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Agricultural bioinputs for sustainable agriculture: a brief overview

Abstract

The continued increase in the world's population, the progressive reduction of arable land due to the expansion of urbanization, and erosion and pollution of soil, water, air, and food due to the accumulation of toxic chemicals are factors that make the application of strategies and biotechnologies essential to increase crop productivity. Among these, the use of agricultural bioinputs stands out, which will allow us to curb the use of agrochemicals and thus partially or completely replace them. The main purpose of this work is to contribute to the understanding of new bioinputs, made with soil microorganisms selected for their potential benefits on the growth of cultivated plants. Formulations of new bioinputs based on species of soil microorganisms associated with the productivity of agricultural plants will be presented. This important alternative has the advantage of being considered an environmentally friendly product and, at the same time, is in balance with the agroecological conditions of the arid and semi-arid regions of the province of Catamarca.

Keywords: biofertilizers, biostimulants, biocontrollers, biopesticides

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Introduction

The continued increase in the world's population, the progressive reduction in arable land due to the expansion of urbanization, soil erosion, and soil contamination due to the accumulation of toxic products are all factors that make the application of strategies and biotechnologies essential to increase crop productivity.[1] Among these, the use of agricultural bioinputs stands out, which will allow us to curb the use of agrochemicals and thus partially or completely replace synthetic fertilization, for example. Relatively simple biotechnologies such as biofertilization and the use of other bioinputs have been practiced for centuries, and extensive research has been conducted on microbial inoculations in plants to explore a strategy for improving the sustainability of agricultural production. They even highlight the biotechnological potential of microbial secondary metabolites to improve growth and have had positive results on crop yield.[2–6] However, this knowledge has not been widely disseminated, and many producers remain unaware of it. Therefore, greater engagement between farmers and scientists is needed to collaborate on improving the production systems and quality of biofertilizers and other bioinputs. Furthermore, advice, guidance, and training on their use for agricultural producers is essential. A bioinput is a product based on compounds and/or extracts of microorganisms or plants, or live microorganisms, capable of improving productivity (or yield), quality, and/or health when applied to plant crops, without generating negative impacts on the agroecosystem.[7–9] Some agricultural bioinputs are prepared with selected beneficial microorganisms for application to soil or plants.

In the development of bioinputs, strategies are used that arise from the study and characterization of what happens in the different interactions between plants and their environment.[10] Therefore, the use of bioinputs, such as biofertilizers, biostimulants, and biopesticides, is an increasingly popular alternative in crop management schemes and represents economically attractive and ecologically acceptable options.[10]

The use of bioinputs made from native and selected microorganisms can fulfill various functions, such as controlling phytopathogens, stimulating plant growth, fixing atmospheric nitrogen, fertilizing crops, and improving yields. Soil conditions can also be improved with the use of organic fertilizers, which include a diverse group of mixtures such as compost, vermicompost, bokashi, and hydrogels as soil conditioners, primarily by increasing the soil's water storage capacity.[11–13]

Furthermore, due to the high degree of specificity and selectivity of microbial interactions with plants, the use of biofertilizers offers numerous advantages for environmental and consumer safety compared to chemical control, and economically, due to the reduction in production costs.[14] Organic fertilizers stimulate soil microbial activity and plant nutrition, which are used for crop fertilization or as soil enhancers that promote root development and exploration, improving the efficiency of nutrient and water absorption by the roots.[15,16]

On the other hand, since soil microorganisms are responsible for the degradation of organic matter, the biotransformation of organic waste is a strategy to reduce the amount of waste and achieve high-quality, high-value products due to the benefits they produce.[16] Therefore, small producers can make their own organic fertilizers with materials found on or near their farms that are low-cost and easy to acquire.

Given the need to produce safe food and protect the environment, and with the goal of achieving sustainable and environmentally friendly agriculture while achieving the best productivity results, bioinputs represent a sustainable and nature-friendly alternative to boost the growth and health of our crops without compromising the quality of our food or harming our environment.[17,18] Therefore, the purpose of this work is to contribute to the dissemination of knowledge about bioinputs for sustainable agricultural production. This brief review analyzes the content of various books, research articles, and references on relevant websites and the AI. This work reports on a wide range of bioinputs, carefully selected and supported by ancestral use. These include biofungicides, bioinsecticides, biofertilizers, and biostimulants, to maximize crop productivity and minimize the negative impact on the environment.

Biofertilizers

Biofertilizers are products derived from biological materials or microorganisms that are used to enrich the soil and provide nutrients to plants in a natural and sustainable way. Unlike chemical fertilizers, biofertilizers are organic products that promote soil health and help maintain ecological balance.[19–22] The best-known biofertilizers are:

Compost: This is a biofertilizer produced through the composting process, which involves the controlled decomposition of organic matter, such as food scraps, garden waste, and dried leaves, among others. Compost is rich in nutrients and improves soil structure, increasing its capacity to retain water and nutrients and promoting beneficial microbial activity.[23–25]

Vermicompost: This type of compost is produced by red worms (*Eisenia foetida*). These worms decompose organic waste and transform it into a fertilizer rich in nutrients and beneficial microorganisms. Vermicompost is especially beneficial for plants due to its high concentration of available nutrients and its ability to improve soil structure.[23,24]

Guano: This is a biofertilizer derived from the droppings of birds, bats, and farm animals. It is rich in nutrients, especially nitrogen, phosphorus, and potassium, and is used as a soil amendment and fertilizer. Guano also contains beneficial microorganisms that promote the decomposition of organic matter and improve the availability of plant nutrients.[23–25]

Seaweed extracts: These are obtained from seaweed and are used as biofertilizers due to their nutrient content and bioactive compounds.[25] These extracts stimulate plant growth, improve nutrient absorption, increase stress resistance, and promote flowering and fruiting. Furthermore, seaweed contains natural plant hormones, such as auxins and cytokinins, which benefit plant development.

Mycorrhizae: These are symbiotic associations between fungi and plant roots. Mycorrhizal biofertilizers contain spores or hyphae of mycorrhizal fungi that are applied to the soil to colonize plant roots. These fungi improve the absorption of water and nutrients, especially phosphorus, and increase plant resistance to environmental stress.[19,23,25]

Inoculants

Biofertilizers or microbiological fertilizers, also known as inoculants, are products containing live microorganisms that help plants access nutrients in the soil. Inoculants are products containing beneficial microorganisms, such as bacteria and fungi, that are used to improve plant and soil health.[19,20,24,25] These microorganisms can have different functions, such as promoting root growth, fixing atmospheric nitrogen, decomposing organic matter, and protecting plants against phytopathogens, among other benefits. The most common inoculants are:

Rhizobial inoculants: These inoculants contain bacteria known as rhizobia, which have the ability to fix atmospheric nitrogen in symbiotic association with the roots of leguminous plants, such as beans, soybeans, peas, and alfalfa. The presence of rhizobia in roots helps provide a nitrogen supply for the plant and improves soil fertility.[25]

Mycorrhizal inoculants: Mycorrhizal fungi form a beneficial symbiosis with the roots of most terrestrial plants.[25] These inoculants contain spores or hyphae of mycorrhizal fungi that colonize plant roots and improve nutrient uptake, especially phosphorus, and stress resistance.

Phosphate-solubilizing bacteria inoculants: Some bacteria have the ability to solubilize phosphorus in the soil and make it more accessible to plants. Inoculants containing these bacteria can improve phosphorus uptake by plants, especially in soils with low phosphorus availability.[20]

Plant growth-promoting bacteria inoculants: These inoculants contain beneficial bacteria that stimulate plant growth in a variety of ways. They can produce plant hormones that promote root and shoot growth, improve nutrient uptake, increase stress resistance, decompose organic matter, and protect plants from harmful pathogens.[20]

Bioinsecticides

Bioinsecticides are products formulated from natural ingredients, such as microorganisms, plant extracts, or substances derived from living organisms, used to control insect pests in an environmentally friendly manner.[26] They are a safer and more sustainable alternative to chemical insecticides. The most commonly used bioinsecticides are:

Bacillus thuringiensis (Bt): This bacterium produces toxins specific to different groups of insects.[23,26] Bt-based bioinsecticides are used to control mosquito larvae, Lepidopteran caterpillars (such as the cabbage moth), and fruit fly larvae.

Neem (*Azadirachta indica*): Neem oil or extract is a bioinsecticide used to control a wide variety of pests, such as aphids, mealybugs, mites, worms, and whiteflies. Neem works by interfering with insect feeding, growth, and development.[26]

Natural pyrethrins: Pyrethrins are substances extracted from certain species of chrysanthemums (*Chrysanthemum* spp.). They are broad-spectrum bioinsecticides and are used to control aphids, flies, mosquitoes, and other flying insects.[26] Pyrethrins work by attacking the nervous system of insects.

Plant extracts: Some plants contain compounds with insecticidal properties, such as garlic extract, onion extract, and chili pepper extract. These extracts are used to control pests such as mites, aphids, and thrips.[24,26]

Beauveria bassiana: This is an entomopathogenic fungus used as a bioinsecticide to control insects such as whiteflies, thrips, and beetles.[26] The fungus infects insects and kills them by colonizing their bodies.

Essential oils: Some essential oils, such as peppermint oil, eucalyptus oil, and citronella oil, have repellent and pesticide properties against certain insects (Mediavilla, 2014). They are used to control mosquitoes, flies, fleas, and other flying and crawling insects.

Biofungicides

Biofungicides are biological products used to prevent or control diseases caused by plant pathogenic fungi.[27] Unlike chemical fungicides, biofungicides are composed of:

Live microorganisms: such as beneficial bacteria or fungi (e.g., *Bacillus subtilis, Pseudomonas fluorescens, Trichoderma*).

Natural extracts: such as plant compounds with antifungal properties (e.g., garlic, neem, or cinnamon extracts).

Organic substances: fermentation derivatives or microbial remains.

Bionematicides

Bionematicides are biological products used to control plant-parasitic nematodes, which attack plant roots and affect their development and productivity.[28] They can be composed of:

Beneficial microorganisms: Bacteria such as *Bacillus firmus* and *Pasteuria penetrans*. Fungi such as *Paecilomyces lilacinus* and *Pochonia chlamydosporia*.

Plant extracts: Garlic, neem, castor oil, among others, with natural nematicidal properties.

Secondary metabolites: Substances produced by microorganisms that affect the life cycle of nematodes.

Biostimulants

Biostimulants are agricultural products containing natural substances or microorganisms that stimulate plant growth, development, and resistance. These products are not fertilizers or pesticides, but rather act as plant metabolism enhancers, improving nutrient absorption, strengthening the plant's defense system, and promoting healthy growth.[21] Some examples of biostimulants:

Algae extracts: Algae extracts, such as those obtained from seaweed, contain a variety of bioactive compounds, such as plant hormones, amino acids, polysaccharides, and antioxidants. These compounds stimulate plant growth, improve nutrient absorption, and increase resistance to abiotic and biotic stress.[25]

Humic and fulvic acids: These are organic compounds present in soil humus. They act as biostimulants by improving soil structure, increasing water and nutrient retention capacity, stimulating microbial activity, and promoting root growth.[21]

Beneficial Microorganism Inoculants: Some biostimulants contain beneficial microorganisms, such as bacteria and fungi, that establish symbiotic or mutually beneficial associations with plants. These microorganisms promote root growth, improve nutrient absorption, and protect plants against harmful pathogens.[25]

Amino Acids: Amino acids are essential components of proteins and can also be used as biostimulants. Amino acids promote plant growth, improve nutrient absorption, and increase the synthesis of proteins, enzymes, and phytohormones.

Microorganism Extracts: Some biostimulants contain extracts of beneficial microorganisms, such as *Azospirillum sp*., *Trichoderma spp*., *Bacillus spp*. or other selected microorganisms.[6] These extracts promote plant growth, improve nutrient absorption, and protect plants from disease.

Ascorbic acid (vitamin C): Ascorbic acid acts as a biostimulant by improving plant response to stress, increasing protein synthesis, and promoting the development of strong roots.

Organic amendments

Organic amendments are natural materials added to soil to improve its structure, fertility, and nutrient retention. These amendments are obtained from organic sources, such as plant and animal residues, and other biodegradable materials.[21,24] The most common organic amendments are:

Compost: This is a widely used organic amendment produced through the controlled decomposition of organic matter, such as orchard and garden waste, dried leaves, and other organic materials. Compost enriches the soil with essential nutrients and improves its structure, water retention, and microbial activity.[24,25]

Manure: Animal manure, such as cow, horse, chicken, or goat manure, is a valuable organic amendment due to its nutrient content, including nitrogen, phosphorus, and potassium.[24,25] However, it is important to use well-composted or cured manure to avoid the presence of pathogens and unpleasant odors.

Worm castings: Worm castings, also known as vermicompost, are a type of organic amendment produced by red worms (*Eisenia foetida*). Worm castings are rich in nutrients, improve soil structure, and promote beneficial microbial activity.[21]

Peat: An organic material formed from the partial decomposition of plants in marshes. It is used as an amendment to improve water retention and soil aeration. However, its sustainable use is debated due to concerns about the degradation of wetland habitats.

Crop residues: Crop residues, such as straw or stubble, can be used as organic amendments.[25] These residues contribute organic matter to the soil, improve its structure, and promote microbial activity.

Alfalfa or clover: Leguminous plants, such as alfalfa, vetch, and clover, are beneficial organic amendments due to their ability to fix atmospheric nitrogen in the soil through a symbiotic association with bacteria called rhizobia. These amendments provide nutrients and improve soil fertility.

Rice husks: The residue from rice milling. It is used as an organic amendment to improve soil structure, increase water retention and provide nutrients such as silica.

Synergies between bioinputs

Biological synergies, or complementarity of bioinputs, refer to the positive interaction between different biological products used in agriculture to achieve better results than if used individually. This means that by combining different bioinputs, their effects can be enhanced and additional benefits achieved in plant nutrition, health, and yield.

Examples of synergies between bioinputs:

Biofertilizers and biostimulants: Biofertilizers, such as nitrogen-fixing or phosphorus-solubilizing microorganisms, can improve nutrient availability in the soil, and biostimulants, such as plant extracts or microorganisms, can improve nutrient uptake by plants.

Biofertilizers and biopesticides (Bioinsecticides, biofungicides, bionematicides): Some biopesticides, such as biofertilizers, may have a residual effect that benefits soil microorganisms. Biofertilizers, on the other hand, can improve plant resistance to diseases and pests, reducing the need for biopesticides.

Plant extracts and microorganisms: Plant extracts may have fungicidal or insecticidal properties that complement the actions of beneficial microorganisms in the soil, creating a synergy in pest and disease control.

Compost and biofertilizers: Compost can improve soil structure and fertility. Combining them with biofertilizers can increase the availability of nutrients to plants and improve compost efficiency.

The combined and strategic use of microbiological bioproducts enhances both soil health and crop productivity. This synergy is essential in agroecological and sustainable models. Synergy occurs when two or more microorganisms work together in a complementary manner, producing a greater effect than if they acted separately. Examples include:

Rhizobium + mycorrhizae: Achieving greater atmospheric nitrogen fixation and phosphorus uptake.

Azospirillum + Trichoderma: Improves crop nutrition and increases protection against phytopathogens.[1]

Pseudomonas + Bacillus: Greater growth stimulation and control of soil-borne diseases.

Mycorrhizae + compost with active microflora: Improves soil structure and microbial biodiversity.

The most notable benefits of these synergies are primarily improved plant nutrition, given that some microorganisms mobilize nutrients (P, K, Fe) or fix atmospheric nitrogen. Greater stimulation of plant growth due to the production of hormones such as auxins and gibberellins. It also promotes natural biological control, competition, antibiosis, and parasitism of phytopathogens. It contributes to soil regeneration by improving soil structure, water retention, and biodiversity. It also increases resilience, as plants better adapt to water stress, salinity, and disease.[29]

Practical applications in agroecological systems include combined bioinoculation, crop rotation and association that favor different microorganisms, and the use of compost, bioferments, or compost teas as active microbial carriers.[30]

Conclusion

In a world where environmental awareness and the search for more responsible agricultural practices are constantly growing, bioinputs are presented as an innovative and promising solution. These products, developed from natural sources and beneficial living organisms, offer a series of benefits for both farmers and the ecosystem at large. Bioinputs can transform the way we grow crops, allowing for healthier, more sustainable crops that are in harmony with nature.

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Conflict of interest

Authors declare that there is no conflict of interest.

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