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Mini Review

Exploration of Plant-Microbe Interaction Based on Secondary Metabolites for Sustainable Agriculture: Mini-Review

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Abstract

Practice of sustainable agriculture is one of the key management towards global food security and better human health. To reduce the extensive use of chemical pesticides and fertilizers, exploitation of plant-microbe interactions in the soil is an ecofriendly approach for food production to feed the growing population worldwide. The association between plant and microbe can be beneficial, neutral or unfavourable which directly affects the plant health and its development. The secondary metabolites play a vital role in the plant-microbe interaction which promote plant growth, defense mechanisms against phytopathogens and production of bioproducts having antimicrobial properties. This mini-review focuses on exploring the significant actions and the characterizations of secondary metabolites during plant-microbe interaction with an aim to sustainable agricultural production.

Keywords: Plant-Microbe Interactions; Secondary Metabolites; Antimicrobial Activity; Sustainable Agriculture

Introduction

Agro-chemicals have long been used in agricultural crops cultivation which create serious pollution, health risks and increase in costs of production. A thorough study of plant-microbe interaction may provide a sustainable practical solution in terms of plant diseases or stress management, beneficial effect of microbes on plant growth and development and use of natural bioproducts as an alternative to synthetic pesticides or fertilizers. The association between plant and microbe is highly diverse as plants thrive and adapt at sensing changes in the environment and integrating multiple signals and modulating growth and development under the changing environment. Plants secrete various bioactive compounds that help the environment enriched with nutrition which is favourable for microbial growth. Soil is the primary reservoir of microorganisms and microbes colonize plants as epiphytically or endophytically which influence plants with either mutual benefits or pathogenic consequences. Plant roots are host to a millions of filamentous microorganisms which make a dynamic community known as microbiome. Secondary metabolites present in plant roots and also secreted from various important microbes play a vital role during the communication and aid in building an ecological relationship between the two. Research on these bioactive compounds or secondary metabolites is fascinating and have taken the key spot while reduction in extensive use of synthetic agro-chemicals needed to be emphasized widely in order to achieve sustainability in the environment.

Secondary metabolites facilitate in developing plant immunity

It took decade for the plant biologists to direct more attention to the secondary plant metabolites activities since it has long been perceived as biologically insignificant [1]. They carry out various functions and might contribute in the integral or pathogen induced phytochemical to develop plant innate immunity [2], although the mechanism behind the role to immunity still needs to be explored explicitly. These phytochemicals are present in small quantity and have antioxidant activity which help in reducing the occurrence of biotic or abiotic related diseases in plants. The major group of secondary metabolites are terpenoids, alkaloids, phenylpropanoids, phenolic compounds, steroids, flavonoids and tannins [3]. The process of induced cellular defense response is known as priming. A plant can acquire its resistance against phytopathogens, herbivores or wounds by many natural compounds that trigger off biochemical signal transduction which may help to develop a primed state. Plant exudates that contain secondary plant metabolites help increase phosphate availability, metals uptake, defence from environmental stress and sometimes show the ability to disrupt bacterial quorum sensing, a regulation process of gene expression in response to cell-population density [4]. Plants can interact with other plants or with the environment through signaling cues. Volatile Organic Compounds (VOCs) which are airborne and high vapour pressured secondary metabolites thought to be as the key factor in this communication. These plant-derived signaling cues are emitted in response to herbivore attack and perhaps internally transmitted through vascular tissues or externally occurs by herbivore-induced plant volatiles (HIPVs) [5]. Secondary metabolites are involved in different activities e.g., attracting pollinators, seed dispersers or play defensive role as deterrent, anti-feedant, antimicrobial agent and prevent pathogenic attacks in plants [6,7]. The defensive secondary metabolites which are constitutively present in plants or synthesized de novo are popularly known as phytoanticipins or phytoalexins respectively [2].

Secreted bioactive compounds from microbial origin

Microorganisms also secrete secondary metabolites which have potential bioactivity against other harmful microorganisms. These can be useful to produce therapeutic drugs and for other medicinal purposes [8]. They play crucial functions during ecological interactions as well. Microorganisms interact through exchanging at metabolic level which leads to biosynthesis of secondary metabolites. These may relate as parasitic, antagonistic or competitive. Siderophores, which are high-affinity iron-chelating compounds secreted by bacteria or fungi are good example of competitive and comparative microbial communication across cell membranes which has signaling and antibiotic activity as well. Bacterial quorum sensing based on stimuli-response at cellular concentration is considered to be well-studied example of microbial interactions too. The coordination between cell-to-cell communications while responding to environmental stimuli is occurring through the help of signaling bioactive molecules [9]. Bioactive compounds from microbes e.g. bacteria, yeast, infected cells by virus etc. showed to be important for improving plant growth, human health and in other industrial productions as in food fermentation, aroma, enzyme and texture agents for household products. As antibiotic agents, these compounds serve highly for competition against other harmful bacteria, fungi, insects; take part in transporting metals and build symbiotic relationship with plants, insects and higher animals [10,11].

The synergism developed during plant-microbe interactions

Plant microbiome is a complex structure associated with plant health which store vast genes that plant can access if necessary. The connectivity between plant and microorganisms is highly influenced by the structure known as rhizosphere zone, made up by root exudates and the microbial exudates within the soil matrix [12]. The set of additional genes that microbiome represent is being used as second genome by the plant which determines its growth, fitness and productivity. The group of microorganisms associated with plants through rhizosphere, endosphere or phylosphere is considered to have specific function during the interaction [9]. Plant synthesizes great amount of bioactive compounds which get released into the rhizosphere that stimulates the biological activity in the zone and thereby the rhizosphere bacteria, which supply increased nutrients, fixed nitrogen, growth promoting compounds to the plants and help to check pathogen invasion as well [4]. It was evidenced that plant cells contain fungal structures and most of the higher plants are colonized by arbuscular mycorrhizal (AM) fungi where the fungus provide mineral nutrients and on the other hand, plants provide carbohydrate produced through photosynthesis [13]. The surface area of plant roots gets enlarged by the fungi which build out to be extended filamentous network releasing enzymes that dissolve the mineral nutrients such as nitrogen, iron and chiefly phosphorus. Given that, they are the key elements for protein synthesis, DNA synthesis and energy production, plants have developed symbiotic relationship with soil bacteria and fungi that provide the elements in suitable form [14]. Study of plant-microbe interactions would let us reveal the occurrence of natural products application as sustainable resources which are environment friendly and help to reduce pollution. The use of symbiotic relationship of plant and microbe is beneficial for plant growth as well as for biocontrol which in turn would reduce the application of synthetic fertilizers and pesticide treatments. The natural compounds that released out from the symbiosis are useful for pharmaceutical or industrial purpose and is an energy efficient process. Plant-growth stimulating free-living bacteria generate natural compounds that directly influence the plant metabolism and phytohormone activity as microbial exudates can mimic perfectly of plant hormones or signal regulations which play the integral part for plant growth and developmental processes. Development of biofertilizers could be explored by studying the symbiotic relationship between endophytic bacteria and non-legume plants for nitrogen nutrition level [15]. The microbial secretions are composed of wide range of chemical compounds having antimicrobial activity plays role in ecological system that on the other hand, are beneficial for higher plants as it helps in nutrient uptake, prevent pathogen attack, promotes growth and rhizobial microbiome zone also forms a pathway in nutrient transformation in the soil [12]. Through quorum sensing mechanism the rhizobial bacteria are involved in different functions e.g. nodulation efficiency, growth prevention, nitrogen fixation and transfer of plasmid [9]. There are also few rhizosphere bacteria that help to promote growth through different mechanisms without involving root nodulation, known as plant growth promoting rhizobacteria (PGPR).

Natural bioproducts from plant and microbes for sustainable growth and disease management

The three-way network between plants, rhizobacteria and mycorrhizal fungi could be well explored to understand the signaling pathways, benefits from nitrogen-fixation and secreted secondary metabolites for production of biofertilizer, microbial solutions to seed treatment, biocontrol agents which would lead to achieve sustainable agricultural practices. The essential group of secondary metabolites such as terpenes, phenolics, nitrogen and sulfur containing compounds which have huge role in protection against predators, phytopathogens based on their toxic level and also act as repellent agent against herbivores or microbes. Biopesticides can be developed efficiently by using these defensive secondary metabolites in bioreactors or through metabolic engineering of economically important crops [16]. Biocontrol agents are commercially available now and these are mechanized to control diseases caused by pathogens through nutrient competition in the infection site, increasing resistance in plants and manipulating bacterial signaling compounds [15]. Use of biocontrol agents could reduce the intensive application of agro-chemicals and synthetic molecules as it contains potential active ingredients. Extracts from microbial origin can be isolated by fermentation in bioreactors which have antiviral or antimicrobial activity against phytopathogens [17].

Conclusion and Future Prospects

Exploitation of the plant-microbe association will benefit us to identify novel compounds having antagonistic ability against disease causing pathogens and provide solution for bioremediation and phytoremediation as well. To expand the chemical diversity of natural products for the isolation of novel compounds, enzymatic biotransformation is a useful approach and the new enzymatically transformed plant metabolites and their derivatives could be examined for the treatment of various plant diseases. A qualitative and quantitative identification of bioactive compounds can be achieved by the application of advanced biochemical techniques. Various advanced sequencing technologies such as transcriptomic data, metabolomics and proteomics study in combination with computational biology can be explored widely to characterize and identify the biosynthetic pathways of bioactive compounds obtained from phytoextracts to produce natural bioproducts to control agricultural pests and insects. Phytoncides having potential bioaction against phytopathogens can be isolated and characterized by GC-MS (Gas chromatography-Mass spectrometry) and be loaded onto a nanomatrix which would aid a controlled delivery for longer duration. Nanoporous material loaded with active compounds can be evaluated as bioformulations for seed treatment to control plant pathogens. Certainly, natural products chemistry will aim to better understanding of the diverse association between plant and microbes and we look forward to reveal the unknown facts of the ecological system to build a sustainable environment.

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Volume 2 Issue 10 October 2018