain. Parboiled rice is sterile in which the nutrients of the husk migrate into the grain. Whole rice has a medium and long grain, being darker than the processed, because it retains the film and the germ, which is more nutritious and rich in vitamins [11].

The rice is responsible for 27% of the daily calorie and 20% of the protein needs of the population, containing thiamine, riboflavin and niacin. It is easily digestible, being a good fiber regulator. The rice-based diet selects fermentative bacteria that are resistant to pathogens. By not containing gluten, it does not cause eating disorders. It has low sodium content, 5 mg in 100 g, and high potassium content, 92 mg in 100 g. It is also useful for osteoporosis because it has selenium (an antioxidant that acts against free radicals and unstable molecules of high reactivity) and silicon that helps forming collagen, elastin and protein of the cognitive tissue [50]. Foods considered new are resulted from new techniques of biotechnology and plant breeding. There are few genetically modified plants being commercialized. The genetic traits that are changed confer resistance to insects, herbicides etc. In order to arouse consumer interest in the products, there must be a higher quality of these that improves health or that has a greater shelf life. Biotechnology can improve organoleptic properties such as flavor and pigmentations [51].

Molecular Biology in Food

At present, the microorganisms have been used in the production of enzymes, antibiotics, solvents, amino acids and dietary supplements. Microbial diversity is a source of genetic resources, with each microorganism playing a unique and particular function. Therefore, first the decoded gene from the specific enzyme is identified and then isolated and transferred by recombinant DNA techniques into a known microorganism. The main bacteria used are: *Escherichia coli* and *Bacillus* sp, The main fungi used is: *Aspergillus* sp. and the main yeast is: *Saccharomyces cerevisiae*. Enzymes are biological catalysts present in all beings, therefore are used in various fields, including the bioremediation. The biocatalysts are protein molecules with an associated catalytic power. These biocatalysts degrade the molecules present in the environment such as cellulose, starch, lignin etc. [52,53].

Application of molecular biology techniques has greatly contributed to the exploration of new enzymes and new enzymatic properties and certainly continued to promote and develop production. Enzymes generate added value to the product in line with the demand of technological, market and environmental preservation characters. The use of catalysis is critical in Brazil, as it helps in environmental renewal, with the increase of enzymes used in pharmacy and food [38].

Conclusion

Agriculture is one of the most important activities, but it is necessary to observe some points, as food production is directly linked to environmental quality. Rice is one of the most consumed foods in the world, one of the most important grains in global economic terms. Rice is a culture that besides being simple is a great resource for human consumption. Rice, although not a food rich in vitamins, has a differential, it is easily assimilated by the starch, which provides power, serving as fuel for the operation body. Currently, crops cultivation methods seek to optimize the potential of agricultural production through the application of fertilizers and pesticides and which consequently cause human health problems and an imbalance in agricultural ecosystems, especially in the communities that inhabit the soil. The rice crops suffer and benefit from various microbial actions, including interactions between plants and microorganisms [54,55]. Rice agroecosystems consist of several micro-habitats and provide the suitability of a wide variety of microorganisms. The management of rice promotes changes of physical and chemical characteristics of the water and due to changes in pH, turbidity, temperature, radiation and amount of organic matter that may be related to the dynamics of microbial communities in the soil. Soil is a habitat full of living microorganisms that directly influence the development of the plant. The bacteria that act in it are inserted in the process of chemical transformations that facilitate nutrient cycling and can be added to the food, generating inputs that provide functionality and well-being to the human being. The challenge of scientists in the area is still the search for a better quality of life, environmental protection and sustainable development, because rice is one of the grains produced in the world and extremely important for the world economy.

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