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Review Article

Disease Management in Brassicaceae family through various biocontrol agents: A review

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Abstract

Biological control being an eco-friendly approach against phytopathogens holds a great potential in near future. Severity of chemical-based pesticides have resulted risk to mankind and the environment. The increasing demand for chemical free products all over the world promotes eco-friendly approach such as biological control as a replacement to chemical pesticides. Various bio-formulations of living organisms can be employed to control several plant pathogens. Studies have shown that bacteria, fungi and plants can act as an important source of biocontrol products and have shown positive results in both in-vitro and in-vivo conditions. This review will help us to provide insight towards the potential of various biological entities against major diseases in Brassicaceae along with mechanisms which might be useful in developing various bio-pesticides against plant pathogens for sustainable agriculture.

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Introduction

Brassicaceae (Cruciferae) is one of the largest angiospermic family under the order Brassicales consisting of biennial, annual and perennial plants. Members of this family belongs to various oilseeds, fodder, vegetables and condiment and are good source for vitamins like A, B1, B2, B6, C, E and K (Raza et al. 2020). The genus *Brassica* is known for its agricultural importance and majority of species under this genus provides edible seeds, leaves, roots, stems, flowers and buds (Rakow 2004) along with oil and cattle feed (Ahuja et al. 2011). Species of *Brassica* like *B. napus* and *B. campestris* are grown in many countries like China, Germany, UK and Canada as oil crops (Zhang et al. 2014). *B. napus* ranks third when crop worldwide (Snowdon 2007) comes to important oilseed. A Brassica rapeseed account for about 30% of total oilseed produced and is the second most edible oilseed in India (Aeron et al. 2011).

Phytopathogens are a major problem to agriculture worldwide deteriorating both the quality and quantity of agricultural products. Pathogens are transmitted from one plant to another *via* air, water and living organisms. Various species of *Brassica* are continuously challenged by number of phytopathogens that caused great losses in this crop. Table 1 summarizes the list of major diseases in different Brassicaceae family responsible for crop losses.

To overcome these losses, synthetic chemical pesticides have been extensively utilized for the management of these plant pathogens. However, such pesticides with their continuous application possess serious threat to mankind and to the overall environment. So, in order to tackle such harmful effects of chemical-based pesticides major importance have been given to eco-friendly approach for pest control. Biological control utilises the resources of biological world in order to maintain plant health against pathogens. Various bacteria, fungi and plants are used to ameliorate crop resistance against plant pathogens. A study showed *Bacillus subtilis* LHS11 and FX2 has potential biocontrol ability against *S. sclerotiorum* pathogen that causes *Sclerotinia* stem rot disease in *B.napus* (Sun et al. 2017). In a different study *B.subtilis* and *Gliocladium catenulatum* formulation

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reduced disease severity *Brassica napus* by 80% against club root caused by *Pieris brassicae* (Peng et al. 2011). Additionally fungal biocontrol agent *Trichoderma* sp. was able to reduce club root in *Brassica chinensis* (Cheah and Page 1997). With this background, the present review attempts to highlight the different classes of biocontrol agents that have been utilized for the management of various diseases in Brassicaceae family.

Different classes of biocontrol agents

Bacteria

A number of endophytic bacteria have been shown to improve plant growth under normal and stress conditions. Such beneficial bacteria demonstrate a positive attribute towards the host plants and impart resistance for the suppression of various bacterial and fungal pathogens. Various strains of *Bacillus amyloliquefaciens* protect economically important plants from different phytopathogens (Daneilsson et al. 2007). The potential of Rhamnolipids (RLs) produced by *Pseudomonas aeruginosa* protects the *Brassica napus* tissues against the ascomycetes *B.cinerea* (Sanchez et al. 2015). Similarly, In *Brassica napus, Bacillus endophyticus* shows an antagonistic activity towards the number of fungal pathogens (Daneilsson et al. 2007). Several biocontrol agents (like *Bacillus pumilus, Bacillus subtilis, Paenibacillus* sp. and several other yeast strains) showed great potential in dealing with *Xanthomonas campestris* pv. *campestris* infections that cause Black rot in many *Brassica* sp. (Assis et al. 1999; Wulff et al. 2002*).* Similarly, *Bacillus pumilus* also shows an antagonistic activity towards *Xanthomonas campestris* in *Brassica oleracea* (Wulff et al. 2002). *Bacillus endophyticus* shows antagonistic activity towards large number of fungal pathogens in *B. napus* (Danielsson et al. 2007). *Microbiospora rosea* suppresses the occurrence of *Plasmodiophora brassicae* in *Brassica rapa* (Lee et al. 2008). Similarly, *Paenibacillus polymyxa* shows antagonism towards *Verticillium longisporum* in *B.napus* (Grane et al. 2003). Similarly, *Bacillus cereus*, *Bacillus lentimorbus* and *Bacillus pumilus* potential antagonistic activity against black rot disease caused by *Xanthomonas campestris* pv. *campestris* in cabbage plants (Massomo et al. 2004). *Paenibacillus* spp. isolates was able to reduce symptoms of black rot in *Brassica oleracea* var. *capitata* caused by *Xanthomonas campestris* pv. *campestris* (Ghazalibiglar et al. 2016). About 91.1% reduction of lesion-forming petals was observed in *Brassica napus* when pre-treated with *Pseudomonas chlororaphis* PA23 against *Sclerotinia sclerotionum* (Duke et al. 2017). A number of bacteria used as a biocontrol agent to manage different diseases of Brassicaceae family are listed in Table 1.

Fungi

Various strains of fungi have been isolated as biocontrol agents against several plant diseases. Beneficial fungi that include class ascomycetes such as *Trichoderma* sp. which is a common soil inhabitant and basidiomycetes such as *Piriformospora indica* demonstrate a good impact on several pathogens (Kim et al. 2007). *Trichoderma* sp. is able to produce various antibiotics, lytic enzymes such as cellulase, chitinase and hemicellulase which protect the plants against various pathogens. Various species of *Trichoderma* such as *T. asperellum, T. harzianum, T. viride and T. hamatum* acts as strong biocontrol agents against various root and foliar diseases (Nieves et al. 1997). *Trichoderma* sp. can interact with both plant rhizosphere and phyllosphere by several mechanisms which includes antagonism, competition for space and nutrients and release of lytic enzymes which directly inhibits the growth of pathogens (Howell 2003; Harman et al. 2004). *Trichoderma* sp. is found to be very effective in suppressing clubroot of Brassica plants caused by *P. brassicae* (Cheah et al. 1997).

Acremonium alternatum forms an endophytic association with *Brassica* species and facilitates biological activity towards bacterial and fungal pathogens. *A. alternatum* inhibits the development of *Plutella xylostella* and *Brevicoryne brassicae* in *Brassica oleracea*, *B. rapa* and *Arabidopsis thaliana* (Doan et al. 2008; Dugassa-Gobena et al. 1998). *Sclerotinia sclerotiorum B. napus* is highly reduced by *Aspergillus flavipes* (Zhang et al. 2014). *Cladosporium* sp. resists *Spodopteralitura* in *B. oleracea* (Thakur et al. 2013). *Piriformospora indica*, a mycorrhizal like fungi is a useful endophyte (Badge et al. 2010; Baltruschat et al. 2008; Lee et al. 2011) which induces systemic resistance towards *Golovinomyces orontii* in *Arabidopsis thaliana* and *B. rapa* and is regarded as the representative amongst the fungi with spectacular biocontrol potential (Schafer et al. 2007). *P. indica* promotes the plant growth, increased seed productions, stimulates nitrogen accumulation, drought tolerance and induced systemic resistance towards *G. sorontii* in *Brassica* *rapa* and *Arabidopsis thaliana* (Oelmuller et al. 2009; Shahollari et al. 2007; Sirrenberg et al. 2007; Sun et al. 2010). *Fusarium oxysporum* shows antifungal activity towards *S. sclerotiorma* and

Table 1 A list of studies that utilized Bacteria as a biocontrol agent to manage different diseases of Brassicaceae family

Bacteria	Host	Disease	Causal organism	References
Pseudomonas fluorescens	*Brassica campestris*	Stem Blight disease	*Sclerotinia sclerotiorum*	Aeron et al. 2011
Flavobacterium hercynium	*Brassica rapa* subsp. *pekinensis*	Clubroot Disease	*Plasmodiophora brassicae*	Hahm et al. 2012
Bacillus subtilis	*Brassica napus*	Clubroot Disease	*Plasmodiophora brassicae*	Lahlali et al. 2013
Paenibacillus sp.	*Brassica oleracea* var. *capitata*	Black rot disease	*Xanthomonas campestris* pv. *campestris*	Ghazalibiglar et al. 2015
Bacillus amyloliquefaciens subsp. *Plantarum*	*Brassica rapa* subsp. *pekinensis*	Damping off Disease	*Rhizoctonia solani*	Kang et al. 2015
Lactobacillus plantarum strain BY	Chinese cabbage	Bacterial soft rot	*Pectobacterium carotovorum* subsp. *carotoorum*	Tsuda et al. 2016
Zhihengliuella aestuarii	*Brassica juncea* var. *tumida tsen*	Mustard clubroot	*Plasmodiophora brassicae*	Luo et al. 2018
Streptomyces angustmyceticus NR8-2	*Brassica rapa* subsp. *pekinensis*	Leaf spots	*Colletotrichum* sp.;*Curvularia lunata*	Wonglom et al. 2019
Bacillus amyloliquefaciens KC-1	*Chinese cabbage*	Soft rot	*Pectobacterium carotovorum* subsp. *carotoorum*	Cui et al. 2019
Bacillus thuringiensis	*Brassica campestris*	Sclerotiniose disease	*Sclerotinia sclerotiorum*	Wang et al. 2020

Botryis cinerea in *B. napus* and *Fusarium tricinctum* promotes plant growth in *B. napus* (Zhang et al. 2014). *Metarhizium anisopliae* inhibits the larvae of *Plutella xylostella* in *B. napus* (Batta 2013). Broth culture filtrates of *Aspergillus flavipes* CanS-34A, *Leptosphaeria biglobosa* CanS-51, *Chaetomium globosum* CanS-73 and *Clonostachys rosea* CanS-43 suppressed leaf blight of *B. napus* caused by *S. sclerotiorum* whereas volatile compounds produced by *Fusarium oxysporum* CanR-46 was able to inhibit both *S. sclerotiorum* and *Botrytis cinerea* (Zhang et al. 2014).

Some of the endophytic fungi like *Chaetomium globosum* show in vitro antifungal activity against *S. sclerotiorum* (Chen et al. 2005; Nan et al. 2011). *Leptosphaeria biglobosa* promotes the growth of the plant and also shows the antifungal activity towards *S. sclerotiorum* in *Brassicanapus* (Zhang et al. 2014). *Muscodor albus* shows antagonistic activity towards *Pythium ultimum* in *Brassica oleracea* (Worapong and Strobel 2009). List of fungi used as a biocontrol agent to manage different diseases of Brassicaceae family are given in Table 2.

Table 2 A list of studies that utilized fungi as a biocontrol agent to manage different diseases of Brassicaceae family

Fungi	Host	Disease	Causal organism	References
Acremonium alternatum	*Brassica rapa, Arabidopsis thaliana*	Clubroot disease	*Plasmodiophora brassicae*	Doan et al. 2010
Trichoderma viridae	*Brassica campestris sp. chinensis*	Yellow disease	*Fusarium oxysporum*	Kataoka et al. 2010
Serratia plymuthica HRO-C48	*Brassica napus*	Blackleg disease	*Phoma lingam*	Hammoudi et al. 2012
Trichoderma harzianum	*Brassica rapa, Arabidopsis thaliana*	Root knot	*Meloidogyne incognita*	Ibrahim et al. 2012
Trichoderma harzianum	*Brassica napus*	Powdery mildew disease	*Erysiphe cruciferarum*	Alkooranee et al. 2015
T. harzianum, T. hamatum, T. longibrachiatum	*Brassica napus*	Stem canker disease	*Leptosphaeria maculens*	Dawidziuk et al. 2016

Plant extracts

Plant extracts are very effective and it is used in biological control against several phytopathogens of *Brassica* sp. Acetone extracts from *Cymbopogon citratus* shows effective results in controlling the black rot disease of Brassica. Beside *C. citratus, extracts of Agapanthus caulescens* along with *Paenibacillus sp.* also demonstrate a biocontrol activity against *Xanthomonas campestris* pv. *campestris* in *B. napus* (Mandiriza et al. 2018). Extracts of *Chrysanthemam cinerariaefolium* and *Melia azedarach* are used for controlling chinese cabbage disease caused by the diamond black moth (*Plutella xylostella*) and mites like *Phytoseiulu spersimilis* and *Hypoaspis aculeifer* (Kim et al. 2010). Another leaf extract of *Agave americana* has antifungal activity against *Alternaria brassicae*, the causal agent of the disease *Alternaria* blight in Indian mustard *Brassica juncea*. Cabbage aphid (*Brevicoryne brassicae*) and diamond back moth (*Plutella xylostella*) lowers cabbage production and to control these plant extracts of *Ageratum conyzoides*, *Nicotiana tabacum*, *Ricinus communis* and *Casia sophera*, were used (Amoabeng et al. 2013). Extracts of neem (*Azadirachta indica*) along with *Trichoderma harzianum* isolate T-2 was found to be very effective against *Alternaria* blight in radish (Arefin et al. 2019). The small white cabbage butterfly (*Pieris rapae*) and diamond back moth (*P. xylostella*) are the important pests in Brassicaceae, which developed resistance to chemical controls. To manage these pests plant enzyme inhibitors and the proteinaceous compounds extracted from wheat, canola, sesame, bean and Triticale were utilized (Dastranj et al. 2017). Root kno3t nematode disease in *B. rapa* was controlled by *A. indica* and *T. harzianum* (Ibrahim et al. 2012). Extracts of *Moringa oleifera*, *Datura stramonium*, *A. indica* and *Cortonbon plandianum* used was found to be effective against some seed borne fungi (*Aspergillus sp.*, *Rhizopus* sp., *Fusarium* sp., *Alternaria* sp., etc. (Ghosh et al. 2020). Extracts derived from *A. indica* and *Zingiber officinale* were able to activate resistance inducing enzymes in mustard leaves (Ojaghian et al. 2019). List of plants that have been used as a biocontrol agent to manage different diseases of Brassicaceae family are outlined in Table 3.

Table 3 A list of studies that showed positive effects of plant extracts in controlling different diseases of Brassicaceae family

Extract of plant used	Disease	Causal organism	Host	References
Chrysanthemum cinerariaefolium *Melia azedarach*	Chinese cabbage disease	Diamond blackmoth *(Plutella xylostella);* Mite *(Phytoseiulus persimilis)* and *Hypoaspis aculeifera*	Chinese cabbage	Kim et al. 2010
Azadirachta indica	Root knot nematode disease	Root knot nematode (RNT)	*Brassica rapa*	Ibrahim et al. 2012
Ageratum conyzoides; Chromolaena odorata; Synedrellanodiflora	Tri-Trophic insecticidal effect	*Brevicoryne brassicae* *Plutella xylostella*	Cabbage	Amoabeng et al. 2013
Triticum aestivum *Brassica napus* *Sesamum indicum* Bean of triticale		*Pieris rapae* *Plutella xylostella*	Cabbage	Dastranj et al. 2017
Moringa oleifera	Black Rot disease	*Xanthomonas campestris* pv. *campestris*	*Brassica oleracea*	Goss et al. 2017
Cymbopogon citratus; Plutella xylostella	Black rot Disease	*Xanthomonas campestris pv. Campestris*	*Brassica napus*	Mandiriza et al. 2018

Azadirachta indica; Trichoderma harzianum	Alternaria blight	*Alternaria brassicae*	*Raphanus sativus*	Arefin et al. 2019
Sapindus trifoliatus; Allium cepa	Alternaria leaf spot	*Alternaria brassicae*	*Brassica oleracea* var. *botrytis*	Valvi et al. 2019
Azadirachta indica; Gingiber officinale	Mustard white mold disease	*Sclerotinia sclerotiorum*	*Brassica juncea* var. *tumida*	Ojaghina et al. 2019
Azadirachta indica		*Lipaphiserysimi (kalt)*	*Brassica campestris*	Bhatta et al. 2019
Moringa oleifera; Datura stramonium; Azadirachta indica; Croton bonplandianum		Seed borne microflora	*Brassica* sp.	Ghosh et al. 2020

Conclusions and future perspective

Brassicaceae family is known to harbour large number of economically important plants. Members of this family is considered as a good source for oil, food and feed along with vitamins and minerals. A large number of diseases in this family have led to serious problems resulting in low quality and lesser yield. In order to overcome such losses agriculture is highly dependent on synthetic chemical pesticides. Use of chemical-based products possesses huge risk to mankind and the environment. Therefore, adoption of eco-friendly approach against phytopathogens is necessary. Biological control generally focuses on the use of biological products against plant pathogens which are environment friendly. Various living organisms or their formulation may be utilized to control number of plant diseases as well molecular mechanism behind the resistance induced by these agents should be studies in great detail.

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