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Review Article

Microbial Contribution in Plant Health: Management of Diseases and Abiotic Stresses

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Abstract

Plant health is one of the primary limiting factors for agricultural productivity and food security. With the recent scenario of climate change, crop plants are more frequently subjected to stresses of both biotic and abiotic origin resulting in alteration of cropping seasons, crop diversity, site composition, and changes in plant physiology. Therefore, several strategies are being used to manage such stresses. These include the usage of synthetic or inorganic compounds which are highly polluting, hazardous and costly, thus; there is an urgent need to develop natural products, less hazardous, cheaper and easily available and sustainable. In this perpetual quest for solutions, researchers have thought it wise to exploit some beneficial microorganisms with ability to improve the disease resistance mechanism of the plant natural defence system. In this chapter authors have focused their attention on the role of microorganism in the management of biotic and abiotic stresses in plants by summarizing current information, covering all aspects of plant stresses, and further discussed the important mechanisms used by microbes in mitigating these stresses.

Keywords: Plant; Micro-organisms; Plant health; Abiotic stress; Biotic stress

Introduction

The current highly growing demand for a steady, healthy and readily accessible plant-based food supply requires an efficient control of the major biotic factors (pests and plant diseases) and abiotic factors (harsh environmental conditions) that negatively impact on plant health. The growing interest in vegetarian diets and plant-based foods is nowadays uncontestable not only because of the exponential boom in global population with respect to limited food productivity, but also because of the some diseases related to the animal-based food consumption coupled to growing movement on animal rights [1]. In addition, the current COVID-19 pandemic has not yet finished impacting on the global food insecurity status, making it urgent to try addressing plant health challenges.

Biotic and abiotic stresses have been recognized to be the major constraints in enhancing the productivity of food crops in general. The current management practices of biotic stresses are based largely on the application of synthetic pesticides which excessive use has been known as a cause of serious environmental and health problems [2]. Therefore, there is a growing demand for new and safer methods to replace or at least supplement the existing control strategies. Biological control, that is, the use of natural antagonists to combat pests or plant diseases has emerged as a promising alternative to chemical pesticides [2]. The Bacilli for instance, offer a number of advantages for their application in agricultural biotechnology. Several Bacillus-based products have been marketed as microbial pesticides, fungicides or fertilizers.

Factors known as abiotic factors such as harsh climatic conditions like water scarcity (drought), extreme temperatures (heat, freezing), photon irradiance, and contamination of soils by high ion concentration (salt, metals) are the major growth stressors that significantly limit productivity and quality of crop species worldwide [3]. During harsh abiotic conditions, plants generally respond by activating tolerance mechanisms at multiple levels of organization (molecular, tissue, anatomical, and morphological); by adjusting the membrane system and the cell wall structure, altering the cell cycle and rate of cell division; and by metabolic tuning [4]. At a molecular level, many genes are induced or repressed by abiotic stress, involving a precise regulation of extensive stress-gene networks. Products of those genes may function in stress response and tolerance at the cellular level. Proteins involved in biosynthesis of osmo-protectant compounds, detoxification enzyme systems, proteases, transporters, and chaperones are among the multiple protein functions triggered as a first line of direct protection from stress. However, the contribution of micro-organisms in the management of plant stresses is the current main focus of the scientific community as it seems to be the prominent best alternative.

Plant health: Does it matter?

Plant health is the process of making sure plants are protected from disease and pests and can sustainably thrive in their natural habitats [5]. According to the FAO [5], plant health matters more than it seems [5]. In fact, the year 2020 was declared and celebrated as the international year of plant health by the United Nations [6]. So many reasons can be put forwards to shed light on the vital position that plants occupy in the life of humans. Human beings could owe plants a lot. This is one of the major points defended by some international year of plant health (IYPH) advocates. According to them, plants are often taken for granted, but it is important to note that their health is linked to humans' health. It might be very difficult to contest the fact that almost 80 percent of the food humans consume as well as about 98 percent of the oxygen they breathe come from plants [7]. However, plants are increasingly under threat. Climate change and human activities have altered ecosystems, reduced biodiversity and creating new niches where pests can thrive. At the same time, international travel and trade has grown and pests and diseases have spread around the world, causing great damage to native plants and local environments [5]. Both cultivated and non-cultivated plants need equal attention as they all have vital roles in human life. The above-mentioned arguments highlighted the importance of cultivated plants (crops).

It has been estimated that more than 25% of prescription pharmaceuticals contain plant-derived ingredients yet only a small percentage of the plants in the world have been evaluated for potential pharmaceutical use [8]. This is partially due to the fact that most plants used in pharmaceuticals are not cultivated plants and therefore has less human attention. It is remarkably noted that about 80 percent of people in developing countries rely on natural herbal product for their primary healthcare [8]. A plant-based extract from *Artemisia annua* L. has recently been used in Madagascar in an attempt to cure and prevent the current COVID-19 pandemic in addition to the contradicted chloroquine-based treatment by the French scientist [9]. These two actions have raised alert on the two plants (*Artemisia annua* L. and *Cinchona officinalis* for chloroquine) for prospective future domestication and industrialization. In that way, attention will be given to those plants for human benefits. In addition, natural products from plants also serve as building blocks for drugs that are synthetically produced. Therefore, plant health does not only matter because of food, oxygen and environment, but also for health benefits it renders to humanity as illustrated in Figure 1.

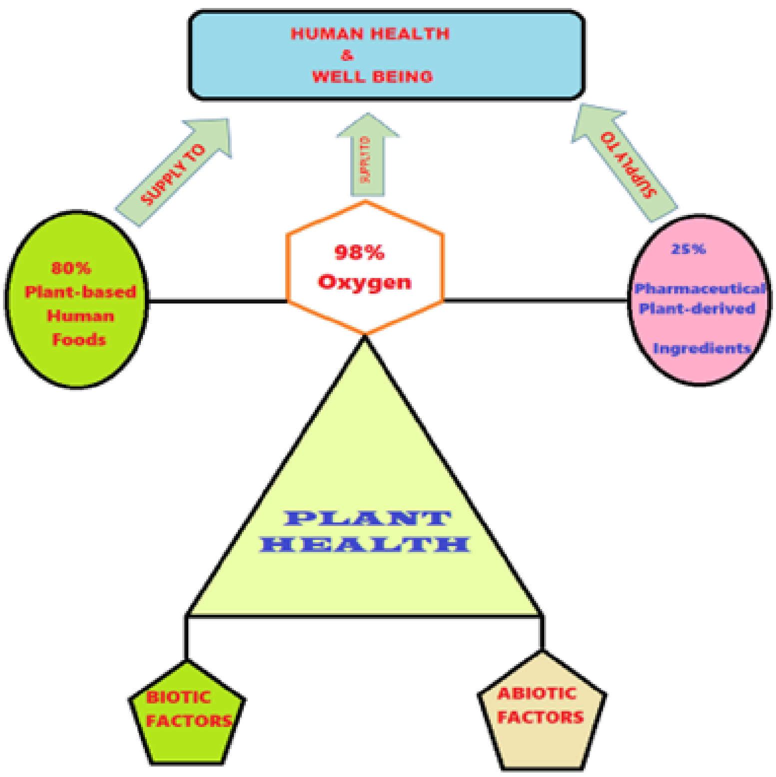

Figure 1: Importance of plant health in human health.

Microbes and the Management of Biotic and Abiotic Stresses in Plants

Mechanisms of biotic stress management in plants

Biotic stress in plants is related to the disease promoting microorganisms in plants. There are several mechanisms involved in plant–microbe interaction leading to the management of the disease promoting micro-organisms. Ad planta, direct mechanisms of plant health promotion are difficult to differentiate from disease suppression mechanisms [10]. Some of the common mechanisms by which microorganisms manage biotic stress can be summarized as follow.

Mitigation of undesired metabolites

Plant growth is sometimes associated with the production of metabolites such as phytohormones, indole-3-acetic acid (IAA), ethylene, cytokinins and gibberellins, which are synthesized by the plant themselves and also by their associated microorganisms. However, plant-associated bacteria can influence the hormonal balance of the plant. In the case of ethylene produced by the plant associated microbe for instance, it is important to note that at low levels, ethylene can promote plant growth in several plant species including Arabidopsis thaliana, while it is normally considered as an inhibitor of plant growth and known as a senescence hormone [10]. Interestingly, bacteria are able to reduce the ethylene level.

Microbial antagonism

a) This includes the following the inhibition of microbial growth by diffusible antibiotics and volatile organic compounds (VOCs), toxins, and biosurfactants (antibiosis).

b) Competition for colonization sites and nutrients.

c) Competition for minerals, e.g., for iron through production of siderophores or efficient siderophore uptake systems.

d) Degradation of pathogenicity factors of the pathogen such as toxins, and Parasitism that may involve production of extracellular cell wall-degrading enzymes such as chitinases and β-1,3 gluconate [10].

Induced systemic resistance

Plant-associated bacteria can reduce the activity of pathogenic microorganisms not only through microbial antagonisms, but also by activating the plant to better defend itself, a phenomenon termed “induced systemic resistance” (ISR) [10]. ISR represent a state of enhanced basal persistence of the plant that depends on the signaling compounds JASMONIC acid and salicylic acid. Pathogens are differently sensitive to the resistance activated by these signaling pathways. These interactions are highly specific to each component: the host plant, the pathogen, as well as the plant growth promoting resistance strain.

Mechanisms of Abiotic Stress Management in Plants

Plant-associated microorganisms have the ability to modify plant evolutionary responses to environmental stress in through one of the following mechanism:

Fitness modification of individual plant genotypes: The expression of plant traits related to fitness, and the strength or direction of natural selection occurring within populations that experience environmental stress can be affected through the microorganisms’ effects on reproductive fitness. Plants generally select a stress-resistance-promoting microbiome under abiotic or biotic stress conditions. The plant traits favored under adverse conditions, especially drought, may depend on changes in the associated microbiome. Several recent studies have proven that naturally occurring and artificial variation in the microbiome can alter plant flowering time on the order of 1-5 days [11]. Drought-induced early flowering has been proposed as a potential mechanism of drought avoidance.

Flowering plasticity: The mechanisms underlying microorganism-induced flowering plasticity remain unknown, but probably they include a combination of direct effects of the microbiome on plant physiology and indirect effects mediated by soil nutrient availability [11].

Hormone production: Drought-mediated production of the plant hormone abscisic acid diminishes the plant immune response, thus facilitating large shifts in the root endophytic community. These fluctuations mitigate water stress, possibly through the production of plant hormones and/or changes in the biochemical activity of host plants [11]. An analysis of recent findings through literature suggests that plant–microbiome interactions are neither beneficial nor deleterious, but instead function as modulators, generating new phenotypes by reshuffling existing traits. Interestingly, for fungal endophytes, traits related to resource use and stress tolerance predicted 26–53% of the endophyte-mediated effects on plant performance under water stress [11].

Plant Health Promoting Microorganisms

It is commonly known that the rhizosphere harbors an extremely complex microbial community including saprophytes, epiphytes, endophytes, pathogens and beneficial microorganisms. In natural systems, these microbial communities tend to live in relative harmony where all populations generally balance each other out in their quest for food and space [12]. Beneficial rhizosphere microorganisms are generally classified into two broad groups based on their primary effects (their most well-known beneficial effect on the plant): Microorganisms with direct effects on plant growth promotion (plant growth promoting microorganisms) and Biological control agents that indirectly assist with plant productivity through the control of plant pathogens. Some plant health and growth promoting microorganisms can be described as follow.

Rhizobium spp.

Rhizobium, Brady rhizobium, Meso rhizobium, Sino rhizobium are generally regarded as microbial symbiotic partners of legumes and are mainly known for their role in the formation of nitrogen-fixing nodules [13,14]. In particular, Rhizobium spp. are a vast group of soilborne rhizobia with representatives that have proven plant growth promoting activities through nitrogen fixation. These bacteria can equally produce plant growth regulators and solubilize organic and inorganic phosphates that would have a role in their plant growth promoting activities [12]. In addition to their plant growth promoting effects, Rhizobium spp. have been increasingly associated with disease suppressive effects in the recent literature [15]. Disease suppression afforded by Rhizobium spp. has been linked to direct inhibition of pathogens development (through competition or antibiosis) as well as indirect inhibition through the stimulation of plant defense mechanisms. Many Rhizobium spp. have been studied with regard to their potential mode of action in directly inhibiting plant pathogen growth, mainly with regard to the extracellular compounds they produce.

Glomus spp.

Arbuscular mycorrhizal fungi are obligate symbionts of more than 80% of terrestrial plants. In exchange for reduced carbon, the fungi supply the plant with mineral nutrients (phosphorus, in particular) and increase water uptake [12]. Glomus spp. Have probably been the most extensively studied of the Arbuscular mycorrhizal fungi and were shown to not only improve plant productivity through nutrient uptake, but to equally possess qualities that may assist their host-plant in staving off disease.

Conclusion

Plant health is an important factor that needs not to be neglected in human life as it is directly linked to human health. The contribution of microorganisms in maintaining the plant health, growth and promotion is so important and untestable as they positively impact in mitigating both biotic and abiotic plant stresses. The industrial production of microorganisms with potentials to promote plant health and growth through mitigation of biotic and abiotic stress is becoming a unanimous and popular method.

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