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COMPONENTS, MECHANISMS OF ACTION, SUCCESS UNDER DIFFERENT CONDITION AND MARKET AVAILABILITY OF BIOCONTROL AGENTS

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Abstract

Traditional Agricultural practices are increasingly being affected by diseases, pests, droughts, decreased soil fertility due to use of hazardous chemical pesticides, pollution and global warming. Thus this review focous components, success and market demands of biocontrol. There is a wide use of microbial pesticides for soil-borne plant pathogens causing serious diseases of crops. This review address the concern of resistance development of human and fruit pathogens is increased using antibiotics in food products. Biocontrols are usually formulated in the form of dry for direct application. There is a success using biological control agent against a wide range of soil borne pathogens under greenhouse and field conditions.

Keywords: Biological control agent, BT toxin, Post-harvest,Soil-borne plant pathogens.

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INTRODUCTION

Worldwide traditional agricultural practices are increasingly being affected by various problems such as diseases, pests, droughts, decreased soil fertility due to use of hazardous chemical pesticides, pollution and global warming. There is thus a need for some eco-friendly biocontrol agents that may help to resolve some of these problems. Biological control, the use of specific microorganisms that interfere with plant pathogens and pests, is a nature-friendly, ecological approach to overcome the problems caused by standard chemical methods of plant protection (Harman *et al.* 2004).At present, it becomes difficult to control soil born diseases by using single method (Hausbek and Lamour, 2004). There are several negative effects like; development of pathogen resistance, hazards to humans, damage to beneficial organisms and environmental pollution as a consequence of Using of chemicals to control soil borne pathogens. For sustainable production, pathogens still need to be controlled in order to ensure healthy plant establishment and growth (Gerhardson, 2002).

Therefore, in order to provide an alternative to chemical control developments of various biological control agents' methods are urgently needed. Among different biological approaches, use of the microbial antagonists like yeasts, fungi and bacteria could be promised, effectively, safely and eco-friendly in controlling many of soil borne pathogens (Gravel *et al.,* 2004). Many biological control agents such as *Trichoderma* spp. and *Bacillus* spp. could be effectively used in suppressing diseases caused by *Fusarium* spp. *Drechslerahalodes*and *Rhizoctoniasolani*as reported by many workers (Hashem and Hamada, 2002; Nourozian*et al.,* 2006; Abdel- Monaim, 2010). Modes of action for beneficial micro-organisms include direct parasitism of plant pathogens, competition for space or nutrients, or production of antibiotics, enzymes or plant hormones (Lugtenberg*et al.*, 2003). This led to promote plant growth during the growing season as reported by Mercier and Manker (2005). However, up to date, only a few antagonist microorganisms have been identified as potential, effective bio-control agents against soil borne pathogens (Spadaro and Gullino, 2005). Also, these bioagents increased significantly due to seed germination and increased of plant growth in wheat and other many crops (Riungu*et al.,* 2007; Zafari*et al.*, 2008; El- Mohamedy*et al.*, 2011).

Therefore this paper presents the components, mechanism of action, successes under greenhouse and field condition and market availability of biocontrol agents.

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Components

Bacteria

The members of the genus *Bacillus* are often considered as microbial factories for the production of biologically active molecules, some of which are potentially inhibitory for fungal growth (Schallmey *et al.* 2004). The most widely used microbial agents are subspecies and strains of *B. thuringiensis* (Bt), accounting for approximately 90 % of the biocontrols market in the USA (Chattopadhyay *et al.* 2004).Several commercial products based on various Bacillus species such as B. amyloliquefaciens, B. licheniformis, B. pumilus, and B. subtilis have been marketed as biofungicides (Fravel2005). Pseudomonads are also extensively used as a biocontrol of pathogens in agriculture (Ganeshan and Kumar 2006). Several species of *Pseudomonas* are being used as biocontrol are;- *P. fluorescence,P. aeruginosa,P. syringae,* etc. Certain strains of *Pseudomonasaure of aciens* are being used against a range of plant pathogens including damping off and soft rots (Kloepper *et al.* 2004; Berg 2009).

Fungal

The well–knoun fugal biocontrol agents are *Trichoderma* that are acclaimed as effective, eco-friendly, and cheap. These biocontrol agents are identified to act against a large number of important soil-borne plant pathogens causing serious diseases of crops (Bailey and Gilligan; 2004). Fungal biocontrols used against plant pathogens include *T. harzianum*, which is an antagonist of *Rhizoctonia,Pythium,Fusarium,* andother soil-borne pathogens (Harman 2005). The *Trichoderma viride*has proved to be very promising against soil-borneplant parasitic fungi (Khandelwal*et al.*2012). There *are* also naturally occurring entomopathogenic fungi such as *B. bassiana*Vuillemin and *Metarhiziumanisopliae*(Metchnikoff) that infect sucking pests including *Nezaraviridula*(L) (green vegetable bug) and *Creontiades*sp. (green and brown mirids) (Sosa-Goméz and Moscardi1998).

Viruses

Viruses are host specific, infecting only one or a few closely related species, thus offering minimal off-target impacts (Raymond et al. 2005; Hewson *et al*. 2011). A bacteriophage is a virus that infects bacterial cell walls. If the virus attacks bacteria that cause plant disease, it can be used as a pesticide. Baculoviruses are particularly attractive for use as biocontrol due to their high host specificity. Each virus only attacks particular species of insects, and they have been shown to have no negative impacts on plants, mammals, birds, fish, or nontarget insects (D'Amico 2007).

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Mechanism of action

According to Blakeman and Parbery 1977 postulate there are four basic mechanism of antagonisms. These include direct parasitism, the production of extracellular antibiotics or other substances, competition and stimulation of host defenses.

Parasitism

Parasitism or predation is process in which antagonist feeds on or within the pathogen, resulting in a direct destruction or lysis of propagules and structure (Bull *et al.*, 1998). As reported by Bonaterra *et al.*,(2003) the direct parasitism by the antagonist on the pathogen propagules has a great advantage in biological control systems, specifically in soil-borne and to a lesser extent foliar diseases. Methods to demonstrate parasitism include burying and retrieving propagules of the pathogen to isolate the antagonist (Gardener and Fravel, 2002). Mycoparasites dissolve their fungal hosts' cell walls and penetrate the cells by using fungal cell-wall-degrading enzymes like chitinases, glucanases and b-1,3-glucanase (Elad*et al.*, 1983).Candida saitoana yeast cells, that associates with fungalhyphae cusedcytological damageand degeneration of the cytoplasm of *B.cinerea mycelium* (El-Ghaouth*et al.*1998).The extracellular enzyme such as exochitinase and b-1,3-glucanase that produced by Aureobasidium pullulans from apple wounds couldplay a role in the biocontrol activity (Castoria*et al.*, 2001).

The virus that infects *Cryphonectriaparasitica*, a fungus causing chestnut blight, which causes, a reduction in disease-producing capacity of the pathogen(hypovirulence) and this mechanism used as biocontroll for chestnut blight in many places (Milgroomand Cortesi 2004).There are several fungal parasites of plant pathogens, including those that attack sclerotia (e.g. *Coniothyriumminitans*) while others attack living hyphae (e.g. *Pythium oligandrum*). And, a single fungal pathogen can be attacked by multiple hyperparasites. For example, *Acremoniumalternatum*, *Acrodontiumcrateriforme*, *Ampelomycesquisqualis*, *Cladosporium oxysporum*, and *Gliocladiumvirens* are just a few of the fungi that have the capacity to parasitize powdery mildew pathogens (Kiss 2003).

Competition

Competition is a situation in which two or more microbial populations are simultaneously demanded for the same resource like, nutrient and spaces. (Droby and Chalutz, 1994). Competition for these resources proposed as a potential mechanism of action in biological control systems (Spadaro *et al.*, 2010). The antagonist should fulfill requirement such as, presenting in large quantities at correct time and location and utilizing resources more efficiently than the pathogen (Larkin *et al.*, 1998). In terms of competition for space, certain microorganisms (yeasts and bacteria) have the added advantage of the formation of an extracellular polysaccharide capsule that can promote adhesion to the fruit surface (Spadaro and Gullino, 2003). There are several studies that shows competition is a mechanism of biocontrol that is likely to be used by many antagonists like, yeasts and bacteria (Wisniewski *et al.*, 1989; Lindow and Brandl, 2003; Vero *et al.*, 2009; Spadaro *et al.*, 2010).

Antibiosis

Antobiosisis a process in which microorganisms are inhibited or destructed by substances such as specific or nonspecific metabolites, lytic agents, or enzymes that are produced by another microorganism (Melin*et al.*, 2007). To be effective, antibiotics must be produced in situ in sufficient quantities at the precise time of interaction with the pathogen (El-Ghaouth et al., 2002). It was discovered that bacteriocins, which are antibacterial proteins, produced by bacteria, kill or inhibit the growth of other bacteria (Cleveland *et al.*,2001). Bacteriocins function by forming pores in the membrane of target cells and depleting the trans-membrane potential. This results in the leakage of cellular materials (Cleveland *et al.*, 200). One well-known example is Pyrrolnitrin, compound produced by some Pseudomonas spp that provided the chemical model for development of Fludioxonil, a broad spectrum fungicide used as seed treatment (Gardener and Fravel, 2002).The production of antimicrobials substances by bacterial strains (Bacillus cereus, Bacillus licheniformis and Bacillus subtilis) against several avocado post-harvest pathogens was reported by (Korsten, 2006). Bacillus thuringiesis is another well-known bacteria that producetoxic compounds; BT toxin (Gerhardson, 2002). Using these antibiotics in food products raises concerns like, resistance development of human and fruit pathogens these compounds (Melin*et al.*, 2007).

Volatile metabolites Production

Volatile organic compounds are chemicals with low molecular weight, high vapour pressure, and low water solubility which allow them to easily evaporate into the air or ‘off-gas’. Volatile compounds from the biological control agents can be an important factor ofthe inhibitory mechanism, especially under closed storage condition, such as ethylene, released by the metabolic activities of the antagonist. Effects will be recorded as changes in radial growth,spore formation and colony forming units of the target fungi, which include P. expansum, B. cinerea and Rhizopusstolonifer (Mercier and Jime´nez, 2004). The potential of the volatile-producing fungus Muscodoralbus for controlling post-harvest diseases of fresh fruit (apples and peaches) by

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biological fumigation was investigated. In vitro tests showed thatM. albus volatiles inhibited and killed a wide range of storage pathogens belonging to species of Botrytis, Colletotrichum, Geotrichum, Monilinia, Penicillium and Rhizopus (Mercier *et al.*,2007). Because M. albus has a sterile mycelium and does notrequire direct contact with the crops to being treated, it could be an attractive biological fumigant for controlling post-harvest diseases. The volatile profile of M. albus colonized grain was measured by gas chromatograph connected to a flame ionization detector (GC-FID) and showed that 2-methyl-1-guatanol and isobutyric acids were the major volatile compounds found(Mercier and Jime´nez, 2004). The fact that volatiles from M. albuskill most storage pathogens exposed in vitro opens up new possibilities to develop biofumigation as a post-harvest treatment for a range of commodities (Mercier *et al.*, 2007).

Market availability

The most widely used microbial pesticides are subspecies and strains of *B. thuringiensis* (Bt), accounting for approximately 90 % of the biopesticide market in the USA (Chattopadhyay *et al.*2004). In India, P. fluorescens biopesticide is effectively being used against late blightof potato; it is available commercially under diverse brand names such as Krishi bio rahat,Krishi bio nidan, Mona, etc. Virulent cells ofbacterial antagonist P. fluorescens are taken to prepare a biopesticide formulation that is effective against phytopathogen Ralstonia sola Nacearum (Bora and Deka2007; Chakravarty and Kalita 2011). Apart from this *B. pumilusm* QST 2808, *B. subtilis* QST GB03 are used for designing biopesticides, namely, Ballad®Plusand Kodiak®, for commercial purposes in theUSA (Stewart et al. 2011).Several different commercially available biopesticides in the USA that are developed from Pseudomonas and effective against fungalphytopathogens are Spot-Less, At-Eze, Bio-Save 10LP, and Bio-Save 11LP (Nakkeeran*et al.* 2005 ; Khalil *et al.* 2013). The market share of baculoviruses is 6 % of all microbial pesticides (Quinlan and Gill 2006; Marrone 2007), and millions of hectares have been treated with registered baculovirus products over the years (Szewczyk*et al.*2009;Kabaluk*et al.*2010;Moscardi*et al*. 2011).

Successes under greenhouse and field condition

Gliocladium species are common soil saprobes and several species have been reported to be parasites of many plant pathogens (Viterbo *et al.,* 2007), for example, Gliocladium catenulatum parasities Sporidesmiumsclerotiorum and Fusarium spp. Gliocladium virens has been used as a biological control agent against a wide range of soil borne pathogens such as, *Pythium* and *Rhizoctonia*under greenhouse and field conditions (Hebbar and Lumsden, 1999; Viterbo *etal*., 2007). Pythium oligandrum has shown ability to control soil-borne pathogens both in the laboratory and in the field. Pythium oligan drum oospores have been applied as seed treatments which reduce damping-off disease caused by P. ultimum in sugar beet (Lewis et al., 1989; Khetan, 2001). The fungal biocontrol Arbuscular Mycorrhiza Fungi (AMF) have enhanced the resistance of cotton variety (Lumian 1) to *Verticillium* wilt under field conditions (QiagnZhag *et al;* 2018).

Formulation and development

Biocontrols are usually formulated as: dry formulations for direct application – dusts (DP), seed granules (GR), micro granules (MG), water dispersible granules (WG), and wet table powders (WP); emulsions, suspension concentrates (SC), capsule suspensions (CS); ultra low volume formulations (Knowles, 2006)

Dusts (DP)

DP are formulated by taking in an active ingredient on finely ground, solid mineral powder (talc, clay, etc.). This is an old formulation type that had been used for many years before granules were developed and they became restricted on the account of their adverse health impact on users. Other dusts are manufactured very simply and they are still used today in many parts of the world (Knowles, 2001)

Granules (GR)

GR are similar to dust formulations, except that granular particles are larger and heavier. Granular biocontrols are mostly used to apply products to soil in order to control weeds, nematodes, and insects living in soil, or for plant uptake by root. Once applied, granules release their active ingredient slowly. Some granules require soil moisture to release their active ingredient (Knowles, 2005; Lyn, 2010).

Wet table powders (WP)

WP are dry, finely ground formulations to be applied after suspension in water. Because of their dustiness during application, wet table powders are gradually suppressed by suspension concentrates or water dispersible granules, which have been the most widely used biocontrol formulations (Knowles, 2005).

Water dispersible granules (WG)

WG have been developed to overcome problems of dustiness of apowder formulations. Water dispersible granules are designed to be suspended in water. Water dispersible granules are usually more expensive than older types of formulations (dusts, wettable powders) but their safety and greater convenience regarding application make them still desirable for many users (Knowles, 2008).

Capsule suspension (CS)

CS are stable suspensions of micro-encapsulated active ingredient in an aqueous continuous phase, intended for dilution with water before use. Bio-agent as its active ingredient is encapsulated in capsules (coating) made of gelatin, starch, cellulose and other polymers.The most frequently applied method of encapsulation uses the principle of interfacial polymerization. Encapsulation in microcapsules has been extensively used to give smaller size and high efficiency to fungal biocontrol formulations (Winder, 2003; Brar, 2006).

Emulsions

It consist of liquid droplets dispersed in another immiscible liquid. Inverted emulsion are considered as good formulation due to their lower evaporation and spray drift as their extrenal phase is oil (Brar, 2006). Studies are currently being conducted to screen a variety of oils and emulsifying agents in order to improve initial invert emulsion formulations for biopesticides (Verner, 2007).

Suspension concentrate (SC)

SC is a mixture of a finely ground, solid active ingredient dispersed in a liquid phase, usually water. Because they are water-based, they offer many advantages, such as of pouring and measuring, safety to the operator and the environment, and economy. Therefore they are becoming a very popular type of formulation (Woods, 2003; Knowles, 2005).

Ultra low volume liquids (UL)

UL are formulations with very high concentration of active ingredient which is extremely soluble in crop-compatible liquid (ultra low volume liquid).UL liquid biopesticides can be formulated in a similar way usinga suspended biocontrol agent as an active ingredient (Woods, 2003).

REFERENCE

1. Abdel-Monaim M.F. (2010). Integrated management of damping- off, root and/or stemrot diseases of chickpea with sowing date, host resistance and bioagents. *Egypt. J. Phytopathol*., 38: 45–61.
2. Bailey D.J.and Gilligan C.A. (2004). Modeling and analysis of disease induced host growth in the epidemiology of take all. *Phytopathology;* 94:535–540.

Tariku et.al / IJIPSR / 6 (09), 2018, 78-91
ISSN (online) 2347-2154
DOI: 10.21276/IJIPSR.2018.06.09.340

3. Berg G. (2009). Plant-microbe interactions promoting plant growth and health: perspectives for controlled use of microorganisms in agriculture. *Appl Microbiol Biotechnol*. 84:11–18.
4. Blakeman J.P. andParbery D.G. (1977). Stimulation of appresorium formation in Colletotrichum acutatum by phylloplane bacteria..*Physiological Plant Pathology* 11, 313–385.
5. Bonaterra A., Mari M., Casalini L. andMontesinos E. (2003). Biological control of Monilinalaxa and Rhizopusstolonifer in post-harvest control of stone fruit by Pantoeaagglomerans and putitive mechanisms of antagonism. *Int. J. Food Micro.* 84, 93–104.
6. Bora L.C.andDeka S.N. (2007). Wilt disease suppression and disease enhancement in (Lycopersiconesculentum) by application of *Pseudomonas fluorescens*based biopesticide (Biofor-Pf) in Assam. *Indian J AgrSci* 77: 490–494.
7. Brar, S.K., Verma, M., Tyagi, R.D., and Valero, J.R. (2006).Recent advances in downstream processing and formulations of *Bacillus thuringiensis* based biopesticides. *ProcessBiochemistry*, 41: 323–342.
8. Bull C.T., Wadsworth M.L., Sorensen K.N., Tekemoto J.Y., Austin R.K. andSmilanick J.L.(1998).Syringomycin E produced by biological control agents controls green mold on lemons. *Biological Control* 12:89–95.
9. Castoria R., De Curtis F., Lima G., Caputo L. andPacifico S. (2001).Aureobasidium pullulans (LS-30) an antagonist of postharvest pathogens of fruits: study on its modes of action. *Postharvest Biology and Technology* 22: 7–17.
10. Chakravarty G., Kalita M.C. (2011). Management of bacterial wilt of brinjal by *P. fluorescens*based bioformulation. *ARPN J AgriBiol Sci.* 6:1–11.
11. Chattopadhyay A., Bhatnagar N.B. and Bhatnagar R. (2004). Bacterial insecticidal toxins. *Crit Rev Microbiol* 30:33–54.
12. Cleveland J., Montville T.J., Nes I.F. andChikindas M.L. (2001). Bacteriocins: safe, natural antimicrobials for food preservation. *International Journal of Food, Microbiology* 71, 1–20.
13. D’Amico V. (2007).Baculovirus in biological control: a guide to natural enemies in North America. http://www.nysaes.cornell.edu/ent/biocontrol/pathogen/baculoviruses.

Tariku et.al / IJIPSR / 6 (09), 2018, 78-91
ISSN (online) 2347-2154
DOI: 10.21276/IJIPSR.2018.06.09.340

14. Droby S. andChalutz E. (1994). Mode of action of biocontrol agents of postharvest diseases. In: *Biological Control of Postharvest Diseases: Theory and Practice*,pp. 63–76, (Wilson C.L. and Wisniewski M.E.,eds). CRC Press Inc, Boca Raton (US).

15. Elad Y., Barak R. and Chet I. (1983). Possible role of lectins in mycoparasitism. *Journal of Bacteriology* 154: 1431–1435.

16. El-GhaouthA., Wilson C.L. and Wisniewski M. (1998). Ultrastructural and cytochemical aspects of the biological control of Botrytis cinerea by Candida saitoana in apple fruit. *Phytopathology* 88, 282–291.

17. El-Ghaouth A., Wilson C.L., Wisniewski M., Droby S., Smilanick J.L. andKorstenL. (2002). Biological control of post-harvest diseases of citrus fruit. In*: Biological Control of Crop Diseases*pp. 289–312, (Gnanamanickam S.S., ed.). Dekker Inc, New York.

18. El-Mohamedy R.S.R., Abd El-Samad E.H., Habib Hoda A.M. andFath El-Bab T.S.H. (2001). Effect of using bio-control agents on growth, yield, head quality and root rot control in broccoli plants grown under greenhouse conditions. Int. *J. Acad. Res*., 3: 71-80.

19. Fravel D.R. (2005) Commercialization and implementation of biocontrol. *Ann Rev Phytopathol* 43:337–359.

20. Ganeshan G. and Kumar M.A. (2006).*Pseudomonas fluorescens*,a potential bacterial antagonist to control plant diseases. *J Plant Interact* 1:123–134.

21. Gardener B.B. and Fravel D.R. (2002). Biological control of plant pathogens: research, commercialization and application in the USA. http://www. apsnet.org/ publications/ apsnetfeatures/Pages/biocontrol.aspx [Accessed on 01 02 2010].

22. Gerhardson B. (2002). Biological substitute for pesticides.*Trends Biotech*., 20: 338-343.

23. Gravel V., Martinez C., Antoun H., Tweddell R.J. (2004). Evaluation of antagonistic microorganisms as bio-control agents of root rot (*Pythium ultimum*) of greenhouse tomatoes in rock wool. *Can. J. Plant Pathol*. 26: 152-159.

24. Harman G.E. (2001). *Trichoderma* spp., including *T. harzianum, T. viride, T. koningii, T. hamatum*and other spp. Deuteromycetes, Moniliales (asexual classification system) In: "*Biological Control:* A Guide to Natural Enemies in North.

25. Harman GE (2005) Overview of mechanisms and uses of *Trichoderma* spp. *Phytopathology* 96:190–194.

Tariku et.al / IJIPSR / 6 (09), 2018, 78-91
ISSN (online) 2347-2154
DOI: 10.21276/IJIPSR.2018.06.09.340

26. Hashem M. and Hamada Afaf M. (2002). Evaluation of two biologically active compounds for control of wheat root rot and its causal pathogens. *Microbiology*, 30: 233–239.

27. Hausbek M.K. and Lamour K.H. (2004). *Phytophthoracapsici*on vegetable crops: research progress and management challenges. *Plant Disease* 88: 1292–1303.

28. Hebbar, P.K. and Lumsden, R.D. (1999). Biological control of seedling diseases. In: *Methods inBiotechnology Vol. 5*: *Biopesticides*: *Use andDelivery* pp.103-116, (FrinklinR.H.and Julius J.M. eds.). Humana press.

29. Hewson I., Brown J.M., Gitlin SA, Doud D.F. (2011).Nucleopolyhedrovirus detection and distribution in terrestrial, freshwater, and marine habitats of Appledore Island, Gulf of Maine. *Microbial Ecol*. 62:48–57.

30. Khalil IAIM, Appanna V., Rick D.P., Ronald J.H., Lucie G., Tharcisse B., Kelvin L., René P., Kathy A.D., Ian K.M., Sharon L.I.L. andKithsiri E.J. (2013). Efficacy of Bio-Save 10LP and Bio-Save 11LP (*Pseudomonassyringae*) for management of potato diseases in storage. *Biol. Control*. 64:315–322.

31. Khandelwal M., Datta S., Mehta J., Naruka R., Makhijani K., Sharma G., Kumar R., Chandra S. (2012). Isolation, characterization and biomass production of *Trichoderma viride* using various agro products. *Appl. Sci. Res.* 3:3950–3955.

32. Khetan, S.K. (2001). Microbial pest control. New York, Basel, Marcel Dekker, Inc: 300.

33. Kloepper J.W., Ryu C.M., Zhang S. (2004). Induced systemic resistance and promotion of plant by *Bacillus* spp.*Phytopathology* 94:1259–1266.

34. Knowles, A. (2001). *Trends in Pesticide Formulations*, Agrow Reports PJB Publications Ltd., UK,pp.89-92.

35. Knowles, A. (2005). *New developments in crop protection product formulation*,Agrow Reports Tand F Informa Ltd, UK, pp. 153-156.

36. Knowles, A. (2006). *Adjuvants and additives*. Agrow Reports, T&F Informa UK Ltd, pp.126-129.

37. Knowles, A. (2008). Recent developments of safer formulations of agrochemicals. *Environmentalist*, 28: 35-44.

38. Korsten L (2006) Advances in control of postharvest diseases in tropical fresh produce. *International Journal of Postharvest Technology Innovation* 1:48–61.

DOI: 10.21276/IJIPSR.2018.06.09.340

39. Lewis, K., Whipps, J.M. and Cooke, R.C. (1989). Mechanisms of biological disease control with special reference to the case study of Pytiumoligandrum as an antagonist. In: *Biotechnology ofFungi for Improving Plant Growth* pp.191-217,(.WhippsJ.M and Lumsden R.D. eds.). Cambridge University Press.

40. Lindow S.E.and Brandl M.T. (2003) Microbiologyof the phyllosphere. *Applied Environmental Microbiology*; 69: 1875–1883.

41. Larkin R.P., Roberts D.P. andGracia-Garza J.A. (1998) Biological control of fungal diseases. In: *Fungicidal Activity: Chemical and Biological Approaches to Plant Protection*, pp. 149–191, (Hutson D & Miyamoto J., ed.). Wiley and Sons, New York.

42. Lugtenberg B.J.J., Bloemberg G.V., WoengC.A.and Thomas F.C. (2003). Phenazines and their role in bio-control by *Pseudomonas* bacteria. *New Phytologist*, 153: 503-523.

43. Lyn, M.E., Burnett, D., Garcia, A.R., & Gray, R. (2010).Interaction of Water with Three Granular Biopesticide Formulations. *Journal of Agricultural and Food Chemistry*, 58: 1804-1814.

44. Marrone P.G. (2007). Barriers to adoption of biological control agents and biological pesticides, CAB reviews: perspectives in agriculture, veterinary science, nutrition and natural resources 2(51). CAB International,Wallingford.

45. Melin P., Sundh I., Hakansson S. andSchnurer J. (2007) Biological preservation of plant derived animal feed with antifungal organisms: safety and formulation aspects. *Biotechnology Letters*298 :1147–1154.

46. Mercier J &Jime´nez J (2004) Control of fungal decay of apples and peaches by the biofumigant fungus Muscodoralbus. *Postharvest Biology and Technology*, 31: 1–8.

47. Mercier J., Jime´nez J. andTamez-Guerra P. (2007). Development of the volatileproducing fungus MuscodoralbusWorapong, Strobel, and Hess as a novel antimicrobial biofumigant. *Revista Mexicana de Fitopatologia*, 25: 173–179.

48. Mercier J. andManker D.C. (2005). Bio-control of soil borne diseases and plant growth enhancement in greenhouse soilless mix by the volatile-producing fungus *Muscodoralbus*. *Crop Protection*, 24: 355-362.

49. Metschnikowiapulcherrima strain to be used as a biofungicide for postharvest disease control. Canadian Journal Microbiology 56, 128–137.

50. Nakkeeran S., Dilantha Fernando W.G., Zaki A. (2005). Plant growth promoting rhizobacteria formulations and its scope in commercialization for the management of pests

DOI: 10.21276/IJIPSR.2018.06.09.340

and diseases. In: *PGPR: biocontrol and biofertilization*. pp 257–296, (Siddiqui Z.A .,ed). Springer, Dordrecht,.

51. Nourozian J, Etebarian HR, Khodakaramian G (2006). Biological control of *Fusarium graminearum*on wheat by antagonistic bacteria. Nutraceutical and Functional Food, 28: 29-38.

52. Qiang Zhang , Xinpeng Gao , Yanyun Ren , Xinhua Ding , JiajiaQiu, Ning Li ,Fanchang Zeng and Zhaohui Chu (2018). Improvement of *Verticillium*Wilt Resistance by Applying Arbuscular Mycorrhizal Fungi to a Cotton Variety with High Symbiotic Efficiency under Field Conditions, *Int. J. Mol. Sci. 19*, 241.

53. Quinlan RJ, Gill A (2006) The world market for microbial biopesticides, overview volume. CPL Business Consultants, Wallingford, p 26

54. Raymond B, Hartley SE, Cory JS, Hails RS (2005) The role of food plant and pathogen-induced behavior in the persistence of a nucleopolyhedrovirus. *J Invert Patho* 88:49–57.

55. Riungu GM, Muthomi JW, Narla RD, Wagacha JM, Gathumbi JK (2008). Management of Fusarium head blight of wheat and deoxynivalenol accumulation using antagonistic microorganisms. *Plant Pathol. J*., 7: 13-19.

56. Schallmey M., Singh A., Ward O..P (2004). Developments in the use of *Bacillus* species for industrial production.*Can J Microbiol* 50:1–17.

57. Sosa-Gomez D.R. andMoscardi F. (1998) Laboratory and field studies on the infection of stink bugs, Nezaraviridula, Piezodorusguildinii, and Euschistusheros (Hemiptera: Pentatomidae) with Metarhiziumanisopliae and Beauveriabassianain. *Brazil J InvertebrPathol* ,2:115–120.

58. Spadaro D &Gullino ML (2003) State of the art and future prospects of biological control of post-harvest fruit diseases. International Journal Food Microbiology 24, 1–10.

59. Spadaro D., Ciavorella A., Dianpeng Z. and Garibaldi AML (2010) Effect of culture media and pH on the biomass production and biocontrol efficacy of a Metschnikowiapulcherrima strain to be used as a biofungicide for postharvest disease control. *Canadian Journal Microbiology*, 56:128–137.

60. Spadaro D., Gullino M.L. (2005). Improving the efficacy of bio-control agents against soil borne pathogens. *Crop Protection*, 24: 601-613.

DOI: 10.21276/IJIPSR.2018.06.09.340

61. Stewart A, Hill R, Stark C (2011).*Desktop evaluation on commercially available microbial-based products for control or suppression of Pseudomonas syringae*pv. Actinidiae. Bio Prot Res Centre, pp 1–26.

62. Vernner, R. and Bauer, P. (2007). Q-TEO, a formulation concept that overcomes the incompability between water and oil. *Pfalzenschutz-Nachrichten Bayer,* 6:7-26.

63. Vero S, Garmendia G, Gonzalez GMB & Wisniewski M (2009) Aureobasidium pullulans as a biocontrol agent of postharvest pathogens of apples in Uruguay. *Biocontrol Science and Technology,* 19: 1033–1049.

64. Viterbo, A., Inbar, J., Hadar, Y. and Chet, I. (2007). Plant disease biocontrol and induced resistance via fungal mycoparasites. In: *Environmental andMicrobial Relationships,* 2nd edn. *The Mycota IV,* pp.127-146, (KubicekC.P. and Druzhinina I.S. eds.).Springer-Verlag Berlin Heidelberg.

65. Winder, R.S., Wheeler, J.J., Conder, N., Otvos, S.S., Nevill, R., andDuan, L. (2003). Microencapsulation: a Strategy for Formulation of Inoculum. *Biocontrol Science and Technology*, 13 : 155-169.

66. Wisniewski M., Wilson C.L. and Hershherger W. (1989). Characterization of inhibition of Rhizopusstolonifer germination and growth by Enterobacter cloacae. *Canadian Journal of Bottany,* 67: 2317–2323.

67. Woods, T.S. (2003). Pesticide Formulations. In *AGR 185 in Encyclopedia of Agrochemicals*,pp. 1-11 (Wileyand Sons .eds.). New York:

68. Zafari D., KoushkiM.M. and Bazgir E. (2008). Biocontrol evaluation of take-all disease by *Trichoderma* screened isolates. *African J. Biotech.,* 7: 3653–3659.