Chapter 1
Plant–Microbe Interactions Promoting Millets Plant Growth and Health: Perspectives for Use of Microorganisms in Millets Production

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Abstract Soil nutrition and health is of utmost importance for the plants to survive and withstand the various stress factors (abiotic and biotic) posed in the present climatic change situation. Millet plant health and its productivity are in turn related to soil ecosystem. The soil microorganisms in specific plant growth-promoting microorganisms (PGPM) play major role in managing the stress factors and thereby augmenting the plant growth and health by different signal cascades. Studies have evidenced the role of different PGPMs in managing/regulating major biotic stress (bacterial, fungal, and viral diseases) and abiotic stress (drought, salinity, and heavy metal). Also, they can increase the carbon sink in the soil by different mechanisms. Hence, a concise review on the different PGPMs used to enhance millet plant health and growth in turn the productivity is given in this chapter.

Keywords Millets · PGPM · Nutrition · Plant growth and health

1.1 Introduction

Over the years, climatic variations have posed increase in temperature and undetermined pattern of rainfall. It has increased the necessity to increase the crop productivity by utilizing various strategies, for which it is important to understand the underlying mechanisms, signal cascades which have crafted the climate resilient smart adaptive features in some of the crop species. The best-studied cereal crops are millets which are semiarid tropical crops grown in minimal environments and used as food or livestock. The different types of millets are pearl millet (*Pennisetum glaucum*), kodo millet (*Paspalum scrobiculatum*), finger millet (*Eleusine coracana*), foxtail millet (*Setaria italica*), little millet (*Panicum sumatrense*) and barnyard millet

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R. N. Pudake et al. (eds.), *Millet Rhizosphere*, Rhizosphere Biology,
https://doi.org/10.1007/978-981-99-2166-9_1

(*Echinochloa frumentacea*), and proso millet (*Panicum milliaceum*) which are considered to be rich in nutritional values (Dayakar et al. 2017; Patil and Kumudini 2019; Numan et al. 2021). In comparison to the other cereal crops, millets are nutritionally rich with high levels of essential amino acids, and micronutrients like vitamins and calcium (Konapur et al. 2014; Nithiyanantham et al. 2019; Sharma et al. 2021; Dey et al. 2022).

Millets are grown and produced in the semiarid and tropical regions. They are considered as underutilized or forgotten or orphan crops (Dey et al. 2022). To overcome this umbrella on millets, United Nations has declared 2023 as the *International Year of Millets*, to unleash the potential of millets for the well-being of people and the environment. Millets are largely produced in India accounting for more emphasis on pearl millet as it serves the food and fodder for many (Dayakar et al. 2017). Therefore, it is now important to have an insight in enhancing the growth and health of the millet crops which in turn is beneficial to the mankind. With this perspective, the current chapter highlighted the importance of plant–microbe interactions in promoting millet health and growth.

1.2 Plant–Microbe Interactions

The continuous, dynamic, and complex mechanism underneath existing since the colonization on earth is plant–microbe interactions (Dolatabadi 2021). This association has created a niche for the beneficial and damaging effects of host and nonhost, which is generally regarded as the battlefield. These interactions further signal the cascade of reactions to induce resistance against infection or biotic stress and to enhance the tolerance to the abiotic stress factors (Kumar and Verma 2018). The interactions are termed as plant–microbe interactions which are beneficial, symbiotic, benefiting both the host and the organism. Plants undergo different signal cascades to bring in the effect when there is an association with the microbes. These can be endophytes (microbes associated in the plant system), plant growth-promoting rhizobacteria (PGPR), or plant growth-promoting fungi (PGPF). These microbes play a vital role in dense, stress alleviation by producing various plant growth-promoting (PGP) metabolites (growth hormones, ammonia, siderophores, and hydrogen cyanide) and activities (phosphate solubilization, iron uptake, and biofilm formation). These bring in the importance of use of microbes for plant growth promotion under biotic or abiotic stress (Kumudini et al. 2017; Pal et al. 2021). Various studies have focused on the plant–microbe interactions and its impact; hence, this review pertains only on millets.

1.3 Role of Endophytes in Millets Health: The In-House Friends

The in-house microbes that colonize the plants, regarded as endosymbionts or endophytes, which result in the production of secondary metabolites possessing bioactive components known for anticancer and antimicrobial effects (Gouda et al.

2016). Bacterial endophytes are also known to alleviate the resistance against fungal pathogens in plants, by releasing pyrazines, chalconoids, and tryptophan derivatives that are attributed for this functioning (Garbeva and Weisskopf 2020). Interactions leading to the ROS signalling, PR protein enhancement, primary and secondary metabolite accumulation are the strategies developed by these endosymbionts for enhancing the plant health and growth (Morelli et al. 2020).

In this regard, Kumar et al. (2020) reported the impact of endophytic bacterial removal and induction in finger millet seeds. Isolated endophytes *Paenibacillus dendritiformis*, *Enterobacter hormaechei*, *Enterobacter cloacae*, *Bacillus safensis*, and *E. hormaechei* were positive for plant growth promoting parameters. These endophytes when inoculated for seedling protection assay showed significant protection against *Fusarium oxysporum* infection, suggesting the role of endophytic bacteria on seed and root colonization and their impact in plant protection. Similar results were observed when seed endophytes (bacteria) were inoculated onto pearl millet seeds by Kumar et al. (2021). Fluorescent microscopic results revealed the inter- and intracellular colonization of bacteria in root hair and parenchymal cells. The secondary metabolites like antifungals and lipopeptides showed leakage of protoplasmic substances of the invading fungi *Fusarium* due to the damage caused on the hyphae and fungal spores (Kumar et al. 2021).

Physiological and morphological changes are being rejuvenated for the enhancement of plant health. In this regard, plant root modifications, phytohormone levels, gene signals, and expressions will vary based on the stress prevailing, accordingly use of certain endophytes can alleviate this stress and modulate the manifestations. Studies by Manjunatha et al. (2022) revealed such a result when treated with the endophytes *Cronobacter dublinensis* strain of pearl millets thereby increasing the levels of abscisic acid, IAA (indole acetic acid) and antioxidants (proline) under field conditions, in turn alleviating the stress-responsive genes.

1.4 Role of PGPM in Millets Plant Health: The Neighbors

Genetic diversity analysis of fungal species adhering to the roots showed the role of different species, *Trichoderma asperellum* and *T. harzianum,* by RAPD (random amplified polymorphic DNA) and ISSR (inter simple sequence repeats) markers. *Trichoderma* spp. was observed to colonize the roots of pearl millet plants efficiently with varied levels of plant growth-promoting traits. Downy mildew pathogen suppression was observed by these species following the induction of systemic resistance, which can be the potential targets as biocontrol agents (Nandini et al., 2021).

Similarly, studies carried out by Mankar et al. (2022) by using *Burkholderia* sp. enhanced the biomass and yield of little millet under polyhouse conditions. This study was carried out to promote little millet production which required sustainable solutions. The study also used the nonnative *Azotobacter chroococcum* before its sowing as an inoculant, revealing the effectiveness of nonnative PGPM in reconditioning the soil. Also, this study validates the studies carried out previously using nonhost inoculants (Patil and Kumudini 2019; Mahadik and Kumudini 2020).

The isolates *Pseudomonas fluorescens, E. hormaechei*, and *P. migulae* stimulated seed germination and promoted growth of foxtail millets under severe drought stress conditions with increased PGP traits like increased ACC (1-aminocyclopropane-1-carboxylic acid) deaminase and exopolysaccharide production (Niu et al. 2018). *E. cloacae* strain showed increased PGP traits like production of ammonia, hydrogen cyanide, siderophore, ACC deaminase, IAA, and phosphate solubilization activity besides tolerance to heavy metals like aluminum, zinc, chromium, lead, and arsenic when treated on five millet cultivars. They showed increased seed germination, enhanced root and shoot elongation, when tested under pH 6.0–8.0 (Labhane 2020). A categorized list of the beneficial microbes in millet plant health enhancement has been enlisted in Table 1.1.

1.5 Microbes for Millet Health

Research on use and study of the mechanism of plant–microbe interactions is innumerable. However, the study on the role of these on millets plant improvement is short coming. Available bioformulations to millets are only a handful (Table 1.2). The novel approaches to ascertain the utilization of microbial formulations is the need of the hour to enhance millet health from the perspective of sustainable development.

From using omics technology, it is possible to tunnel the signalling mechanisms involved in millets under varying stress conditions, providing base for effective use of bio-inoculants to target the specified mechanism inducing plant resistance or tolerance. This will thereby enhance the millet plant health and growth. Also, appropriate guidelines on the use and manufacturing of the bioformulations must be congregated to minimize the repetitive data set accumulation, which can foster deeper systematic study in-depth on the efficacy of the same.

1.6 Conclusion and Future Prospects

Plant–microbe interactions, role of rhizosphere niche for plant growth and health, have been well established since decades with respect to different host systems. This suggests the behavioral changes pertaining to that host system with different manifestations (biotic or abiotic stress). In the wake of climate change, food security, it is now important to investigate the microbial interactions with millet crops. This can be well aided with usage of omics approaches—genomics, transcriptomics, proteomics, and metabolomics. A new approach will be to equip artificial intelligence in understanding the belowground interactions which suggests the new approaches to enhance millet plant growth and health as a holistic approach. This chapter and next chapters have highlighted the importance of using rhizospheric microorganism for the increased production on millets. These chapters will help the researchers to work to achieve nutrient security for global population through millets.

Table 1.1 Perspectives on millet plant health management by PGPM

Strain	Host	Effect on plant health	Reference
Acinetobacter calcoaceticus, *Penicillium* sp.	Foxtail millet	Enhanced accumulation of glycine betaine, proline, sugars, and decrease in lipid peroxidation by P-solubilizing microbes against drought stress	Kour et al. (2020)
Curtobacterium sp., *Microbacterium* sp., *Methylobacterium* sp., *Bacillus amyloliquefaciens*	Browntop millet	Protection against *Fusarium* infection was elucidated by antifungal lipopeptide genes for surfactin and iturin	Verma and White (2017)
Variovorax sp., *Achromobacter* sp., *Pseudomonas* spp., *Ochrobactrum* sp.	Finger millet	The treatments elevated the levels of antioxidants which scavenged the ROS under water stress and irrigated conditions	Chandra et al. (2020)
Fluorescent pseudomonad strains	Finger millet	Microbes showed accumulation of PR proteins in the primed plants which acted as antifungal agents against blast fungi	Patil et al. (2016)
Pseudomonas aeruginosa	Finger millet	Seed priming induced phenylpropanoid pathway signalling for host dense response against *Magnaporthe grisea*	Patil and Kumudini (2019)
		Primed plants increased levels of salicylic acid and other primary metabolites during induction of disease resistance	Patil et al. (2020)
Pseudomonas aeruginosa, Pseudomonas resinovorans	Finger millet	Treated plants showed enhanced growth promotion and plant health under high saline conditions	Mahadik and Kumudini (2020)
Pseudomonas spp.	Finger millet	ACC deaminase producing bacteria isolated from finger millet rhizosphere was able to improve the growth and nutritional parameter under drought stress under greenhouse conditions	Chandra et al. (2018)
Streptomyces griseus, Streptosporangium roseum	Pearl millet	Root colonization increased under greenhouse conditions along with disease-resistance capacity of the isolates against downy mildew	Jogaiah et al. (2016)
Pseudomonas extremorientalis, Bacillus subtilis, Bacillus amyloliquefaciens	Pearl millet	Single and in consortium these microbes enhanced plant growth by increased root and shoot length, chlorophyll, carotenoids, total soluble sugar content, phenolics, and flavonoids	Kaur et al. (2022)
Bacillus pumilus	Pearl millet	Associated with induction of disease resistance by hypersensitive reaction, accumulation proteins, antioxidants also demonstrated by histochemical studies on downy mildew pathogen	Raj et al. (2012)

(continued)

Table 1.1 (continued)

Strain	Host	Effect on plant health	Reference
Pseudomonas fluorescens, Trichoderma virens	Pearl millet	Defense-related enzymes accumulation was high in treated plants against *Magnaporthe grisea* which enhanced the growth	Basavaraj et al. (2019)
Bacillus amyloliquefaciens, Bacillus subtilis, Stenotrophomonas maltophilia	Pearl millet	ACC deaminase producing microbes when primed with pearl millet showed enhanced expression levels of antioxidant genes which thereby defend plants against drought stress	Murali et al. (2021)
Penicillium oxalicum	Pearl millet	Downy mildew disease resistance was achieved by treating the plants with fungi which showed increased resistance attributed to enhanced chitinase activity	Murali and Amruthesh (2015)
Dyadobacter sp.	Millets	Isolate showed enhanced plant growth with nitrogen fixation activity owing for their psychrotolerance isolated from Western Himalayas	Kumar et al. (2018)

Table 1.2 Prospective use of formulations for millets plant health

Strain	Host	Effect on plant health	Reference
Enterobacter cloacae	Millet cultivars	Abiotic stress	Labhane (2020)
Pseudomonas sp.	Finger millet	Blast disease reduction with liquid formulation	Sekar et al. (2018)
Azotobacter chroococcum, Bacillus megaterium, Pseudomonas fluorescens	Finger millet	Liquid, alginate-based, fluid-bed dryer-based, lignite formulations when treated showed increased plant growth parameters; however, better results were observed on treatment liquid formulation	Gangaraddi et al. (2020)
Streptomyces nanhaiensis	Pearl millet	Liquid formulation of the strain enhanced plant growth with increased leaf biomass and pigment production. This significantly mediates mineralization and accumulation of minerals in rhizospheric region of the millet crop under pot trials	Patel and Thakker (2020)
Bacillus subtilis spp.	Finger millet	Talc-based formulation of the strain was used for seed treatment, seedling dip, and foliar spray. It increased defense enzymes (phenylalanine ammonia lyase, chitinase, and superoxide dismutase) in resistant plants. This isolate showed promising results against *Magnaporthe grisea* infection	Gnanasing and Ahila (2017)

Acknowledgments Authors acknowledge JAIN (Deemed-to-be University), Bengaluru for the financial support.

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