MICROBIAL MITIGATION OF STRESS RESPONSE OF FOOD LEGUMES

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CRC Press
Taylor & Francis Group

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Microbial Mitigation of Biotic Stresses in Soybean (Glycine max*)*

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20.1 Introduction

Healthy plants are essential to the survival of humans and animals on earth. Several stress conditions limit crop production worldwide, and among these is biotic stress. Biotic stress agents such as pathogens, parasitic weeds, and harmful insects cause severe damages and losses to agricultural products. Biotic stresses reduce the health, yield, and nutritional value of plants and plant-based products (Fletcher et al. 2010). Pathogens attack virtually all plants, including those cultivated for ornamental purposes and those in natural ecosystems such as forests and rangelands.

Soybean is one of the earliest crops cultivated by man (Stagnari et al. 2017). Its nutritional value includes carbohydrate, which makes 30%; protein (36%); oil (20%); and appreciable amounts of vitamins, minerals, and dietary fiber. Soybean is a relatively cheap protein source of high quality compared to beef, chicken, and eggs. It is an important crop for producing edible oil. However, optimum soybean production is constrained by weeds, insect pests, and diseases.

Conventional agriculture employed to alleviate the menace of biotic agents of crops promotes heavy reliance on the use of agrochemicals such as herbicides, pesticides, and fungicides to control biotic stress agents of plants. Though these had increased food production, it has also been reported that these chemicals have adverse effects on soil, plant, human, and animal health (Aremu et al. 2017, Alori and Babalola 2018). According to Alori and Babalola (2018) and Biswas et al. (2018), hazardous effects associated with the use of agrochemicals to combat biotic stress agents include birth defects, cancer, mutagenicity, neural disorders, and reproductive and developmental anomalies. One of the most devastating consequences of conventional agriculture is soil degradation (Baishya 2015). Inappropriate use of agrochemicals kills helpful soil organisms, increases soil nitrate content, alters soil pH levels, and causes eutrophication of water (Aremu et al. 2017). There is therefore an imperative need for a more reliable and high-yielding agricultural system to meet the increasing demand for food and energy by the ever-increasing global population. More often, plants reduce the burden of biotic stresses with the aid of the inhabitant microorganisms (Turner et al. 2013). Plant-beneficial microorganisms stimulate plant growth and enhance plant resistance to biotic stress (Vimal et al. 2017). Microorganisms enhance seed germination and also form mutual relationships with plants at the root surface or form endophytic relationships within the roots, stems, or leaves (Jalil and Ansari 2018). Microorganisms support plants by securing supplements and fight against or defend infections (Turner et al. 2013). Plant-microbe interaction stimulates plant defense mechanisms against biotic stresses.

Biocontrol technology via microbial inoculants is therefore a promising tool for mitigating the effects of biotic stress agents on crops and thereby minimizing the use of agrochemicals in crop production, while keeping our environment safe (Alori and Babalola 2018). Commercialized microbial inoculant strains used for mitigating biotic stresses in crops include *Azotobacter chroococcum, Pseudomonas syringae, P. chlororaphis, P. fluorescens, P. solanacearum, P. aureofaciens, Agrobacterium radiobacter, Pantoea agglomerans, Azospirillum brasilense, Bacillus fimus, B. licheniformis, B. megaterium, B. pumilus, B. mucilaginous, B. subtilis, B. subtilis* var. *amyloliquefaciens, Delftia acidovorans, Streptomyces griseoviridis, S. lydicus, Burkholderia cepacia, Paenobacillus macerans, Azospirillum lipoferum, Serratia entomophilia*, and several *Rhizobia* spp. (Glick 2012, Alori and Fawole 2017). In the present review, the mitigation of biotic stress due to diseases, insect pests, and weeds in soybean production is discussed. The mechanism of action of microbial inoculants in disease control is also expatiated.

20.2 Biotic Stresses of Soybean

20.2.1 Diseases of Soybean

Soybean is susceptible to many pathogens that cause severe damage to the crop. Wrather et al. (2010) reported a loss of 59.9 million metric tons of soybean to pathogens in the top eight soybean-producing countries in 2006.

Some of these pathogens affect the root, some other ones the stem, while others affect the leaves (Markell and Malvick 2018). One of these pathogens is *Macrophomina phaseolina*, which causes charcoal root rot (Vasebi et al. 2013). Other root diseases of soybean include: *Fusarium* root rot, *Rhizoctonia* root rot, sudden death syndrome, *Phytophthora* root and stem rot, *Phytium* root rot, and soybean cyst nematode (Markell and Malvick 2018). Stem diseases of soybean include anthracnose, stem canker, brown stem rot, white mold, pod and stem blight, while the leaf diseases include bacterial pustule, downy mildew, frogeye leaf spot, powdery mildew, bean pod mottles virus, soybean mosaic virus, *Cercospora* leaf blight, and *Septoria* brown spot (Markell and Malvick 2018).

Another of the most destructive soilborne diseases of soybean is damping off. Damping off diseases of soybean are caused by a number of organisms such as *Rhizoctonia solani, Phytophthora sojae*, *Aphanomyces euteiches, Sclerotium rolfsii*, *Pythium* spp., *Fusarium* spp., etc. (Omara et al. 2017).

20.2.2 Pests of Soybean

Insect pest infestation constitutes a major biotic stress to soybean production worldwide. Soybean is attacked by several insect pests that range from beetles, worms, and maggots to aphids and bugs. Some of these pests feed on the leaves, causing defoliation that results in a reduction in yield. Pests also feed on the pods, causing scarring, thereby reducing seed quality, besides exposing the seeds to secondary infection by pathogens that may cause rotting and discoloration. Insect pests such as bean leaf beetles transmit several viruses such as soybean mosaic virus, bean pod mottle virus, cowpea mosaic virus, alfalfa mosaic virus, and southern bean mosaic virus. Other damages by pest infestations include covering of sooty mold, yellow and wrinkled leaves, reduction in gas exchange and photosynthetic rates, stunted plants, reduction in seed size, and aborted pods leading to significant yield loss of up to 40% and more (Wang et al. 2006, Beckendorf et al. 2008, Ragsdale et al. 2011, Tilmon et al. 2011). The larvae of some pests feed on soybean root nodules (Hadi et al. 2012).

The common insect pests of soyben include: beet armyworm (*Spodoptera exigua*), Western striped armyworm (*Spodoptera praefica*), Western striped cucumber beetle (*Acalymma vittata*), Western spotted cucumber beetle (*Diabrotica undecimpunctata*), bean leaf beetle, soybean leaf miner, green clover worm, alfalfa caterpillar, cabbage looper, yellow wooly bear, painted lady, imported longhorned weevil, Dectes stem borer, soybean thrips, whiteflies, soybean aphids, potato leafhopper, two-spotted spider mite, green stink bug, and brown stink bug (Stewart 2016).

20.2.3 Weeds of Soybean

Soybean production is seriously challenged by weed infestation. The prevalence of weed in soybean production is associated with a decline in crop quality and yield. Nave and Wax (1971) reported a reduction in soybean yield of up to 25% and 13% as a result of pigweed (*Amaranthus hybridus* L.) and giant foxtail (*Setaria faberii* Herrm.) infestations, respectively. Weed infestation also causes a decrease in branch number, pod number, node number, and seed number per plant.

Some of the common weeds of soybean crop are: *Conyza bonariensis* (L.) Cronq, *Conyza canadensis* (L.) Cronq, *Eleusine indica* (L.) Gaertn, *Echinochloa crusgalli* (L.) *Eleusine indica* (L.) Beauv, *Sorghum halepense* (L.) Pers., *Bidens pilosa* L. *Ambrosia artemisiifolia* L. *Phyllanthus niruri*, *Trianthema portulacastrum, Brachiaria reptans*, *Cleome gynanadra*, *Amaranthus spinosus Dactyloctenium aegyptium* (L.) *Willd, Leptochloa chinensis* (L.) *Nees*, and *Phyllanthus niruri* (L.) (Keramati et al. 2008, da Silva et al. 2013).

20.3 Microbial Mitigation of Biotic Stresses

Many soil microorganisms exhibit antifungal and antibacterial activities and are therefore used for mitigating stress from plant pathogens (Alori and Babalola 2018). Microbial inoculants in the control of plant pathogens offer an alternative strategy to a chemical control method because they are environmentally friendly and resistance to microbial metabolites has not yet been reported (Alori and Babalola 2018). They do not pose any adverse effect to indigenous microflora or to host plants (Dunne et al. 1996). Table 20.1 shows some microorganisms that have demonstrated antimicrobial properties against phytopathogens of soybean and their mechanisms of action. According to Laditi et al. (2012), no disease incidence was observed in soybean inoculated with *Bacillus* spp. and *Trichoderma* spp.

The application of beneficial soil microorganisms such as fungi, bacteria, and viruses to eradicate weeds has received great attention (Harding and Raizada 2015). Several microbes with herbicidal properties have been identified (Chutia et al. 2007). Examples include several species of *Colletotrichum*, *Xanthomonas*, *Phoma*, *Pseudomonas*, and *Sclerotinia* (Harding and Raizada 2015). Research has shown that soybean inoculated with *Colletotrichum coccodes* significantly reduced velvet leaf seed yield up to 60% (Uremis et al. 2005, Ditommaso et al. 2017).

20.3.1 Mechanism of Action

Biocontrol agents exert their activity in different ways. The various mechanisms of action include:

1. **Competition:** Rhizobacteria, due to their fast chemotactic movement toward root exudates, outcompete pathogen population in the acquisition of nutrients and specific niche and thereby reduce pathogen population. Microbial inoculants such as mycorrhizal fungi and other phosphorus solubilizing microbes increase phosphorus enough to offset symptoms caused by the pathogen (Siddiqui and Akhtar 2007). According to Pal and Gardener (2011), exudates/leachates consumption, siderophore, scavenging, and physical niche occupation are examples

TABLE 20.1

Some Examples of Microbial Mitigation of Biotic Stresses in Soybean

Biotic Stress Agent	Microbial Inoculant	Activity	Author
Sclerotinia sclerotiorum, Rhizoctonia solani, Phomopsis sojae	*Bacillus* sp., *Burkholderia* sp.	Peptides, Bacteriocins, Secondary metabolites	de-Almeida et al. (2018)
Macrophomina phaseolina h-7	*Trichoderma harzianum* (strain 6, 14, 17, 21, 44), *T. asperellum* 26, *T. virens* 32, *T. harzianum* Tj17	Antagonism via production of volatile metabolites	Barari and Foroutan (2016)
Sclerotinia stem rot	*Sporidesmium sclerotivorum*	Parasitism	del Rio et al. (2002)
Sclerotium rolfsii Sacc	*Trichoderma harzianum, T. koningi*	Antagonism	Deb and Dutta (1991)
Sclerotium rolfsii, Pythium, Fusarium oxysporum, Rhizoctonia solani, Fusarium udum, Macrpohomina and *Phytophthora*	*Methylobacterium*	Antagonism	Poorniammal et al. (2009)
Macrophomina phaseolina	*Pantoea agglomerans, Bacillus* sp. BIN, *Trichoderma harzianum* T100	Antagonism	Vasebi et al. (2013)
Macrophomina phaseolina (Tassi)	*Trichoderma harzianum T2 T10 and T12*	Volatile metabolites production (e.g., acetaldehyde, isocyanide) derivatives	Khalili et al. (2016)
Phytophthora sojae Kauf. & Gerd. (*Phytophthora* root rots)	*Streptomyces*	Antagonism	Xiao et al. (2002)
Heterodera glycines	*B. velezensis* strain Bve2, *Bacillus mojavensis* strain Bmo3, *Bacillus safensis* strain Bsa27	Antagonism	Xiang et al. (2017)
Rhizoctonia solani	*Methylobacterium aminovorans* and *Methylobacterium rhodinum, Bradyrhizobium japonicum* (St. 110); *Bacillus megaterium* var. *phosphaticum;* and *Trichoderma viride*	Increased the activities of most soil enzymes	Omara et al. (2017)
Heterodera glycines	*Hirsutella rhossiliensis* *Hirsutella minnesotensis*	Antagonism	Chen and Liu (2005)
Armyworm	*Bacillus thuringiensis*	Antagonism	CABI (2010)
Fusarium spp.	*Bacillus* spp. and *Trichoderma* spp.	Antagonism	Laditi et al. (2012)
Northern jointvetch (*Aeschynomene virginica*)	*Colletotrichum gloeosporioides* f.sp. *aeschynomene*	Antagonism	Harding and Raizada (2015)
Round leaf mallow (*Malva pusilla*)	*Colletotrichum gloeosporioides* f.sp. *malvae*	Antagonism	Harding and Raizada (2015)
Velvetleaf (*Abutilon theophrasti*)	*Colletotrichum coccodes*	Competition	Ditommaso et al. (2017)

of competition. Siderophores from microbial inoculants inhibit some phytopathogens from acquiring a sufficient amount of iron, thereby limiting their ability to multiply (Glick 2012). Production of a great amount of indole-3-acetic acid (IAA) by *Azospirillum* spp. enhances plant lateral and adventitious root formation, which improves mineral and nutrient uptake (Babalola and Glick 2012).

2. **Antibiosis:** The rhizobacteria having capacity to produce antibacterial and antifungal compounds directly inhibit pathogen growth. Microbial inoculants cause a reduction in galling and

nematode multiplication (Akhtar and Siddiqui 2008). Production of antibiotics such as 2,3-dihydroxybenzoic acid, aminochelin, azotochelin, protochelin, and azotobactin were reported by Kraepiel et al. (2009) and Mali and Bodhankar (2009). These antibiotics have decolonizing efficiency against plant pathogens in rhizoplane soil (Nagaraja et al. 2016). Compound produced by *Bacillus amyloliquefaciens* CNU114001 and identified as iturin, a lipopeptide (LP), exhibit antifungal effect against fungal plant diseases (Ji et al. 2013). *Methylobacterial* spp. produce antibiotics that inhibit the mycelia growth of fungal pathogen such as *Fusarium. oxysporum* and *F. Udum*.

3. **Production of amino acids:** Inoculation with mycorrhizal fungi increase amino acids such as phenylalanine and serine in tomato roots; these amino acids inhibit growth and multiplication of pathogens such as nematodes (Siddiqui and Akhtar 2007).
4. **Production of enzymes:** Enzymes such as β-1,3 glucanases, chitinases, proteases, cellulases, and lipases that can lyse a portion of the cell walls of many plant pathogens are produced by biocontrol bacteria (Glick 2012). Increased production of soil dehydrogenase, urease, and phosphatase activities are also reported (Omara et al. 2017). Some other lytic enzymes produced by microbial inoculants include chitinases, glucanases, and proteases (Pal and Gardener 2011). Dunne et al. (1996) reported production of chitinase and protease enzymes by *Stenotrophomonas maltophilia* strain W81 (P).
5. **Plant immunization:** Colonization of plants by microbial inoculants activate a plant's innate defense system, causing it to respond strongly to the pathogen attack. This mechanism is also referred to as induced resistance (Jain et al. 2013). Microbial inoculants enhance protection against pathogens through augmented elicitation of host defense responses by triggering phenylpropanoid and antioxidant activities and by activating accumulation of total phenol, proline, and pathogenesis-related (PR) proteins (Jain et al. 2012). Siddiqui and Akhtar (2007) also reported systemic resistance induced by *Pseudomonas* as a mechanism for the biocontrol of plant pathogens. Arbuscular mycorrhizal fungi induced systemic resistance in crops attacked by *Meloidogyne incognita* and *Pratylenchus penetrans* (Vos et al. 2012).
6. **Production of volatile secondary metabolites:** Hydrocyanic acid (HCN) is one of the volatile secondary metabolites that inhibit the growth and development of plant pathogens (Ahmad et al. 2008). Other volatile compounds such as albaflavenone and dimethyl disulphide produced by microbial inoculants also inhibit the growth of fungal pathogens (Panpatte et al. 2017). Volatile compounds from microbial inoculants stimulate the antagonistic potential of microorganisms against plant pathogens (Aremu et al. 2017). Hexanedioic and butanoic acids are volatile compounds emitted by *Alcaligenes faecalis* strain JBCS129 (Bhattacharyya et al. 2015). *Pseudomonas fluorescens* F113 was reported to produce 2,4-diacetylphloroglucinol (antifungal secondary metabolite) in its attack against *Pythium ultimum* (Dunne et al. 1996). Table 20.1 shows some biotic stress agents whose actions were mitigated by beneficial microbes and the mechanisms of action exhibited by these microbes.

20.4 Conclusion

The biotic stresses to which crop systems are exposed pose serious challenges to global food security. Plant biotic stresses need to be controlled to maintain abundant and quality food production. This reviewed article provides evidence that beneficial microorganisms have the potential to protect or control soybean diseases, weeds, and insect pests for sustainable food production and hence, food security. Mitigating biotic stresses of soybean via microbial inoculant technology will reduce overall production costs and minimize negative environmental and human exposure effects associated with a chemical control method.

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