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Review Article

Management of Plant Pathogens with Microorganisms

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Biological control has become an attractive alternative strategy for the control of plant diseases to reduce the excessive use of agrochemicals and its health hazards. There are various naturally occurring soil microbes that aggressively attack on plant pathogens and benefit plants by disease suppression and hence referred to as biocontrol agents. Besides this, biocontrol agents also help in controlling insect pests and weeds. Among the variety of biological control agents available for use, screening of potent biocontrol agents is necessary for their further development and commercialization. Biocontrol agents comprise of multiple beneficial characters such as rhizosphere competence, antagonistic potential, and ability to produce antibiotics, lytic enzymes and toxins. These biological control activities are exerted either directly through antagonism of soil-borne pathogens or indirectly by eliciting a plant-mediated resistance response. The mechanisms of biocontrol involve antibiosis, parasitism, competition for nutrients and space, cell wall degradation by lytic enzymes and induced disease resistance. Many researches have been conducted on various aspects of biological control but we need to look still forward to carry out new researches to facilitate new biocontrol technologies and applications by improving the efficacy of biocontrol agents and their biocontrol potential. The present article focuses on an overview of biological control including its history, screening, modes of actions, enhancement of biocontrol potential and application under field conditions to manage important diseases of crops.

Key Words: Plant Pathogens; Biological Control; Biopesticides; Disease Suppression

Introduction

Plant pathogens causing major damages to crop plants include fungi, bacteria, viruses and nematodes. Crop losses are creating a major threat to the food production with about 27 to 42% loss in global food production attributed to plant disease caused by plant pathogens which otherwise would have been doubled if no disease management strategies are applied. The estimated global crop losses in different regions due to plant diseases can be seen in Fig. 1. These plant pathogens are the biotic constraints that have led to chronic threat to food production and caused serious calamities in the past. For example, the Great Bengal Famine of 1943 caused by *Cochliobolus miyabeanus* in rice, the Irish potato famine, caused by *Phytophthora infestans*, in Ireland in the 1840s, the southern corn leaf blight epidemic of 1970-1971 in the USA. Many methods, measures, strategies and tactics have been used in the management of plant diseases. These methods included development of resistant varieties through plant breeding, genetically engineered plants, use of agrochemicals and physical methods, but all of them having some limitations. Development of resistant varieties through plant breeding is a time consuming process and resistance does not exist against all the diseases. Similarly, genetically engineered resistance is a sensitive issue that has been banned by national governmental policies. On the other hand, use of agrochemicals is a costly affair that has harmful effects on the environment because these adversely affect soil fertility, soil microfauna and human health [78].

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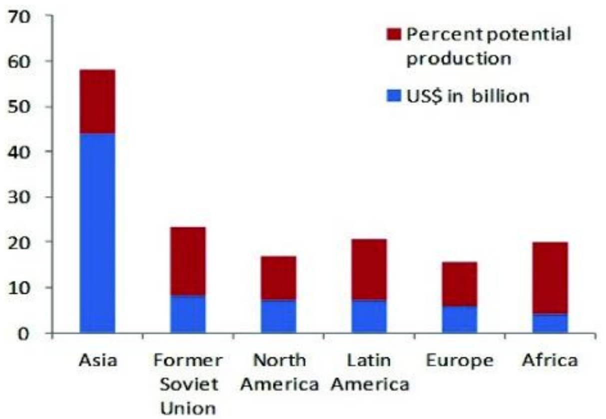

Fig. 1: Estimated crop losses due to plant diseases by region, 1988-90, adopted from : Oerke *et al*. [22]

Accumulation of chemical pesticides in plants, reduction of beneficial soil microorganisms, contamination of environment and water resources, and development of resistant pathogens have led to environmental and human health problems. Biological control is, thus, being considered as an alternative and ecofriendly way to control plant diseases and reduce the use of chemicals in agriculture [4, 11, 73, 80]. The term biological control is used not only to control diseases in plants but also to control weeds and insects [8]. Biological control was originally defined "the action of parasites, predators, or pathogens in maintaining another organism's population density at a lower average than would occur in their absence" [50]. The idea of using microbes as a method of biological control dates back to the 19th century. Since then the efficacy of various biocontrol agents has been demonstrated against a large number of plant pathogens (Table 1).

Biocontrol microbials/micro-organisms are cellular or noncellular entities, capable of replication or of transferring genetic material. Various soil and rhizosphere microbes have been identified as potential antagonists that possess characteristics of suppressive soils. However, with increase in the research related to biocontrol potential microorganisms, it was realized that such microbes have a wider range of activities that are related to biological management of plant pathogens apart from antagonism. The other mechanisms include increase in plant vigour, competing out the pathogens from nutritional resources and occupation of ecological niche, and by inducing systemic resistance in the host through elicitation of the host defence mechanisms against the invading pathogen. The beauty of the elicitation of defence mechanism is that the biocontrol potential microbes play their role even without coming into direct confrontation with the pathogens [29]. Biological control of plant pathogens basically rely on two approaches, viz., management of resident populations of organisms (the 'black box' approach) and introduction of specific organisms (the 'silver bullet' approach) to reduce the diseases. Several potential microorganisms have been identified against several dreaded phytopathogens for their biological management. However, use and commercialization of biocontrol agents should not be random and, therefore, as the regulatory authority, Central Insecticide Board (CIB) permits biocontrol agents for registration and commercialization after reviewing the reports submitted for registration.

The list of biocontrol agents included in CIB for registration are *Bacillus subtilis, Pseudomonas fluorescens, Gliocladium* spp., *Trichoderma* spp., *Beauvaria bassiana, Metarrhizium anisopliae, Verticillum lecanii*, granulosis viruses, nuclear polyhedrosis viruses (NPV), *Nomurea rileyi, Hirsutella* species, *Verticillium chlamydosporium, Streptomyces griseoviridi, Streptomyces lydicus, Ampelomyces quisqualis, Candida oleophila, Fusarium oxysporum* (non pathogenic), *Burkholderia cepacia, Coniotyrium minitans, Agrobactarium radiobacter* strain 84, *Agrobactarium tumefaciens, Pythium oligandrum, Erwinia amylovora* (hairpin protein), *Phlebia gigantean, Paecilomyces lilacinus, Penicilliuim islanidicum* (for groundnut), *Alcaligenes* spp., *Chaetomium globosum, Aspergillus niger* – strain AN27, VAM fungi, *Myrothecium verrucaria, Photorhabdus luminescences* akhurustii strain K-1, *Serratia marcescens* GPS 5, *Piriformospora indica* as shown in Table 2. However, the market share of the microorganisms is very poor and currently biopesticide is occupying about 4% of the total pesticide market share in India. For increasing the use of biocontrol agents by farmers, the bottlenecks should be identified and immediate attention may be given to overcome them.

Table 1: Management of plant pathogens/diseases of important crops by various biocontrol agents

Crop	Disease	Pathogen	Possible biocontrol agents
Cereals			
Rice	Blast	*Pyricularia oryzae*	*P. fluorescens Trichoderma* spp.
	Bunt	*Neovossia indica*	*T. harzianum, T. viride, T. virens, T. deliquescens*
	Sheath blight	*Rhizoctonia solani*	*P. fluorescens* & *P. putida, T. harzianum, T. viride, T. virens, A. niger* AN27
	Brown spot	*Drechslera oryzae*	*T. viride*
	Bacterial leaf blight	*Xanthomonas oryzae*	*Bacillus* spp.
Wheat	Karnal bunt	*Neovossia indica*	*T. viride, T. harzianum, T. pseudokoningii* & *T. koningii*
	Loose smut	*Ustilago segetum*	*T. viride, T. harzianum, T. Koningii, T. lignorum*
	Root rot	*S. rolfsii, F. oxysporum,*	*T. harzianum*
	Take-all	*Gaeumannomyces graminis var. tritici*	*T. harzianum*
Maize	Charcoal rot, Banded Blight	*Macrophomina phaseolina, R. solani*	*Trichoderma* spp.
Sorghum	Charcoal rot	*M. phaseolina*	*A. niger* AN27
Pulses			
Pigeon pea	Wilt	*Fusarium udum*	*T. viride, T. hamatum, T. harzianum, T. koningii, B. subtilis*
	Seed-borne disease	*Xanthomonas campestris pv. vinae*	*T. viride, T. harzianum*
Chickpea	Wilt	*F. oxysporum* f. sp. *ciceri*	*T. viride, T. harzianum, T. virens, B. subtilis A. niger* AN27
	Root rot	*Rhizoctonia solani/ M. phaseolina*	*T. viride, T. harzianum*
	Collar rot	*Sclerotium rolfsii*	*T. viride, T. harzianum, P. fluorescens*
	Grey mold	*B. cinera*	*Trichoderma sp.*
	Stem rot	*S. sclerotiorum*	*T. harzianum*
Cowpea	Wilt	*F. oxysporum* f. sp. *ciceris*	*T. viride*
	Charcoal rot and wilt	*M. phaseolina, F. oxysporum* f. sp. *tracheiphilum*	*T. viride, T. harzianum, T. koningii, T. pseudokoningii*
Soybean	Dry root rot	*M. phaseolina*	*T. viride, T. harzianum*
Mungbean	Root rot	*M. phaseolina*	*T. harzianum, T. viride*
Oil Seed Crops			
Groundnut	Crown rot	*Aspergillus niger*	*T. viride, T. harzianum, B. subtilis*
	Stem & pod rot	*Sclerotium rolfsii*	*T. harzianum, Rhizobium*
	Late leaf spot	*Phaeoisariopsis personata*	*Penicillum islandicum, P. fluorescens T. harzianum, B. subtilis*
	Root and stem rot	*R. solani*	*T. virens, T. longibrachiatum*
	Rust	*Puccinia arachidis*	*Verticillium lecanii, T. harzianum*
Castor	Wilt	*Fusarium oxysporum* f. sp. *ricini*	*T. viride, A. niger* AN27
	Grey mold	*Botrytis cinerea*	*T. viride, P. fluorescens,*
Mustard	Damping off	*Pythium aphanidermatum*	*T. harzianum, T. viride*

Table 1 contd ...

Continuation of Table 1

Crop	Disease	Pathogen	Possible biocontrol agents
Seasamum	Blight	*Phytophthora* sp.	*T. harzianum, T. viride*
	Wilt	*F. oxysporum* f. sp. *sesami*	*A. niger* AN27
	Root rot	*M. phasolina*	*Trichoderma* sp., *Gliocladium* sp., *B. subtilis*
Sunflower	Blight	*Alternaria helianthii*	*T. virens*
	Root/collar rot	*S. rolfsii, R. solani,* *S. sclerotiorum*	*T. harzianum, T. hamatum*
Vegetables			
Bottlegourd	Wilt	*F. oxysporum*	*A. niger* AN27
	Root rot	*R. solani*	*A. niger* AN27
	Collar rot	*Sclerotinia sclerotiorum*	*T. viride, T. virens, B. subtilis*
Cauliflower	Damping off	*Rhizoctonia solani*	*T. harzianum*
		P. aphanidermatum	*A. niger* AN27
	Stalk rot	*S. sclerotiorum*	*A. niger* AN27
Chilli	Root rot	*S. rolfsii*	*T. harzianum*
	Fruit root and die back	*Colletotrichum capsici*	*T. viride, T. harzianum, T. konningii,* *T. hamatum, T. longibrachiatum, T. pileatus*
Cucumber	Seedling diseases	*Phytophthora* or *Pythium* sp.	*T. harzianum*
		Fusarium *oxysporum* f. sp. *cucumerinum*	*A. niger* AN27
Egg plant	Wilt, Damping off	*F. solani, P. aphanidermatum*	*T. viride, T. konningii*
	Collar rot	*S. sclerotiorum*	*T. viride, T. virens*
Fenugreek	Root rot	*R. solani*	*T. viride, P. fluorescen*
French bean	Root rot	*R. solani*	*T. viride, T. hamatum*
Okra	Wilt	*Pythium* spp.	*A. niger*
Pea	Seed and Collar	*Pythium* sp., *R. solani*	*T. harzianum, T. hamatum*
	White rot	*S. sclerotiorum*	*T. viride*
Potato	Black-scurf	*R. solani*	*T. viride, T. viride, B. subtilis*
	Charcoal rot	*M. phaseolina*	*A. niger*
	Late blight	*P. infestans*	*Trichoderma* sp.
Tomato	Damping off and wilt	*F. oxysporum, B. cinerea* f. sp. *lycopersici*	*T. harzianum, P. fluorescens*
	Grey, *B. cinerea*	*Meloidogyne incognita*	*T. harzianum*
	Root Knot-*Meloidogyne incognita, M. javanica*	*M. javanica*	*T. harzianum*

Mechanisms Employed by Biocontrol Agents for Management of Plant Diseases

The biocontrol activity is exerted either directly through antagonism of soil-borne pathogens or indirectly by eliciting a plant-mediated resistance response [59, 63]. Direct antagonism results from physical contact and/or a high-degree of selectivity for the pathogen by the mechanism(s) expressed by the biocontrol agents whereas indirect antagonisms result from activities that do not involve sensing or targeting a pathogen by the biocontrol agents. Stimulation of plant host defence pathways by non-pathogenic biocontrol agents is the most indirect form of antagonism. Fig. 2 indicates detail mode of action of biocontrol agents.

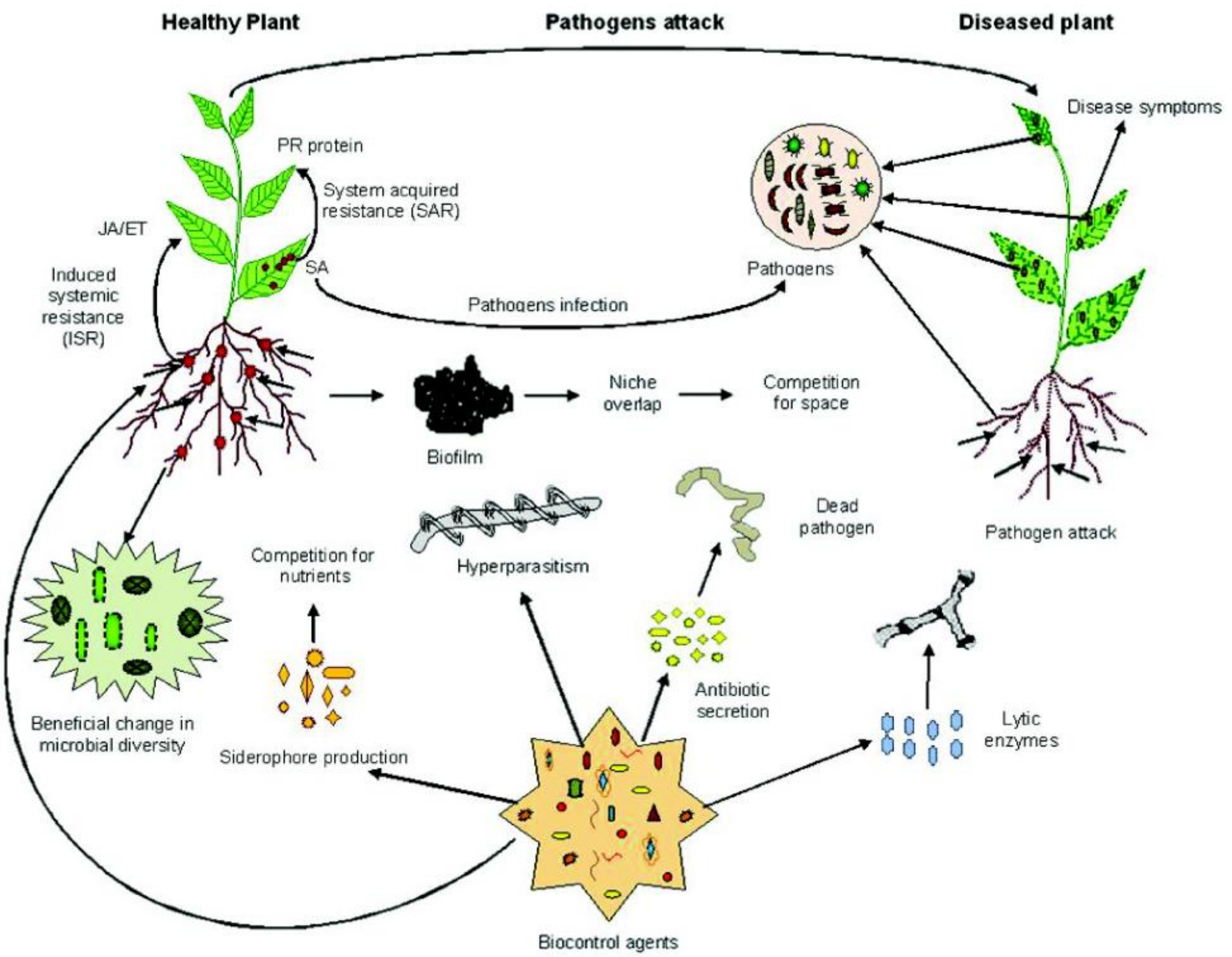

Fig. 2: Mechanism of actions implemented by biocontrol agents for management of plant diseases

Competition for Available Resources

To successfully colonize the phyllosphere or rhizosphere, a microbe must effectively compete for the available nutrients supplied in the form of exudates, leachates or senesced tissue. The rhizoplane and surrounding rhizosphere are significant sources of carbon [5] and photosynthate allocation to this zone can be as high as 40 per cent [33]. Thus, along root surfaces, there are various suitable nutrient rich niches attracting a great diversity of microorganisms, including phytopathogens. Competition for these nutrients and niches is a fundamental mechanism by which an effective biocontrol agent can protect plants from phytopathogens [10]. Using this competition approach, control of soil-borne pathogens such as *Fusarium* and *Pythium* that infect through mycelial contact, has been achieved with greater success as compared to other pathogens that directly germinate on plant surfaces and infect through appressoria and infection pegs. Effective catabolism of nutrients has been identified as a mechanism contributing to the suppression of *Pythium ultimum* by *Enterobacter cloacae* [47, 48]. Active motility and chemotactic response towards chemical attractants present in root exudates include organic acids, amino acids, and specific sugars govern arrival of biocontrol agent to the root surface [21, 23, 71].

Active Metabolites Mediated Suppression of Pathogens

Production of active microbial metabolites including iron-chelating siderophores, antibiotics, biocidal volatiles, lytic enzymes, and toxins play a very

Table 2: List of microbes used as biological control agents registered under the Insecticide Act of 1968 in India

Biocontrol agents	Details
Antagonistic Fungi	*Bacillus subtilis*
and Bacteria	*Bacillus* spp.
Chaetomium	*Beauvaria bassiana*
globosum	*Streptomyces griseoviridis*
Myrothecium	*Streptomyces lydicus*
verrucaria	*Gliocladium* spp.
	Pseudomonas fluorescens
	Trichoderma spp.
	Burkholderia cepacia
	Agrobactarium radiobacter strain 84
	Agrobactarium tumefaciens
	Erwinia amylovora (Hairpin protein)
	Alcaligenes spp.
	Ampelomyces quisqualis
	Candida oleophila
	Coniotyrium minitans
	Pythium oligandrum
	Phlebia gigantean
	Penicillium islanidicum
	Aspergillus niger-strain AN27
	VAM-Vesicular arbuscular mycorrhizae
	Piriformospora indica
	Photorhabdus luminescences akhurustii Strain K-I
	Serratia marcescens GPS 5
Entomopathogenic	*Beauvaria bassiana*
Fungi	*Metarrhizium anisopliae*
Paecilomyces	*Nomuraea rileyi*
lilacinus	*Verticillium lecanii*
	Verticilium chlamydosporium
	Hirsutella species
Baculoviruses	GVs
	NPVs

significant role in determining the offensive biocontrol activity [6, 7, 30, 81].

Antibiotics

Antibiotics can poison or kill other microorganisms at low concentrations. To be effective, antibiotics must be produced in sufficient quantities near the pathogen to result in a biocontrol effect [17, 19]. Some examples of antibiotics reported to be involved in plant pathogen suppression include 2, 4-diacetyl phloroglucinol against *Pythium* spp. [17], Agrocin 84 against *Agrobacterium tumefaciens* [2], Iturin A against *Botrytis cinerea* and *Rhizoctonia solani* [45], Phenazines against *Gaeumannomyces graminis* var. *tritici* [57]. The relative importance of antibiotic production by biocontrol bacteria has been demonstrated by generating mutant strains incapable of producing antibiotics like phenazines and phloroglucinols, which fail to suppress soil-borne root diseases [13, 57].

Iron Chelating Siderophores

Biocontrol agents are able to decrease the availability of particular substance/nutrients to the pathogens because of their efficient uptake or utilizing capacity. This phenomenon of competition for nutrients can limit the growth of pathogens [21, 24, 44]. Iron is an essential growth element for all living organisms and scarcity of its bioavailablity in soil habitats and on plant surfaces creates a furious competition [38]. Moreover, iron competition in alkaline soils may be a limiting factor for microbial growth in such soils [74]. Under iron-limiting conditions, biocontrol agents produce low-molecular-weight compounds called siderophores to competitively acquire ferric ion [43]. Kloepper *et al.* [46] were the first to demonstrate the importance of siderophore production as a mechanism of biological control of *Erwinia carotovora* by several plant growth promoting *Pseudomonas fluorescens* strains A1, BK1, TL3B1 and B10. Some bacteria, especially fluorescent pseudomonads, produce siderophores that have very high affinities for iron as compared to fungal siderophores [16] and can sequester this limited resource from other microflora thereby preventing their growth [37]. Earlier reports have demonstrated the importance of *P. fluorescens* siderophores in disease suppression [40, 74].

Lytic Enzymes

Various extracellular hydrolytic enzymes produced by microbes play important role in suppression of plant pathogens. Chitinase and ß-1, 3-glucanase attack on chitin and ß-1, 3-glucan, major constituents of many fungal cell walls [75], resulting in its degradation which further kills the pathogens [50]. Chitinase produced by *S. plymuthica*, *Serratia marcescens*, *Paenibacillus* sp. and *Streptomyces* sp.

was found to be inhibitory against *Botrytis cinerea*, *Sclerotium rolfsii*, *Fusarium oxysporum* f. sp. *cucumerinum* [3, 34]. Similarly, laminarinase produced by *Pseudomonas stutzeri* digest and lyse mycelia of *F. solani* [31]. ß-1, 3-glucanase synthesized by *Paenibacillus*, *B. cepacia* destroy *F. oxysporum, R. solani, S. rolfsii, and Pythium ultimum* cell walls [58]. Recently, genetic evidence for the role of these enzymes in biocontrol has been obtained where *ChiA* from *S. marcescens* was inserted into the non biocontrol agent *Escherichia coli* and the resulting transgenic bacterium reduced disease incidence of Southern blight of bean caused by *Sclerotium rolfsii* [68]. Similarly, transformed *Trichoderma harzianum* with *ChiA* from *S. marcescens* [72] was more capable of suppressing *Sclerotium rolfsii* than the original strain. More recently, a trademark in the history of biocontrol was established by generating transgenic plants containing the gene for endochitinase from *T. harzianum* with increased resistance against plant pathogenic fungi [60]. These results indicate that these enzymes play an important role in biocontrol and the biocontrol ability of some microbes may be improved by transformation with chitinolytic enzymes.

Root Colonization and Protection of Infection Sites

Root colonization ability of biocontrol agents and potential to survive and proliferate along growing plant roots over a considerable period, in the presence of the indigenous microflora results in intimate associations that directly provide a selective adaptation to plants towards specific ecological niches [9, 39, 42]. Also, the ability of biocontrol agent to colonize specific substrates or sites, whether a seed, root, shoot area, stump or fruit surface [39], provides protection to infection site from pathogen attack. However, they are effective only when provided with an additional competitive advantage, such as high initial cell numbers [14], earlier establishment than the pest or pathogen, or the production of antibiotic substances [57]. Therefore, rhizosphere competence is considered as a prerequisite of effective biological control. Understanding root-microbe communication [30, 51], as affected by genetic [66] and environmental [62] determinants in spatial [30] and temporal [70] contexts, will significantly contribute to improve the efficacy of these biocontrol agents. Once biocontrol agents establish on the site, the mechanism of antagonism might be competition for nutrients, space, siderophore production [41], antibiosis [18], production of hydrolytic enzymes or other active substances.

Detoxification of Virulence Factors

The detoxification mechanisms involve production of a protein that binds with pathogen toxin reversibly or irreversibly which ultimately results in decrease in the virulence potential of pathogen toxin. For example, role of certain biocontrol agents such as *Alcaligenes denitrificans* and *P. dispersa* in detoxifying albicidin toxin produced by *Xanthomonas albilineans* has been reported previously [53, 54, 64, 79]. Similarly, strains like *B. cepacia* and *Ralstonia solanacearum* hydrolyze fusaric acid, a phytotoxin produced by various *Fusarium* species [25, 26].

Induction of Systemic Resistance

Certain biocontrol agents show indirect mode of antagonism against the pathogens by inducing a state of plant resistance [35]. This induced resistance is of two types representing two distinct pathway responses: systemic acquired resistance (SAR) and induced systemic resistance (ISR). Typically, SAR is induced by pathogens while ISR is salicylic acid-independent and is induced by non-pathogenic bacteria [55]. SAR is mediated by a compound called salicylic acid which is frequently produced following pathogen infection that leads to expression of pathogenesis related (PR) proteins such as PR-1, PR-2, chitinases, and some peroxidases [47, 49, 77]. These PR proteins can cause lysis of invading cells, reinforcement of cell membranes to resist infections, or induce localized cell death. In contrary, certain biocontrol agents do not induce PR proteins but increase accumulation of peroxidase, phenylalanine ammonia lyase, phytoalexins, polyphenol oxidase, and/or chalcone synthase [1, 12, 61]. A second pathway referred to as ISR is mediated by jasmonic acid (JA) and/or ethylene, which are produced following applications of some nonpathogenic rhizobacteria. ISR was first observed on carnation with reduced susceptibility to wilt caused by *Fusarium* sp. [69] and on cucumber with reduced susceptibility to foliar disease caused by *Colletotrichum orbiculare* [52]. ISR results in strengthening of plant cell wall and alteration of host plant physiology and metabolic responses, leading to an enhanced synthesis of plant defence chemicals upon challenge by pathogens and/or abiotic stress factors [36, 77].

Biopesticides

Biopesticide formulation based on bacteria, fungi, viruses, nematodes, protozoa etc. are known as microbial pesticides. These microbial pesticides also include antagonistic organisms for biological control of plant diseases. Nine microbes, namely *Bacillus subtilis*, *Gliocladium* spp., *Trichoderma* spp., *Pseudomonas fluorescens, Beauvaria bassiana, Metarrhizium anisopliae, Verticillium lecanii*, granulosis viruses and nuclear polyhedral viruses (NPV) have been included in a schedule vide as an amendment in Insecticides Act, 1968 for the commercial production of biopesticide and published in the Gazette of India dated 26th March 1999. To date, 26 more microbes have been included in the schedule to the Insecticide Act 1968 for production of microbial biopesticides.

From our local free-living *Trichoderma* isolates, we have extracted and separated different chemical fractions in search of novel bioactive metabolites for their *in vitro* testing against phytopathogenic fungi and bacteria [27, 28]. In our recent observations, we have noticed the enhancement of antioxidant and free radical scavenging properties in different vegetable crops treated with *Trichoderma*. These *Trichoderma*-treated crops are organic, free from pesticidal contaminations, and safer for human consumption. Maximum colony forming units and shelf life of *Trichoderma* was observed in wheat bran and bajra grains. For effective production of inoculum at farmer's level, cow dung inoculation technique has been standardized and transferred to farmers. Three U.S. Patents have been awarded for this work on *Trichoderma harzianum*. Our work on a novel *Trichoderma* strain with enhanced fungicidal, nematicidal and growth promotion property is significant among the fungal bioinoculants consisting of *Trichoderma harzianum*. The technology was transferred to Department of Agriculture, U.P., Government for its commercial production by U.P. Government's 9 biopesticide manufacturing units. This technology has also been transferred to Gujarat Green Revolution Company limited (GGRC), Vadodara, a joint venture of Gujarat State Fertilizer and Chemicals Limited (GSFC), Vadodara; Balaji Crop Care Pvt. Ltd., Hyderabad. The products have reached farmer's fields in several states of the country. The product 'Sardar Ecogreen Biofungicide' and "TRICHA" are based on a potential strain of *Trichoderma harzianum* NBRI-1055, having the abilities to control phytopathogenic fungi, tolerate abiotic stress, stimulate plant growth, induce phenol contents in plants, induce systemic resistance in plants against several phytopathogenic organisms, as well as an efficient root colonizer with longer shelf life. A talc-based formulation (2% WP) using *Trichoderma viride* strain 2953 has recently been transferred to Balajee Crop Care Pvt. Ltd., Hyderabad for commercial production.

Present Scenario of Biopesticide

The current pest management strategy relies heavily on synthetic chemical pesticides which causes adverse effects even on the beneficial organisms, pesticide residues in food, feed and fodder, and environmental pollution. Although intensive agriculture provides sufficient food grains, it treads heavily in the environment. Due to the problems of resistance development in pests and withdrawal of some products for either regulatory or commercial reasons, a fewer chemical pesticides are available in the market. Out of the 215 pesticides registered for use in India, 39 have been banned for use or withdrawn from the market (as on September, 2008). The increased public concerns about the potential adverse environmental effects associated with the use of synthetic plant protection and production agrochemicals prompted search for the technologies and products based on biological processes to control the pests. Therefore, demand for biopesticides have increased as compared to previous decades due to the awareness and the extensive targeted research going on in this field to continuously improve the quality, affectivity, reliability and ecological stability of the biocontrol agents which have been successful to allure the farmers for better yield and low crop losses. Interestingly, with reference to the data of past five years, the global chemical pesticide market has increased only at an average annual growth rate (AAGR) of 1.1% in 2010 while the AAGR for the biopesticide global market has been 9.9% [32]. Notably, an increase of 4.0 per cent has been recorded in the share of biopesticides in the market as shown in Fig. 3 [65, 76]. Present scenario in India represents only 4.0 per cent contribution of biopesticides whereas the major part is still held by the insecticides and fungicides (Fig. 4). At global scale, the increase in the share of biopesticides has been major in Europe with AAGR of 15 per cent followed by that in Asia with AAGR of 12 per cent and a minute increase of 5% was noticed in the Latin America (Industrial Equipment Newsletter). This development signifies the growing trend in the developing countries for promoting biocontrol strategy of disease management as an initiative towards the most awaited evergreen revolution.

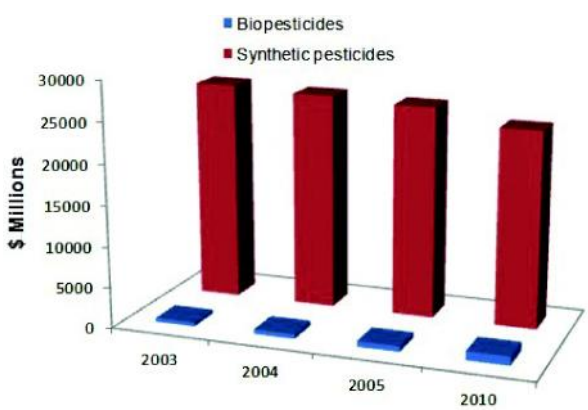

Fig. 3: Global pesticides and synthetic pesticides market, 2003-2010 ($ Millions) Source: BCC, Inc.

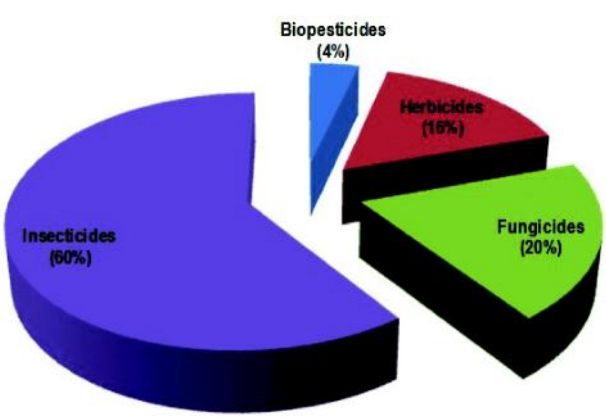

Fig. 4: Present scenario of the use of biopesticides and pesticides use in India

A look into the matter reveals a striking discrepancy between the rich inventories of potential biocontrol agents described by scientists and a very small number of commercial products available in the market. An important bottleneck for further exploitation of biocontrol agents in biological control is the limited knowledge of host-pathogen interaction at the microbial genotype level. Other crucial factors include the spurious products that are being marketed by a number of fly-by-night companies and there is no proper check for such practices currently in India. Because of this, the biopesticides are not gaining faith of the farmers. In Addition, adequate focus is not being given before commercializing the biopesticides for their adaptability to different types of soil and agroclimatic situations. Its slowness in efficacy compared to synthetic chemicals is also not contributing to its cause. There is a need for educating the farmers about these facts to win back their faith. Based on the above facts, few issues have been identified that need to be addressed at various levels for augmenting biocontrol research and applications in India.

Researchable Issues

* devise better strategies for the screening of biocontrol agents
* develop super strains with augmented biocontrol efficacy
* development of microbial consortium for different soil type and agroclimatic zones
* compatibility of biocontrol agents with different types of agrochemicals
* improve knowledge on efficacy-related issues

* promote multidisciplinary approaches to integrate better biocontrol with IPM and other production issues
* develop adapted delivery technologies
* safeguard the durability of biocontrol
* exploitation and utilization of useful genes from biocontrol agents for development of transgenics.

Developmental Issues

* training of advisers and farmers
* development and dissemination of Decision Support Systems (DSS)
* establishment of demonstration schemes and development of farmers' networks

Industrial Issues

* quality control
* improve distribution systems

Regulatory Issues

* registration guidelines under the Insecticide Act 1968 be relaxed particularly for toxicological data generation of those microbial species whose toxicological data are already available for different strains
* strict penalizing policies be implemented to the producers of spurious biopesticide products

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