

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/328655437>

The potential of entomopathogens in biological control of white grubs

Article · November 2018

CITATIONS
0

READS
558



Saurbh Soni

CSK HPKV Palampur

6 PUBLICATIONS 3 CITATIONS

SEE PROFILE



Sumit Vashisth

Dr. Yashwant Singh Parmar University of Horticulture and Forestry

38 PUBLICATIONS 39 CITATIONS

SEE PROFILE



Mandeep Pathania

Punjab Agricultural University

38 PUBLICATIONS 56 CITATIONS

SEE PROFILE



Pawan K Mehta

CSK HPKV Palampur

101 PUBLICATIONS 274 CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:



Insect Pest Management of Citrus [View project](#)



Doctoral Research [View project](#)



The potential of entomopathogens in biological control of white grubs

Ravinder S. Chandel, Saurbh Soni, Sumit Vashisth, Mandeep Pathania, Pawan K. Mehta, Abhishek Rana, Ashok Bhatnagar & V. K. Agrawal

To cite this article: Ravinder S. Chandel, Saurbh Soni, Sumit Vashisth, Mandeep Pathania, Pawan K. Mehta, Abhishek Rana, Ashok Bhatnagar & V. K. Agrawal (2018): The potential of entomopathogens in biological control of white grubs, International Journal of Pest Management, DOI: [10.1080/09670874.2018.1524183](https://doi.org/10.1080/09670874.2018.1524183)

To link to this article: <https://doi.org/10.1080/09670874.2018.1524183>



Published online: 10 Oct 2018.



Submit your article to this journal [↗](#)



Article views: 109



View Crossmark data [↗](#)



The potential of entomopathogens in biological control of white grubs

Ravinder S. Chandel^a, Saurbh Soni^a, Sumit Vashisth^b, Mandeep Pathania^c, Pawan K. Mehta^a,
Abhishek Rana^a, Ashok Bhatnagar^d and V. K. Agrawal^e

^aDepartment of Entomology, Himachal Pradesh Agricultural University, Palampur, Himachal Pradesh, India; ^bDivision of Entomology, ICRIASAT, Patancheru, Hyderabad, Telangana, India; ^cPunjab Agricultural University, Regional Research Station, Abohar, Punjab, India; ^dRajasthan Agricultural Research Institute, Durgapura, Jaipur, Rajasthan, India; ^eSchool of Agriculture, JECRC University, Jaipur, Rajasthan, India

ABSTRACT

White grubs are highly polyphagous and most destructive soil pests inflicting damage to a wide variety of crops. In India, more than 1000 species of white grubs are known of which over 40 species attack wide range of plants. White grubs are naturally infected by various entomopathogens which include fungi, bacteria and nematodes. Entomopathogenic fungi offer great potential and members of genera *Beauveria* and *Metarhizium* are widely used against white grubs. Several commercial products of entomopathogenic fungi like Bio Green, ORY-X, Grub X 10G, Betel, Biotrol FMA and Meta-Guard have been developed for the control of white grubs. In India, good control of white grubs in paddy, ginger and sugarcane has been achieved with different entomofungi. Among EPNs, *Heterorhabditis bacteriophora* is moderately effective against *Popillia japonica* and *Rhizotrogus majalis*. *H. indica* and *H. bacteriophora* are effective against potato white grubs in India. *Paenibacillus popilliae* cause milky disease in *P. japonica* grubs. The bacterium is pathogenic to *Holotrichia consanguinea*, *H. serrata* and *Leucopholis lepidophora*. In north-western Himalaya, *B. cereus* is highly toxic to the grubs of *H. seticollis* and *Anomala dimidiata*.

ARTICLE HISTORY

Received 23 February 2017
Revised 15 July 2018
Accepted 7 September 2018

KEYWORDS

Biological control;
entomopathogenic bacteria;
entomopathogenic fungi;
entomopathogenic nematodes; white grubs

1. Introduction

The superfamily Scarabaeoidea contains a large number of species whose larvae live in the soil and are commonly known as white grubs. As many species of white grubs are root feeders, they are also known as rootgrubs, but not all white grubs are rootgrubs (Gardner 1935). The white grubs are found chiefly in grasslands feeding on roots of various plants. Others grow on decaying organic matter (Misra and Chandel 2003). They live concealed and sudden increase in their population takes up in places having enough food and least soil-disturbance (Chandel and Kashyap 1997). The white grubs cause extensive damage to the roots of grasses, legumes, small fruit plants, shrubs and trees in many parts of the world (Pathania 2014). Larvae of greatest economic importance belong mainly to the tribe Melolonthini (Ritcher 1958). The first known white grub damage to crops in India is that by Stebbing (1902) from Punjab. More than 1000 species of white grubs are known from the Indian sub-continent of which over 40 species attack a wide range of crop plants (Veeresh et al. 1991). First major epidemic of white grubs in India was reported in sugarcane from Bihar during 1956 (Gupta and Avasthy 1956). They have now been included in the

category of five national pests (Misra and Chandra 1989), and are reported from every state causing damage to a wide variety of cultivated crops. Yadava and Sharma (1995) reported that *Holotrichia serrata* Fab., *Holotrichia consanguinea* Blanch., *Holotrichia longipennis* Blanch., *Brahmina coriacea* (Hope), *Holotrichia seticollis* Moser, *Anomala dimidiata* (Hope), *Holotrichia reynaudi* Blanch., *Leucopholis lepidophora* Blanch., *Leucopholis coneophora* Brum., *Melolontha* spp and *Lepidiota* spp are the key pest species that attack different plants in different regions of the country.

The current method for the control of white grubs is through the use of chemical pesticides. However, concern about safety, environmental contamination and poor efficacy of recommended insecticides has increased the need to develop IPM approaches for these pests (Kumawat 2001). The naturally occurring entomopathogens (fungi, nematodes, bacteria and viruses) are important components in the soil ecosystem which brings about effective suppression of soil pests in nature. We provide an overview of microbial control of white grubs in different crops with special reference to fungi, nematodes and bacteria and their future prospects in white grub management.

2. Nature of injury and economic importance of white grubs

All white grubs are polyphagous and they can feed on any root or underground stem (Veeresh 1988). The first stage larvae feed in part on organic matter in the soil, while the second and third instar grubs feed largely on roots or underground stems. The economic importance of chafers is primarily due to feeding activity of the third instar grubs (Chandel et al. 2015). Grubs prefer to feed on fibrous roots for normal growth and the crops with a tap root system suffer more as compared to those with an adventitious root system (Yadava and Vijayvergia 2000). In general, the underground parts of all plants are susceptible to grub feeding. The symptom of the damage is root pruning by grubs thereby showing varying degrees of wilting, yellowing and browning, followed by death of the plant. In crops such as potato and ginger, large holes are inflicted on the tubers or rhizomes which are then rendered unfit for marketing. Mehta et al. (2010) reported that almost all field crops grown during the rainy season, viz. potato, vegetables, groundnut, sugarcane, maize, pearl millet, sorghum, cowpea, pigeon pea, green grass, cluster bean, soybean, rajmash (kidney beans), upland rice, ginger etc are damaged by white grubs.

In India, the grubs of *H. consanguinea* are of major economic importance attacking groundnut and sugarcane in Rajasthan, Bihar, Gujarat, Uttar Pradesh, Haryana and Punjab. In endemic areas, the damage to groundnut ranges from 20% to 100%. The larvae of *H. serrata* are destructive to the roots of vegetables, pulses, oilseeds, cereals, millets, tobacco, sugarcane and sorghum in Karnataka, Maharashtra, Andhra Pradesh, Tamil Nadu and Kerala. In peninsular India, *Leucopholis* larvae injure the roots of coconut palms and also attack cassava, sweet potatoes, yams and colocasia (Nirula et al. 1952). In north western Himalaya, grubs of *B. coriacea* and *H. longipennis* cause wide spread damage to potato and several other crops. Chandel and Chandla (2003) reported that tuber damage in potato often exceeds 50% in the endemic areas of Shimla hills of Himachal Pradesh.

3. Potential entomopathogens for control of white grubs

White grubs are naturally infected by various entomopathogens which are disease causing organisms that kill their hosts or debilitate their future generations (Singh 1991). Important entopathogens which infect white grubs include fungi, bacteria, viruses and nematodes. Entomopathogenic nematodes are not strictly microbes; however, they have been

included with entomopathogens, because most of them are associated with insect-pathogenic bacteria (Dhaliwal and Koul 2007). Under certain favourable situations, they cause disease epizootics in the field. Disease is common in dense insect populations and under environmental conditions suitable to the microorganisms and entomopathogenic nematodes. However, at low host density, disease incidence is often low due to lack of contact between the pathogens and their insect hosts (Gullan and Cranston 2005). The infected insects are unable to feed properly, remain stunted, lose their body colour and become paralysed (Singh 1991). Arora et al. (2000) reported that entomopathogens exert a controlling effect on grubs by means of their invasive properties, toxins, enzymes and other substances. Entomopathogenic fungi and nematodes have received more attention than other groups of microbial organisms with potential for use in the management of white grubs. Yadava and Sharma (1995) have reported that several microorganisms such as *Paenibacillus* (= *Bacillus*) *popilliae* (Dutky), *Metarhizium anisopliae* (Metchnikoff) Sorokin, *Beauveria bassiana* (Bals.) Vuill., *B. brongniartii* (Saccardo), *Heterorhabditis bacteriophora* Poinar 1976, *Steinernema glaseri* (Steiner 1929) and *Steinernema feltiae* (Filipjev 1934) are pathogenic to white grubs and are effective in suppressing their population under field conditions. The present review highlights the major developments of last 3-4 decades along with current status as well as comments on the future possibilities.

3.1. Entomopathogenic fungi isolated from white grubs

Entomopathogenic fungi offer great potential in controlling insect-pests, as they have a wide host range, infect at different ages and stages of their hosts and cause spectacular epizootics (Zimmerman 1993). There are about 750 species of entomopathogenic fungi, although only a few dozen naturally infect insect pests (Figure 1) of agricultural importance (Gupta 2004). Fungi are also particularly important for the control of Coleoptera, as viral and bacterial diseases are rare among them (Hajek and St Leger 1994). Members of the genera *Beauveria*, *Metarhizium*, *Entomophthora*, *Verticillium* and *Paecilomyces* have received maximum attention and are widely used against white grubs. *M. anisopliae* has profuse, irregularly branched conidiophores and cylindrical to clavate phialides, tapering abruptly towards the apex (Gupta 2001). In genus *Beauveria*, the conidiogenous cells are swollen, ampulliform or nearly spherical. They form a narrow conidiogenous rachis which elongates sympodially and conidia

range from 2 to $3 \times 2.0\text{--}2.5 \mu\text{m}$ in length. In *B. brongniartii*, the conidiogenous rachi are shorter and the ellipsoid conidia are $2\text{--}3 \times 1.5\text{--}2.5 \mu\text{m}$ long, whereas the conidia are globose to sub globose ($2\text{--}3 \times 2.0\text{--}2.5 \mu\text{m}$) with conidiogenous structures forming dense clusters in *B. bassiana* (Samson 1981). In *Verticillium*, phialides in whorls are borne on branched verticillate conidiophores. The phialides are typically awl-shaped and form many conidia in heads (Ramarethinam et al. 2005). The primary conidiophores of *Entomophthora* are simple or branched and have zygospores with a hyaline to coloured to very dark outer wall layer. These are never formed within the layers of two gametangia (King and Humber 1981). Bose and Mehta (1953) isolated *Pandora* (= *Entomophthora*) *brahminae* from adult beetles of *Brahmina* sp and *Anomala rufiventris* Kollar and Redtenbacher in India.

M. anisopliae and *B. bassiana* are perhaps the most heavily researched EPFs because of their high host specificity, non-persistence and non-toxicity to the environment, unique mode of action and an appreciable shelf life (McCoy et al. 1988). Fungal spores that contact and adhere to an insect, germinate and send out hyphae. These penetrate the cuticle, invade the haemocoel and cause death either rapidly, owing to release of toxins, or more slowly,

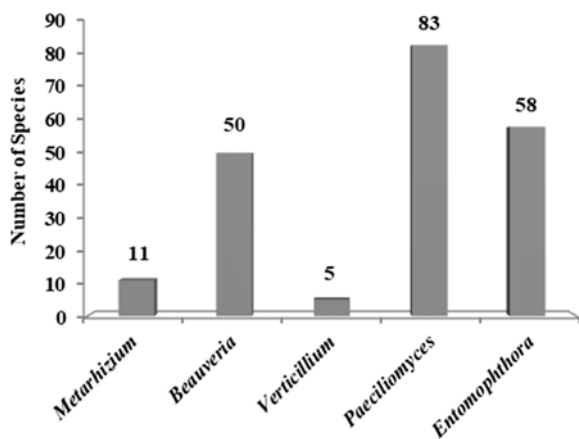


Figure 1. Species diversity in leading genera of entomopathogenic fungi.



Figure 2. *Leucopholis lepidophora* grub infected with *M. anisopliae*.

owing to massive hyphal proliferation that disrupts insect body functions (Gullan and Cranston 2005). The genus *Metarhizium* is pathogenic to a large number of insect species, many of whom are agricultural and forest insects (Ferron 1978). *M. anisopliae* was first described in Ukraine from infected larvae of wheat cockchafer *Anisopliae austriaca* in 1879 (Tulloch 1976). *Metarhizium* causes a disease known as 'green muscardine' in insect hosts because of the green colour of its conidial cells (Figures 2 and 3). *B. bassiana* is a fungus that grows naturally in soil and acts as a pathogen on various insect species and causes 'white muscardine' disease in white grubs. The *B. bassiana* or *B. brongniartii* usually appear as loose white cottony growth, at times almost completely enveloping the insect (Figures 4 and 5). Currently *M. anisopliae* consists of four genetic groups (Driver et al. 2000).

Rao and Vijayalakshmi (1959) observed *M. anisopliae* and *B. bassiana* killing large populations of *H. serrata* in south India. Avasthy (1967) reported good control of white grubs in India by *M. anisopliae*. Epizootics of *M. anisopliae* and *B. bassiana* have been reported against several scarab species



Figure 3. Healthy (1) and *M. anisopliae* infected (2-4) grubs of *Holotrichia consanguinea*.



Figure 4. Healthy (H) and *Beauveria bassiana* infected grubs (D) of *H. consanguinea*.

and other soil inhabiting Coleoptera (Fleming 1968; Hurpin and Robert 1977; Young 1974).

Ranganthiah et al. (1973) collected fungus-infected grubs of *H. serrata* from an Areca garden in Mysore and isolated *B. brongniartii* from these grubs. *Oryctes rhinoceros* is a major pest of palm in many Pacific islands and south-east Asian countries. *M. anisopliae* has been used successfully to control *O. rhinoceros* for several years (Gupta 2001).

In Himachal Pradesh, Singh (1978) found about 20% infestation of *M. anisopliae* in potato white grubs. Jongelleen et al. (1979) isolated a number of entomopathogenic fungi from *L. stigma* and *L. rorida* in Indonesia and reported that *M. anisopliae* was the most commonly encountered insect pathogenic fungus. Veeresh (1977) found strong cases of fungal infections in *H. serrata* grubs from coffee estates in Karnataka. Padmanaban et al. (2003) conducted a survey in Karnataka and Kerala, and isolated *Aspergillus flavus*, *Metarhizium* sp and *Fusarium* sp from field collected grubs of *L. brumeisteri*. Yubak Dhoj et al. (2004) conducted exploratory studies for EPFs in Nepal and reported that *M. anisopliae* was associated with white grubs to the tune of about 2% in fields with arable soil. *B. bassiana* was also isolated from a few soil samples.

Milner et al. (1992) reported an unidentified *Hirsutella* sp on scarabs in Burma. In India, *V. lecanii*

was isolated from soil which caused 48%–53% grub mortality in *H. consanguinea* after application to soil (Gour and Dabi 1988). Brown and Smith (1957) reported infection of *Paecilomyces fumosoroseus* from *M. melolontha* under synonym '*Spicaria fumoso-rosea*'. Vanderberg et al. (1998) found a strain of *P. farinosus* highly pathogenic to larvae of *Costelytra zealandica* in New Zealand. *Entoderma colletosporium* has been isolated from larvae of *Popillia japonica* by Hanula et al. (1991). In Himachal Pradesh, Chandel (2000) isolated *Entomophthora* sp from full-fed grubs of *B. coriacea* collected from Shimla region. Sharma et al. (2012) isolated 16 species belonging to nine genera from cadavers of white grubs and adult beetles in Himachal Pradesh. Most abundantly occurring fungi associated with beetles/grubs were *M. anisopliae*, *Aspergillus flavus*, *Fusarium oxysporum*, *B. bassiana*, *Aspergillus clavatus*, *Fusarium solani* and *Rhizopus oryzae*. Kalia (2013) isolated *B. brongniartii* from grubs of *B. coriacea*. On the basis of ISSR markers, wide variability exists among isolates of *B. brongniartii* present in Himachal Pradesh. Shillaroo strain has been reported to be highly virulent in nature against potato white grubs.

3.1.1. Use of entomopathogenic fungi for the control of white grubs

Most research on entomopathogenic fungi has been aimed at developing them as inundative biological control agents of white grubs. Most of the commercially produced fungi are species of either *Beauveria* or *Metarhizium* and both are relatively easy to mass produce. Production requirements include reasonable cost, long-term stability, and, most importantly, consistent efficacy under field conditions. The development of a suitable formulation is mandatory in order to enhance spore application and successful utilization in soil. Some important formulations tested against white grubs are listed in Table 1.



Figure 5. *Brahmina coriacea* grub infected with *B. brongniartii*.

Table 1. Commercial products of entomofungi being developed specially for control of white grubs.

Fungi	Product	Target pests	Producer/company
<i>M. anisopliae</i>	Bio Green	Redheaded cockchafer (<i>Adoryphorus couloni</i>)	Australia Bio-care Technology
<i>M. anisopliae</i>	ORY-X	<i>O. rhinoceros</i>	Malaysian Palm Oil Board, Malaysia
<i>M. flavoviridae</i>	Bio Green	Red headed cockchafer	Australia
<i>B. brongniartii</i>	Engerlingspilz	White grubs	Andermatt, Switzerland
	Schweizer	White grubs	EricSchweizer, Switzerland
	Melocont	White grubs	Kwizda, Austria
	Betel	White grubs	NPP (Valioppe, France)
<i>B. bassiana</i>	Daman	<i>B. coriacea</i>	Pancea Biotee, India
<i>M. anisopliae</i>	Grub x 10 G	<i>B. coriacea</i>	Pest Control India Ltd., India
<i>B. bassiana</i>	Commercial formulation	White grubs in golf course	Multiplex Agro Technology, Bangalore, India
<i>B. bassiana</i>	ABG 6178	White grubs	Abbott laboratory, USA
<i>B. bassiana</i>	Betel	Scarab beetle	Reunion
<i>M. anisopliae</i>	Biotrol FMA	Scarab larvae	Nutrilite Products, Inc., USA
<i>M. anisopliae</i>	Meta- Gaurd	White grubs and termites	Ajay Biotech (India) Ltd. Pune, India.

3.1.2. Field utilization of entomopathogenic fungi against white grubs

Keller (1983) used soil application of *B. brongniartii* against *M. melolontha* by spraying blastospores on adults in Europe. He observed a significant decrease in pest population during the second generation. In Australia, sub-surface application of rice fungus granules of *M. anisopliae* for control of red-headed cockchafer, *Adoryphorus couloni* in pasture and turf, resulted in 60% mortality of third instar grubs (Rath 1992). Li et al. (1992) tested eight varieties of *B. brongniartii* and *B. bassiana* against the grubs of *Blitopertha pallidipennis* on *Larix* (L) seedlings in China. The mortality of larvae infested by AB, LB and YB varieties ranged from 40.3% to 83.3%. The mortality of larvae infected by *M. anisopliae* introduced from Germany was 53.8%.

Cravanzola et al. (1996) found 21.1% grubs of *M. melolontha* to be infected with *B. brongniartii* (58% of them with 1×10^3 CFU/g dry soil and 13% with more than 1×10^4 CFU/g soil) in north-western Italy, with a mean larval density of 9.7 grubs/m². They did not find any relationship between infestation level of larvae and diffusion of fungus in soil. Keller et al. (1997) conducted large-scale field trials using blastospores of *B. brongniartii* against *M. melolontha* and found reduction in average reproduction rate from 5.09 to 2.19 larvae or adults. In Uttarakhand, good control of *H. longipennis* was achieved with *M. anisopliae* in upland paddy (Gupta 2001). In Sikkim, *M. anisopliae* was applied against grubs of *H. seticollis* attacking ginger. There was 23.5% increase in yield of ginger rhizomes after this treatment (Anonymous 2000).

Chandel and Mehta (2005) tested a Jaipur culture of *B. bassiana* and *M. anisopliae* @ 5×10^{13} conidia/ha against potato white grubs (*B. coriacea*) in Shimla hills, but neither of these fungi were found to be effective. Similarly, Chandel et al. (2005) did not find satisfactory control of *B. coriacea* grubs in potato in Shimla hills with the application of *B. bassiana* and *M. anisopliae* dusts. Contrary to this, *B. bassiana*, *B. brongniartii* and *M. anisopliae* have been reported to be highly effective in Kashmir against white grubs @ 1×10^8 spores/ml (Mohi-ud din et al. 2006). These cultures produced 100% mortality of grubs after 20–24 days of treatment. Lozano-Gutierrez and Espana-Luna (2008) investigated the virulence of two strains viz. BbZ3 and BbZ4 of *B. bassiana* by introducing infected cadavers of *Galleria mel/onella* through the orifices on the stem pads of nopal plant. Both these strains caused 100% mortality in the larvae of *Laniifera cyclades*. Kulye and Pokharkar (2009) studied the efficacy of *M. anisopliae* and *B. bassiana* against *H. consanguinea* infesting potato. Use of *M. anisopliae* @

2×10^{12} conidia/ha showed average efficacy of 46.74%, with 44.44% mycosis of grubs. The differences in field efficacy of entomopathogenic fungi may be due to variable environmental factors which affect pathogenicity as well as mode of virulence of entomopathogenic fungi. Soil temperature is a major factor which affects the success or failure in the establishment and production of fungal inoculums. Ouedraogo et al. (2004) has demonstrated that stress temperature alters the vegetative growth among isolates of entomopathogenic fungi. Many fungi are also sensitive to pesticides, especially fungicides. In crops like potato, there is heavy use of fungicides having a broad spectrum of activity which adversely affects the efficacy of entomopathogenic fungi, resulting in poor control of white grubs in potato in north western Himalaya. Gupta (2001) reported that *B. bassiana* has a lower temperature profile as compared with *M. anisopliae* and that the combined use of the two ensures better efficacy over a wide range of temperature.

Prasad and Hussain (2011) reported that grubs of *H. serrata*, *H. consanguinea*, *H. froges* and *Autoserica nathani* were highly susceptible to *B. brongniartii*. Its application in groundnut fields @ 10.0×10^{14} conidia/ha resulted in 41.5 and 45.5% disease in *H. consanguinea* and *H. serrata* grubs, respectively. Ghosh et al. (2009) observed that two applications of *M. anisopliae* (GRUB X 10% GR) @ 12 kg/ha increased the yield of sugarcane (70t/ha) over its single application @ 8 kg/ha. Srikanth et al. (2010) evaluated *B. brongniartii* against *H. serrata* in sugarcane @ 1×10^{14} and 1×10^{15} spores/ha, applied through fungus-colonized sorghum grains in furrows. Third instar grubs collected from the root zone about a month later, showed equal infection levels at both doses. Application of *M. anisopliae* in sugarcane @ 4×10^9 conidia/ha registered 92% reduction in grub population of *H. serrata* in Tamil Nadu on 60th DAT. The incremental benefit-cost ratio (IBCR) was high with *M. anisopliae* (7.58) as compared with chlorpyrifos (6.09) as observed by Manisegaran et al. (2011). In Assam, Bhattacharya and Pujari (2014) evaluated *B. brongniartii* and *M. anisopliae* alone and in combination with insecticides against white grubs in green gram. Both *B. brongniartii* and *M. anisopliae* in combination with imidacloprid 200 SL were effective in reducing plant mortality caused by white grubs resulting in a significant increase in grain yield.

3.2. Biocontrol potential of entomopathogenic nematodes in controlling white grubs

The nematodes belonging to the families Steinernematidae and Heterorhabditidae are

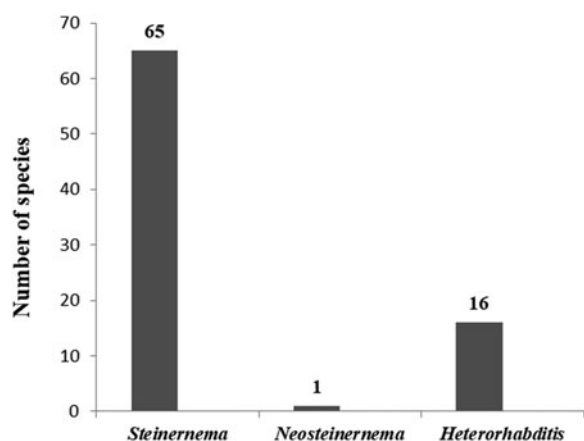


Figure 6. Species diversity in predominant genera of entomopathogenic nematodes.

commonly termed as entomopathogenic nematodes (Ganguly et al. 2011). A highly desirable attribute of entomopathogenic nematodes in control programmes is rapid host mortality which prevents the degree of insect damage to crops (Kaya 1985). They have host-searching ability and are highly virulent, have a high reproductive potential and have the potential to recycle themselves in environment. There are two genera under Steinernematidae - *Steinernema* with 65 species and *Neosteinernema* with single species. In Heterorhabditidae, there is only one genus - *Heterorhabditis* with 16 identified species as shown in Figure 6 (Kepencki 2014).

These nematodes have symbiotic relationships with bacteria that are species specific. The *Xenorhabdus* spp are associated with *Steinernema*, while *Photorhabdus* spp are associated with *Heterorhabditis*. On locating a host insect, they enter through the natural openings (Steinernematids), and additionally by rupturing the insect cuticle (*Heterorhabditis*) to finally reach the haemocoel as their ultimate destination (Gaur and Mohan 2005). Insects infected by EPNs may often be recognized by their appearance. Infected insects are often flaccid, and change colour to orange, yellow or brown (Steinernematids, Figure 7) or a brownish-red to brick red that shows faint luminescence in the dark (*Heterorhabditis*, Figure 8). Internal tissues are disintegrated to a mass of gummy consistency. The EPNs have a potential in inundative and inoculative releases and have insignificant effects on non-target organisms (Bathon 1996). They are mobile in soil and can persist for years. Chandel et al. (2009) reported that *Heterorhabditis* are encountered frequently in sandy loam soil that has high organic matter content. There are several reports where natural infection of nematodes has been recorded in white grubs as summarized in Table 2.

3.2.1. Field application of entomopathogenic nematodes in biological control of white grubs

Entomopathogenic nematodes (EPNs) have been applied successfully against soil-inhabiting insects (soil application) as well as above-ground insects (foliar spray) in cryptic habitats (Arthers et al. 2004). However, EPNs are better able in controlling soil pests as compared with foliage-feeding insects (Sharma et al. 2011). The major reason for lack of success of foliar application is the intolerance of juveniles to extremes of desiccation (Lello et al. 1996), temperature (Grewal et al. 1994) and ultra-violet radiations (Gaugler et al. 1992). In India, the EPNs were first used when DD-136 (exotic strain of *S. carpocapsae*) was employed against insect pests of rice, sugarcane and apple in 1966 (Hasan et al. 2009).

The first attempt to control white grubs with nematodes was made in the 1930's by using *S. glaseri* against *P. japonica*. Initial results were encouraging with high beetle mortality (Glaser 1932). Subsequent applications were not as encouraging against this insect (Glaser and Farrell 1935; Glaser et al. 1940) or on grass grubs (Hoy 1955). Later, Kain et al. (1982) conducted a trial using nematodes cultured with associated bacteria and found 66% reduction in the population of grass grubs. Kaya and Gaugler (1993) reported that failure of EPNs against *P. japonica* results from the use of unsuitable nematode species or strains. The instances of poor field efficacy despite excellent laboratory results may often be due to use of a nematode poorly adapted to the target insect. Potter and Held (2002) reported that grubs of Japanese beetle possess defense mechanisms against entomopathogenic nematodes. These include grooming with legs, mouth parts and raster when nematodes are present on the cuticle (Wang et al. 1995). Mannian et al. (2001) evaluated *H. bacteriophora* and *H. marelatus* and observed poor to moderate control of *P. japonica* @ 5×10^9 IJs/ha. Wright et al. (1988) investigated the use of various nematode species applied to potted Japanese yew a few days after inoculation with *P. japonica* and *Rhizotrogus majalis*. Control of *P. japonica* grubs with *H. heliothidis* ranged from 60–90% and 0–58% with *S. glaseri*. However, against *R. majalis*, the control with two nematode species ranged between 0 and 86%. Mannian et al. (2001) and Neilson and Cowles (1998) reported poor results with *H. bacteriophora* against *R. majalis*, *P. japonica* and *A. orientalis* in potted cotoneaster. Inability of the nematodes to persist or survive may have been the reason for the unsuccessful control. Temperature also affects the efficacy of entomopathogenic nematodes, and the grub mortality increases at higher temperatures (Wu et al. 2014). Georgis et al. (2006)

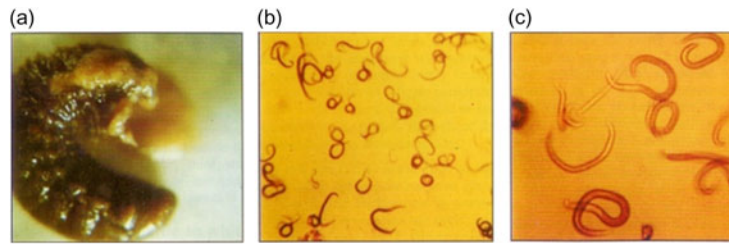


Figure 7. (a) *H. consanguinea* grub infected with *Steinernema glaseri*; (b) Infective juveniles; (c) Adults and parasitic juveniles.



Figure 8. *H. longipennis* grub infected with *H. indica*.

reported that application timing is critical for successful use of EPNs against white grubs in nurseries and greenhouses. In Germany, epizootics have been observed in grub populations infested with *Heterorhabditis* sp achieving 71% control in a sugarcane field (Akhurst et al. 1992), and 80% reduction in the population of the garden chafer, *Phyllopertha horticola* (Peters 1996). An increased infestation of EPNs in white grubs (56%), following one time release of *H. bacteriophora* was reported during second year in New Zealand (Jackson and Wouts 1987). In Germany, *H. bacteriophora* is used inundatively to control *P. horticola* grubs in turf. On many plots treated with nematodes, the grub population was below the damage threshold in following years (Ehlers and Peters 1998).

In India, EPNs have been tested against white grubs by many workers. In Tamil Nadu, Sundrababu et al. (1984) conducted preliminary tests with *S. carpocapsae* (DD-136) against potato chafer grub and found this to be pathogenic to *Anomala* sp. Poinar et al. (1992) isolated *H. indicus* from sugarcane top borer, *Scirpophaga excerptalis* and found this species pathogenic to *H. serrata*. In Himachal Pradesh, Gupta et al. (1992) reported that young grubs of *B. coriacea* are more sensitive than the older ones, and *H. bacteriophora* was more effective than *Neoaplectana bibionis*. Inoculum level of 40 dauer larvae/cm² produced 60 and 50% mortality in second instar larvae of *B. coriacea* with *H. bacteriophora* and *N. bibionis*, respectively. Against third instar larvae, 200 dauer larvae/cm² resulted in maximum kill of 54.5 and 45.5% with *H. bacteriophora* and *N. bibionis* after three weeks of treatment.

When these species were tested against third instar grubs of *Maladera insanabilis*, *H. bacteriophora* recorded maximum virulence. When third instar grubs were exposed to *H. bacteriophora* infective juveniles (IJs) in soil, lower inoculation doses were required to kill the host (LD₅₀ 14090 IJs/100 g soil/grub), the IJs invaded the host at a faster rate (LT₅₀: 18.38 h), host mortality occurred earlier (LT₅₀ 5–65 days) and more IJs were produced per cadaver of infected host (69840/grub; 607.30 IJ/mg host body weight) as compared with other tested nematodes (Bhatnagar et al. 2004). Shinde et al. (1995) evaluated *S. glaseri*, *S. feltiae* and *Steinernema* sp (Ecomax strain) against grubs of *H. consanguinea*, *H. serrata*, *Anomala bengalensis*, *A. dimidiata*, *M. insanabilis* and *L. lepidophora*. They reported that all these species of white grubs were susceptible to the tested EPNs. Mathur et al. (1995) reported the susceptibility of all these white grub species to *H. bacteriophora* and *Heterorhabditis* sp (Ecomax strain). In *H. consanguinea*, first instar grubs were more vulnerable to the attack of *S. glaseri* as compared with second instar, third instar, pupae and adults. Bhatnagar (2001) evaluated six EPNs against *M. insanabilis* and found *H. bacteriophora* to be highly virulent with maximum susceptibility to first instar grubs as compared with other stages of this insect. In general, the eggs of white grubs are not susceptible to infection by EPNs (Bareth 2001; Bhatnagar 2001; Gupta et al. 1992). Chandel et al. (2005) reported that *B. coriacea* grubs were highly susceptible to *H. indica*. In laboratory assays, *H. indica* caused 100 and 80.46% mortality of second and third instar grubs, respectively. The applications of *H. indica* in field reduced the damage by grubs to potato tubers. Fewer number of *B. coriacea* grubs were observed in nematode-treated potato fields and white grub infestation was 8.13% as compared with 11.28% in untreated fields.

In Srinagar, the infestation of *H. longipennis* is wide spread in golf courses. Hussaini et al. (2005) applied talc-based formulations of *H. indica* PDBC EN 13.3, *H. bacteriophora*, *S. carpocapsae* PDBC EN 11 and *S. abbasi* PDBC EN 3.1 @ 5 × 10⁹ IJs/ha in a heavily infested golf course with 40–50 grubs/m². *S. carpocapsae* and *S. abbasi* caused 30–40% mortality, whereas for *H. indica* and *H. bacteriophora*, it was

Table 2. Natural infection of EPNs in field populations of white grubs.

Species	Habitat	Host	Country	Reference(s)
<i>S. khoisanae</i> , <i>Steinernema</i> sp, <i>H. bacteriophora</i>	Fruit orchards	White grubs	South Africa	Hatting et al. (2009)
<i>S. feltiae</i> , <i>H. bacteriophora</i> , <i>H. downesi</i>	Oak, deciduous forests, new plantation and fruit orchards	<i>M. melolontha</i>	Hungary	Toth (2006)
<i>H. bacteriophora</i>	Maize	White grubs	Mexico	Ruiz-Vega and Aquino-Bolanos (2002)
<i>S. glaseri</i> , <i>H. bacteriophora</i>	Turfgrass	<i>Adoretus tenuimaculatus</i>	Korea	Lee et al. (2002)
<i>S. glaseri</i>	Turfgrass	<i>Anomala</i> sp	Japan	Yamanaka et al. (1995)
<i>S. carpocapsae</i>	Vegetable fields	<i>Anomala</i> sp	India	Rajeswari et al. (1984)
<i>H. megidis</i>	–	<i>P. japonica</i>	USA	Poinar et al. (1987)
<i>H. zealandica</i>	–	<i>Heteronychus arator</i>	New Zealand	Poinar (1990)
<i>S. glaseri</i>	–	<i>P. japonica</i>	USA	Wouts et al. (1982)
<i>S. kushidai</i>	–	<i>Anomala cuprea</i>	Hamikita	Mamiya (1988)

20–25%, 10 days after nematode application. The overall reduction in grub population was to the tune of 55.7% with *S. carpocapsae* and 53.1% with *S. abbasi*. The grub population decreased by 42.3 and 39.6% with *H. indica* and *H. bacteriophora*, respectively. Singh and Gupta (2006) isolated *H. bacteriophora* and *S. feltiae* from fruit orchards of Himachal Pradesh and tested them against third instar grubs of *B. coriacea* and *Holotrichia* sp in sterilized soil in glass jars. There was 100% mortality in *B. coriacea* and 58.6% mortality in *Holotrichia* sp after 21 days of inoculation. The *S. feltiae* showed 59.2% mortality in *B. coriacea* grubs. In Shimla hills of Himachal Pradesh, *S. carpocapsae* and *H. indica* used @ 1, 3 and 6×10^5 IJs/m² were effective in reducing the population of *B. coriacea* grubs and resultant tuber damage in potato. *H. indica* reduced grub population by 66%–80%, while a 83% reduction in grub population was reported with *S. carpocapsae*. There was more than 60% reduction in tuber damage (Sharma et al. 2009).

Ganguly et al. (2011) evaluated the bio-efficacy of liquid formulations of *S. thermophilum* and *S. glaseri* against grubs of *H. consanguinea* in groundnut at Jaipur. The nematodes @ 10000 IJs were applied around the rhizosphere of groundnut plants infested with white grubs. There was 65.71 and 42.85% reduction in plant mortality with *S. thermophilum* and *S. glaseri*, respectively. Prasad et al. (2012) recorded high variability in mortality of *H. consanguinea* grubs by *H. indica* in Uttar Pradesh. They reported that white grubs have strong mandibles that crush the nematodes entering through the mouth, perform frequent defecation that prevents nematode entry through anal route, have the presence of tuft-like hairs on the spiracles that pose an obstacle in nematode entry and possess a strong immune system which encapsulates the invaders before they can kill the grub. The EPNs are compatible with chemical insecticides, fungicides, acaricides, and other entomopathogens (Ishibashi 1993; Wu et al. 2014), and therefore can be applied with other pesticides as IPM tool. Some pesticides, such

as imidacloprid (Koppenhofer et al. 2000), tefluthrin (Nishimatsu and Jackson 1998) and *Bacillus thuringiensis* (Koppenhofer and Kaya 1997) are synergistic with EPNs. *P. popilliae* acts as a stressor and boosts susceptibility of white grubs to nematode infection (Thurston et al. 1994). *S. glaseri* and *H. bacteriophora* interact synergistically with imidacloprid against *P. japonica* grubs (Koppenhofer et al. 2000). There is a reduction in grooming and evasive behaviour in response to nematode attack in treated grubs. The sluggishness of imidacloprid-treated white grubs facilitates host attachment and subsequent penetration of infective juvenile nematodes. Wu et al. (2014) have observed additive or synergistic interactions between *Heterorhabditis megidis* and *B. bassiana*, and between *H. bacteriophora* and *M. anisopliae* or *B. bassiana* against third instar of *Cyclocephala lurida*. The combination of nematodes and fungi may achieve an effect comparable or superior to insecticides for curative control of white grubs.

3.3. Biological control potential of entomopathogenic bacteria against white grubs

Using entomopathogenic bacteria as biological control agent offers considerable potential. Only a few strains of bacteria, such as *Paenibacillus* (= *Bacillus*) *popilliae* and *Serratia* spp have been tested and used against white grubs (Bourner et al. 1996). *P. popilliae* and *P. lentimorbus* are the causal organisms of types A and B milky disease, a lethal infection of *P. japonica* grubs and other species of white grubs. Grubs ingest spores along with soil and roots. These spores then germinate in the gut, and vegetative cells invade the haemocoel, leading to depletion of fat bodies (Sharpe and Detroy 1979). Proliferation of spores and parasporal bodies during the final stage of infection gives the haemolymph a milky white colour (Potter and Held 2002) termed as milky disease. These bacterial infections can be seen as apparent epizootics in insect populations (Kaya et al. 1993) or can weaken insects leading to their



Figure 9. Healthy and bacterial infected white grubs collected in north western Himalaya.

death either directly or indirectly (Thurston et al. 1994). *P. popilliae* has been used as a biopesticide since 1937 when Dutky artificially added diseased larvae to field plots (Dutky 1940). Klein and Kaya (1995) reported that *P. popilliae* was the first microbial agent registered in the United States in 1948. Matsuki et al. (1997) isolated a new strain of *P. popilliae* that caused natural incidence of milky disease for the first time in *P. japonica* larvae in Japan. Small-scale use of *P. popilliae* dusts did not increase milky disease incidence nor did it reduce localized grub infestations in turf (Redmond and Potter 1995). Lack of methods for *in vitro* sporulation has limited the commercial production of *P. popilliae* (Klein 1986). The sporulation of this bacterium occurs easily in insect body and the *in vivo* production technology makes the product highly expensive, thus limiting its commercialization. In USA, M/S Fairfax Biological Laboratory marketed *P. popilliae* under the trade name “Doom” for the first time during the 1980s (Mathur 2001). The application of “Doom” was recommended @ 11.0 kg/ha as talc formulation containing 10^8 spores/g to the soil surface against white grubs (Gupta 2001). *P. popilliae* was tested against different species of white grubs in India and in Gujarat, 20–25% grubs of *Holotrichia* spp showed infection of *P. popilliae* in the subsequent years following the application of Doom. The pathogenicity of this bacterium has been reported by Shinde and Sharma (1971) against *Lachnosterma* (= *Holotrichia*) *consanguinea* from Rajasthan. SubbaRao and Veeresh (1988) tested *P. popilliae* against *H. serrata* in Karnataka. Veeresh et al. (1982) conducted studies on the management of *L. lepidophora* with *P. popilliae* and observed its infection in grubs present only upto a depth of 15 cm, whereas grubs of *L. lepidophora* are distributed up to 60 cm. Birds are indiscriminate feeders and they pick up both healthy and diseased grubs at the time of ploughing. The birds like *Acridotheres tristis* (Linn), *Corvus splendens* (Vieillot), *Corvus macrorhynchos* Wagler and *Bubulcus ibis* (Linn.) have shown to reduce

45%–60% grub population during three subsequent ploughings in Gujarat in groundnut fields (Parasharya et al. 1994). The digestive juices of birds, such as house sparrows, have no effect on *P. popilliae* spores. These predatory birds can be useful dispersal agents of the milky disease organisms (Vyas et al. 1988). The birds being long-distance fliers, indirectly help in the dispersal of this pathogen and create natural epizootic control (Parasharya et al. 1994). *P. popilliae* was totally ineffective against grubs of *B. coriacea* in Himachal Pradesh. A few similar reports are available which indicate that the use of *P. popilliae* does not provide adequate control of grubs (Knodel et al. 2012). This may be due to lack of persistence of the bacterium in the soil and/or loss of virulence. *P. popilliae* formulated as wettable powder or dusts loses its virulence under wet conditions, and its application also becomes difficult because of lumping and caking of carrier (Mathur 2001).

A novel isolate of *B. thuringiensis japonensis* strain (Btj) isolated from Japanese soils is highly effective against grubs of *P. japonica* (Suzuki et al. 1992). In Uttrakhand, a region of north western Himalaya, upto 20% population of the white grubs exhibits symptoms of bacterial infection. White grubs killed by bacteria rapidly darken in colour (Figure 9) and are often very soft. The internal tissue and organs are rapidly broken down into a viscid consistency, accompanied sometimes by a putrefied odour. The cadaver shrivels, dries and hardens. Sushil et al. (2008) isolated *B. cereus* from white grubs that showed symptoms of bacterial infection at Almora. Of the 27 bacterial isolates tested against *A. dimidiata*, WGPSB-2 was found to be highly toxic. The first instar grubs of *A. dimidiata* and *H. seticollis* were more susceptible than second instars. In outdoor microplots, a dose of 1.7×10^{10} spores/m² provided good control of white grubs. In Himachal Pradesh, *B. cereus* (WGPSB-2) was tested against grubs of *B. coriacea* by mixing in soil and through oral feeding by treating the tubers. The results were not very encouraging and maximum mortality of 37.77% was recorded when the dust containing 1×10^{10} spores/g was mixed @ 12 g/kg soil. Similarly, under field conditions, *B. cereus* failed to control the infestation of white grubs in potato in Shimla hills. There was 47.80% tuber infestation in potato after seed treatment with *B. cereus* dust (1×10^{10} spores/g) @ 5g/kg seed. When this dust was applied in furrows (12 g/plot) at the time of sowing, the tuber infestation was recorded to be 45.02% as compared with 60.75% in control (Anonymous 2009). In Himachal Pradesh, Sharma et al. (2013) isolated 10 bacteria belonging to genera *Bacillus*, *Psychrobacter*, *Paracoccus*,

Paenibacillus, *Mycobacterium*, *Staphylococcus* and *Novosphingobium* from infected grubs of *B. coriacea*. Bioassay studies revealed 100% mortality with *B. cereus* and 88.89% with *P. pulmonis* after 30 days of treatment. In Karnataka, extensive surveys have been conducted to identify and select the strains of *B. thuringiensis* that are highly toxic to *H. serrata* for use as bio control agents. Manju et al. (2009) identified 34 putative *B. thuringiensis* isolates that are active against white grubs. Activity tests of these cultures against grubs of *H. serrata* revealed that the proportion of *B. thuringiensis* active against white grubs was not correlated to the total load of CFU bacilli per g ($r=0.273$), while there was significant correlation between the members of *B. thuringiensis* and the proportion infective to *H. serrata* ($r=0.616$). Yu et al. (2006) indicated that the cultures of *B. thuringiensis* active against one species would potentially be useful in tackling other white grubs.

4. Future perspectives and conclusion

The key factor for successful microbial control of pests is the availability of a highly virulent strain or isolate of pathogen that can be economically mass produced *in vitro*, be compatible with the prevailing environmental conditions and with commonly used agro chemicals. Ecological studies on natural occurrence and distribution of entomofungi in different soil types and in different geographical regions for specific target species of white grubs are needed. Most often, fungal epizootics do not contain insect populations to economic threshold levels. To harness epizootics, we must understand which interactions are critical determinants of pathogenicity and epizootic development. Inoculation of the white grub endemic fields with fungal entomopathogens has provided limited control in some situations, but the inundative use of formulated products has proven to be a more effective method for decimating insect populations. Only naturally occurring fungal strains indigenous to limited geographic sites have been tried successfully, while many strains remain to be examined against white grubs. In many cases, the success or failure of a myco-insecticide usage is determined by the temperature and RH that occur after inoculative applications. Hence, there is an urgent need for improved formulation of technologies to preserve spore viability during storage and to allow spore germination at sub-optimal RH. The knowledge of EPF ecology such as tolerance to environmental stress can contribute to a better understanding of the effect of optimum factors on the survival and distribution of EPFs in field. This in turn can enable prediction and application

time, and/or promote habitats that encourage amplification of natural inoculums and the induction of epizootics. Molecular biology provides exciting opportunities for improving fungi for pest control. There can be many features that may benefit from genetic improvement. Further investigations on new technologies are needed, especially genetic manipulation and hybridization, to induce new biotypes for improved performance.

The opportunities for using entomopathogenic nematodes against white grubs in the soil are excellent. The challenges for researchers include isolation of more native nematode species, their characterization and matching them against the target species of white grubs. Field efficacy is one of the required components for commercialization. Efficacy data which are essential to support any claim are lacking for many of the economically important species of white grubs. The conditions under which the nematodes are or are not effective need to be delineated. This type of data will require extensive field testing as laboratory data do not necessarily predict field efficacy. The selection or development of nematode strains that can undergo anhydrobiosis will be a great challenge. Apparently, Steinernematids and *Heterorhabditis* do not have this capability; however, selection for this trait has not been attempted seriously. A more promising future for nematodes in white grub management may lie in developing alternative approaches to their use as bio-pesticides. The alternative approaches include conservation and even better manipulation of the widespread natural nematode populations in soils that could be used to buffer white grub outbreaks. In addition, although the nematodes may be produced and formulated, they must still be made easily available to the farmers who must be then properly trained so that the nematodes are used effectively against the target pests. Bacteria, especially *P. popilliae*, may also play a role if their virulence can be genetically enhanced and *in vitro* production methods are developed. The isolation of white grub active strains of *B. cereus* in north-western Himalaya and *B. thuringiensis* in peninsular India, offers more scope for bacterial products in the management of white grubs. There exists immense variability in activity of different bacterial isolates and their testing against different species of white grubs can help in selection of effective and selective isolates of bacteria.

Making entomopathogens as a component of an integrated approach can provide significant and selective insect control. In the near future, we expect to see synergistic combinations of different microbial control agents with other technologies such as semio-chemicals, soft chemicals, other natural enemies, ecological engineering that will enhance

the effectiveness and sustainability of integrated control strategies against white grubs. A truly integrated approach is required in which all good agricultural practices, including other control options, should be considered to obtain maximum effect from a given intervention or practice without interfering with the effectiveness of other interventions. Further, the IPM, which combines the best of all pest control methods, holds the key to sustainable agriculture through the effective and successful containment of white grubs which are extremely destructive and highly polyphagous soil pests.

Acknowledgments

This work was supported by Network Coordinator, All India Network Project on Soil Arthropod Pests, Jaipur (India), and Head, Department of Entomology, CSKHPKV Palampur, Himachal Pradesh, India. We are thankful to Dr SS Kanwar, former Director of Research, CSK HPKV Palampur and Dr Malvika Jaswal, freelance language editor for their language review and suggestions in improving the manuscript during re-revision.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by Network Coordinator, All India Network Project on Soil Arthropod Pests, Jaipur (India), and Head, Department of Entomology, CSKHPKV Palampur, Himachal Pradesh, India.

References

- Akhurst RJ, Bedding RA, Bull RM, Smith RJ. 1992. An epizootic of *Heterorhabditis* spp (Heterorhabditidae: Nematoda) in sugarcane scarabaeids (Coleoptera). *Fundam Appl Nematol.* 15:71–73.
- Anonymous. 2009. Annual Report, 2008–09. Palampur, India: All India Network Project on White Grubs and Other Soil Arthropods.
- Anonymous. 2000. Annual Report, All India Coordinated Research Project on White grubs, XII Annual Group Meeting G.B. Ranichauri: Pant University of Agriculture and Technology, College of Forestry and Hill Agriculture; May 22–23.
- Arora R, Battu GS, Ramakrishnan N. 2000. Microbial pesticides: Current status and future outlook. In: Dhaliwal GS, Singh B, editors. *Pesticides and environment*. New Delhi: Commonwealth Publishers; p. 344–395.
- Arthers S, Heinz KM, Prasifka JR. 2004. An analysis of using entomopathogenic nematode against above-ground pests. *Bull Entomol Res.* 94:297–306.
- Avasthy PN. 1967. Sugarcane pests in India and their control (a review). *PANS* 13:111–117.
- Bareth SS. 2001. Evaluation of entomopathogenic nematode, *Steinernema glaseri* (Steiner) as a biocontrol agent against *Holotrichia consanguinea* (Blan.). PhD thesis, Rajasthan Agriculture University Bikaner, Rajasthan.
- Bathon H. 1996. Impact of entomopathogenic nematodes on non-target hosts. *Biocont. Sci. Tech.* 6:421–434.
- Bhatnagar A. 2001. Assessment of entomopathogenic nematodes for management of white grubs *Maladera insanabilis* Brenske (Scarabaeidae: Coleoptera). PhD thesis, Rajasthan Agriculture University Bikaner, Rajasthan.
- Bhatnagar A, Shinde V, Bareth SS. 2004. Evaluation of entomopathogenic nematodes against white grubs, *Maladera insanabilis* Brenske. *Int. J. Pest. Manage.* 50(4):285–289.
- Bhattacharya B, Pujari D. 2014. Field evaluation of *Beauveria brongniartii* and *Metarhizium anisopliae* against white grubs damaging green gram in Assam. *Int J Pl Prot.* 7(1):67–70.
- Bose SK, Mehta PR. 1953. A new series of *Entomophthora* on beetles. *T Brit Mycol Soc.* 36:52–56.
- Bourner TC, Glare TR, O'Callaghan M, Jackson TA. 1996. Towards green pastures- pathogens and pasture pests. *N Zool J Ecol.* 20:101–107.
- Brown AHS, Smith G. 1957. The genus *Paecilomyces* Bainier and its perfect stage *Byssoscleromyces* Westing. *T Brit Mycol Soc.* 40:17–89.
- Chandel RS, Chandla VK, Dhiman KR. 2005. Vulnerability of potato white grubs to entomogenous fungi and nematodes. *Potato J.* 32 (3–4):193–194.
- Chandel RS, Chandla VK. 2003. Managing tuber damaging pests of potato. *Indian Hort.* 48:15–17.
- Chandel RS, Kashyap NP. 1997. About white grubs and their management. *Farmer and Parliament.* 37(10):29–30.
- Chandel RS, Pathania M, Verma KS, Bhattacharyya B, Vashisth S and Kumar V. 2015. The ecology and control of potato white grubs of India. *Potato Res.* 58: 147–164.
- Chandel YS, Kapoor S, Kumar S. 2009. Virulence of *Heterorhabditis bacteriophora* (Poinar) against cutworms, *Agrotis segetum* (Denis and Schiff). *J Biol Cont.* 23(4):409–415.
- Chandel YS, Mehta PK. 2005. Efficacy of some insecticides and entomopathogenic fungi against white grub complex infesting potato in H.P. *Indian J Ecol.* 32: 195–199.
- Chandel, RS. 2000. Natural enemies of *Brahmma coriacea* (Hope) in Himachal Pradesh. *Insect Environ.* 6(2):85.
- Cravanzola F, Piatii P, Ozino OJ, Bondaz F, Vallet S. 1996. Occurrence of entomopathogenic fungus *Beauveria brongniartii* in the soil of valle d' Aosta and infestation level of *Melolontha melolontha*. *Bull OILB SROP.* 19:59–64.
- Dhaliwal GS, Koul O. 2007. *Biopesticides and pest management: Conventional and biotechnological approaches*. New Delhi: Kalyani Publishers; p. 455.
- Dutky SR. 1940. Two new spore-forming bacteria causing milky-disease of Japanese beetle larvae. *J Agric Res.* 61: 57–68.
- Driver F, Milner RJ, Trueman JWH. 2000. A taxonomic revision of *Metarhizium* based on a phylogenetic analysis of r DNA sequence data. *Mycol Res.* 104:134–150.
- Ehlers RU, Peters A. 1998. Bekamp-fung von Engerlingen auf Sportrasen. *Rasen/Turf/Gazon.* 293:60–67.
- Ferron P. 1978. Biological control of insect pests by entomogenous fungi. *Annu Rev Entomol.* 23:409–442.
- Fleming WE. 1968. Biological control of Japanese beetle. *USDA Technical Bull No.* 1383:78.
- Ganguly S, Rathour KS, Kumar S, Singh M. 2011. *Steinernema meghalayensis* sp. n. (Rhabditida:

- Steinernematidae) from North Eastern hilly regions of India. *Indian J Nematol.* 41(1):83–97.
- Gardner JCM. 1935. Immature stages of Indian Coleoptera. *Indian Forest Records* 1:1–33.
- Gaugler R, Bednark A, Campbell JF. 1992. Ultraviolet inactivation of *Heterorhabditids* and *Steinernematids*. *J Invertebr Pathol.* 59:155–160.
- Gaur HS, Mohan Sharad. 2005. Role of nematodes as bio-pesticides. In: Souvenir. Biopesticides Conference (Biopesticides: Emerging trends BET 2005); 2005 November 11–13; Palampur, India: IHBT; p. 33–40.
- Georgis R, Koppenhofer AM, Lacey LA, Belair G, Duncan LW, Grewal PS, Samish M, Tan L, Torr P, Van Tol RWHM. 2006. Successes and failures in the use of parasitic nematodes for pest control. *Biol Cont.* 38: 103–123.
- Ghosh SK, Choudhary M, Pawar S, Prabhakar MS. 2009. Bio-efficacy of GRUB – X 10% GR, a granular formulation of *Metarhizium anisopliae* against root grubs *Holotrichia* sp (Coleoptera: Scarabaeidae) on Sugarcane. In: Fifth International Conference on Bio pesticides: Stakeholders' perspective. Society for Promotion and Innovation of Bio pesticides; New Delhi, India; p. 206.
- Glaser RW, Farell CC. 1935. Field experiments with the Japanese beetle and its nematode parasite. *J N Y Entomol Soc.* 43:345–371.
- Glaser RW, McCoy EE, Girth HD. 1940. The biology and economic importance of a nematode parasite in insects. *J Parasitol.* 26:479–495.
- Glaser RW. 1932. A pathogenic nematode of the Japanese beetle. *J Parasitol.* 18:119.
- Gour HN, Dabi RK. 1988. Biological control of white grubs using *Verticillium lecanii* (Zimm.). *Viegas. Curr Sci.* 57:620–621.
- Grewal PS, Gaugler S, Wang Y. 1994. Enhanced cold tolerance of the entomopathogenic nematode *Steinernema feltiae* through genetic selection. *Ann Appl Biol.* 129(2): 335–341.
- Gullan PJ, Cranston PS. 2005. The insects- An outline of entomology. 3rd ed. USA: Blackwell Publishing; p. 505.
- Gupta. 2004. Biological control of insects pests. In: Verma LR, Verma AK, Gautam DC, editors. Pest management in horticultural crops. New Delhi, India: Asiatic Publishers, Inc; p. 90–133.
- Gupta BD, and Avasthy PN. 1956. White grub attack on sugarcane. *IISR Newsletter.* 10:4.
- Gupta PR, Chandel RS, Chander R. 1992. Vulnerability of some soil inhabiting insects of apple orchards to indigenous entomogenous nematodes. In: Proc. Nat. Sym. Recent Advances in Integrated Pest Management; Oct 12–15; PAU Ludhiana. p. 80–81.
- Gupta RBL. 2001. Fungal pathogens in the management of white grubs and other soil dwelling pests. In: Sharma G, Mathur YS, Gupta RBL, editors. Indian Phytophagous Scarabs and Their Management. Jodhpur, Rajasthan: Agrobios India; p. 112–130.
- Gupta RBL. 2011. Insect pathogenic microbes, their production and utilization in pest management. In: Bhardwaj SC, Saxena RC, Swaminathan R, editors. Plant Protection: New horizons. Udaipur, Rajasthan: Agrawal Offset Printer Pvt Ltd; p. 61–65.
- Hajek AE, St Leger RJ. 1994. Interaction between fungal pathogens and insect hosts. *Annu Rev Entomol.* 39: 293–322.
- Hanula JL, Andreadis TG, Blackwell M. 1991. *Entoderma colletosporium* gen. and sp nov., a unique cuticular fungus infecting Japanese beetle *Popillia japonica*. *J Invertebr Pathol.* 58:327–334.
- Hasan W, Singh CP, Askary TH. 2009. Entomopathogenic nematodes- as a bio control agent for insect pests of various crops. *Indian Farming Digest.* 42: 15–18.
- Hatting J, Stock SP, Hazir S. 2009. Diversity and distribution of entomopathogenic nematodes (Steinernematidae, Heterorhabditidae) in South Africa. *J Invertebr Pathol.* 102:120–128.
- Hoy JM. 1955. The use of bacteria and nematodes to control insects. *N. 2. Sci Rev.* 13:56–58.
- Hurpin B, Robert PH. 1977. Comparison of the activity of certain pathogens of the cockchafer *Melolontha melolontha* in plots of natural meadowland. *J Invertebr Pathol.* 19:291–298.
- Hussaini SS, Nagesh M, Shakeela V. 2005. Survival of infective juveniles of entomopathogenic nematodes under storage and their infectivity against *Galleria mellonella* and *Spodoptera litura*. *Indian J Plant Prot.* 33(1):68–71.
- Ishibashi N. 1993. Integrated control of insect pests by *Steinernema carpocapsae*. In: Bedding R, Akhurst R, Kaya HK, editors. Nematodes and biological control of insects, East Melbourne, Australia: CSIRO; p. 105–113.
- Jackson TA, Wouts WM. 1987. Delayed action of an entomophagous nematode *Heterorhabditis* sp (V16) for grass grub control. In: Proc 40th New Zeal weed and pest control conference; p. 33–35.
- Jongelleen FJJ, Soesanto, Moekidjo A. 1979. Studies on pathogen of two species of Scarabaeidae from Indonesia. *Z Ang Ent.* 87:412–417.
- Kain WM, Bedding RA, Vander MCJ. 1982. Preliminary evaluation of the parasitic nematodes for grass grub (*Costelytra zealandica* white) control in Hawke's Bay of New Zealand. *New Zeal J Exp Agric.* 10:447–450.
- Kalia M. 2013. Characterization and evaluation of entomopathogenic fungi associated with white grubs in Himachal Pradesh. PhD Thesis, Department of Entomology, CSK Himachal Pradesh Krishi Vishwavidyalaya, Palampur, India; p 138.
- Kaya HK, Gaugler R. 1993. Entomopathogenic nematodes. *Annu Rev Entomol.* 38:181–206.
- Kaya HK, Klein MG, Burlando TM. 1993. Impact of *Bacillus popilliae*, *Rickettsiella popilliae* and entomopathogenic nematodes on a population of the Scarabaeids, *Cyclocephala hirta*. *Biocont Sci Technol.* 3: 443–453.
- Kaya HK. 1985. Entomogenous nematodes for insect control in IPM systems. In: Hoy MA, Herzog DC, editors. Biological control in Agricultural Integrated Pest Management Systems. Cambridge, MA: Academic Press, Inc; p. 283–302.
- Keller S, Schweizer C, Keller E, Brener H. 1997. Control of white grubs (*Melolontha melolontha*) by treating adults with fungus of *Beauveria brongniartii*. *Biocont Sci Technol.* 7:105–116.
- Keller S. 1983. Die mikrobiologische Bekämpfung des Maikafers (*Melolontha melolontha* L.) mit dem Pilz. *Beauveria brongniartii* Mitt. Schweiz Landwirt Schaft. 31:61–64.
- Kepenckci I. 2014. Entomopathogenic nematodes (Steinernematidae, Heterorhabditidae: Rhabditida) of Turkey. *Pakistan J Nematol.* 32:59–65.
- King DS, Humber RA. 1981. Identification of the Entomophthorales. In: Burges HD, editor. Microbial

- Control of Pests and Plant Diseases 1970–1980. London: Academic Press; p. 107–127.
- Klein MG. 1986. *Bacillus popilliae*-problems and prospects. In: Sampson RA, Vlcek JM, Peters D, editors. Fundamental and Applied Aspects of Invertebrate Pathology. Wageningen, The Netherlands. ICIP; p. 534–537.
- Klein MG, Kaya HK. 1995. *Bacillus* and *Serratia* species for scarab control. Mem Inst Oswaldo Cruz, Rio de Janeiro, 90(1):87–95.
- Knodel JJ, Beauzay, PB, Charles E. 2012. Integrated Pest Management of Japanese beetle in North Dakota, E 1631. Fargo, North Dakota: NDSU Extension Service North Dakota State University.
- Koppenhofer AM, Grewal PS, Kaya HK. 2000. Synergism of Imidachloprid and entomopathogenic nematodes against white grubs: the mechanism. Entomol Exp Appl. 94:283–294.
- Koppenhofer AM, Kaya HK. 1997. Additive and synergistic interaction between entomopathogenic nematodes and *Bacillus thuringiensis* for scarab grub control. Biol Cont. 8:131–137.
- Kulye MS, Pokharkar DS. 2009. Evaluation of two species of entomopathogenic fungi against white grub, *Holotrichia consanguinea* (Blan.) infesting potato in Maharashtra, India. J Biol Cont. 23(1):1–4.
- Kumawat KC. 2001. Evaluation of some insecticides against field termites in wheat. Ann Pl Protec Sci. 9: 51–53.
- Lee DW, Choo HY, Shin OJ, Yun JS, Kim YS. 2002. Damage of perennial ryegrass, *Lolium perenne* by chestnut brown chafer, *Adoretus tenuimaculatus* (Coleoptera: Scarabaeidae) and biological control with Korean isolate of entomopathogenic nematodes. Korean J Appl Entomol. 41:217–223.
- Lello ER, Patel MN, Mathews GA, Wright DJ. 1996. Application technology for entomopathogenic nematodes against foliar pests. Crop Prot. 15:567–575.
- Li LZ, Cui YS, Yan J, Zhou XS, Guo ZH, Yang HP and Jiang ZL. 1992. Control of *Holotrichia diomphalia* by *Beauveria* spp and *Metarhizium anisopliae*. Collection of achievements on the technique cooperation project of PR China and FR Germany; p. 132–135.
- Lozano-Gutierrez J., Espana-Luna MP. 2008. Pathogenicity of *Beauveria bassiana* (Deuteromycotina: Hypomycetes) against the White Grub *Laniifera Cyclades* (Lepidoptera: Pyralidae) under Field and Greenhouse Conditions. Florida Entomol. 91(4): 664–668.
- Mamiya Y. 1988. *Steinernema kushidai* n. sp (Nematoda: Steinernematidae) associated with Scarabaeid beetle larvae from Shizuoka. Japan Appl Entomol Zool. 23: 313–320.
- Manisegaran S, Lakshmi SM, Srimohanpriya V. 2011. Field Evaluation of *Metarhizium anisopliae* (Metschnikoff) Sorokin against *Holotrichia serrata* (Blanch) in sugarcane. J Bio Pesticides. 4(2):190–193.
- Manju K, George S, Kumar ARV, Manjula Kumari D. 2009. Distribution of the *Bacillus thuringiensis* Berliner strains in the soils of different habitats and their activity against white grubs. Karnatka J Agric Sci. 22(3-spl. Issue):628–630.
- Mannian CM, Mclane W, Klein MG, Moysenko J, Oliver JB, Cowan D. 2001. Management of early instar Japanese beetle (Coleoptera: Scarabaeidae) in field grown nursery crops. J Econ Entomol. 94:1151–1161.
- Mathur YK. 2001. Entomogenous bacteria in the management of soil dwelling insect pests: Present scenario and Future Perspectives. In: Sharma G, Mathur YS, Gupta RBL, editors. Indian phytophagous scarabs and their management: Present status and future strategy; Agrobios India; p. 131–141.
- Mathur YS, Bareth SS, Shinde VKR, Yadva CPS. 1995. *Heterorhabditis* nematodes as parasites of phytophagous scarabs. National Seminar on Integrated Pest Management in Agriculture Dec 29–30, Nagpur, Souvenir, p 79 (Akola, India, Directorate of Research).
- Matsuki N, Asano SI, Bando H, Lizuka T. 1997. New isolates of *Bacillus popilliae* isolated from milky disease larvae of *Popillia japonica*, *Anomala rufocuprea* and *A. dimidiata* (Coleoptera: Scarabaeidae). Appl Entomol Zool. 32:583–588.
- McCoy CW, Samson RA, Boucias DG. 1988. Entomogenous fungi. In: Ignoffo CM, Mandevia NB, editors. Handbook of Natural Pesticides, Microbial Insecticides, Part A Entomogenous protozoa and fungi, Boca Raton, FL: CRC Press; p. 151–236.
- Mehta PK, Chandel RS, Mathur YS. 2010. Status of white grubs in North–Western Himalaya. J Insect Sci. 23:1–14.
- Milner RJ, Pierrard G, Baw A, Chit Myo. 1992. The potential of *Metarhizium anisopliae* for the control of scarab pests of groundnuts in Myanmar (Burma). In: Jackson TA, Glare TR, editors. Use of pathogens in scarab pest management, Andover, MA: Intercept Ltd; p. 277–280.
- Misra SS, Chandel RS. 2003. Potato white grubs in India. Technical Bull No. 60. India: Central Potato Research Institute Shimla; p. 47.
- Misra SS, Chandla VK. 1989. White grubs infesting potato and their management. J Indian Potato Assoc. 16: 29–33.
- Mohi-ud din S, Zaki FA, Munshi NA, Jan Arif, Sultan P. 2006. Evaluation of some entomopathogenic fungal isolates from Kashmir for the biocontrol of white grubs infesting turf grass in golf course. J Biol Cont. 20: 45–50.
- Neilson DG, Cowles RS. 1998. Preventing white grub infestation in container grown nursery stock. J Environ Hort. 16:202–207.
- Nirula KK, Antoney J, Menon KP. 1952. Investigations on the pests of coconut palm: the rhinoceros beetle. Indian Coconut J. 5(2):57–70.
- Nishimatsu T, Jackson JJ. 1998. Interaction of Insecticides, entomopathogenic nematodes, and larvae of the western corn rootworm (Coleoptera: Chrysomelidae). J Econ Entomol. 91:410–418.
- Ouedraogo A, Fargues J, Goettel MS, Lomer CJ. 2004. Effect of temperature on vegetative growth among isolates of *Metarhizium anisopliae* and *Metarhizium flavoviride*. Mycopathologia. 137:37–43.
- Padmanaban B, Rajan P, Daniel M. 2003. Biocontrol agents recorded from palm white grubs. Ind J Entomol. 65:434–438.
- Parasharya BM, Dodia JF, Mathew KL, Yadav DN. 1994. Natural regulation of white grubs (*Holotrichia* sp: Scarabaeidae) by birds in agroecosystem. J Biosci. 19(4):381–389.
- Pathania M. 2014. Studies on phytophagous white grubs of Himachal Pradesh. Ph.D Thesis, Department of Entomology, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, India; p. 258.

- Peters A. 1996. The natural host range of *Steinernema* and *Heterorhabditis* spp and their impact on insect populations. *Biocont Sci Technol.* 6:389–402.
- Poinar GO Jr, Jackson T, Klein M. 1987. *Heterorhabditids magidis* sp n. (Heterorhabditidae: Rhabditida), parasitic in the Japanese beetle, *Popillia japonica* (Scarabaeidae: Coleoptera) in Ohio. *Proc Helminthol Soc Wash.* 53: 53–59.
- Poinar GO Jr, Karunakar G, David H. 1992. *Heterorhabditis indicus* (Rhabditida: Nematoda) from India, Separation of *Heterorhabditis* species by infective juveniles. *Fundam Appl Nematol.* 15:467–472.
- Poinar GO Jr. 1990. Biology and taxonomy of Steinernematidae and Heterorhabditidae. In: Gaugler R, Kaya HK, editors. *Entomopathogenic nematodes in biological control.* Boca Raton, FL: CRC Press; p. 23–61.
- Potter DA, Held DW. 2002. Biology and management of Japanese beetle. *Annu Rev Entomol.* 47:175–205.
- Prasad CS, Hussain MA, Pal R, Prasad M. 2012. Virulence of nematode *Heterorhabditis indica* (Meerut strain) against lepidopteran and coleopteran pests. *Vegetos* 25(1):343–351.
- Prasad CS, Hussain MA. 2011. Entomopathogenic fungi for Sustainable Agriculture. In: Bhardwaj SC, Singh Swaroop, Bhatnagar A, editors. *Plant Protection through Eco-friendly Techniques.* New Delhi, India: Pointer Publishers; p. 264.
- Rajeswari S, Vasudeva Menon PP, Vadivelu S. 1984. Preliminary tests with DD-136 for the control of potato chafer grub, *Anomala* sp. *Indian J Nematol.* 14: 187–189.
- Ramarethinam S, Marimuthu S, Murugesan NV. 2005. Entomopathogenic fungi, *Verticillium lecanii* – An overview. *Pestology.* 24(12):9–30.
- Ranganathiah KG, Veeresh GK, Govindu HC. 1973. A new entomogenous fungus on the root grubs, *Holotrichia serrata* F. from Mysore. *Curr Sci.* 42:432–433.
- Rao GN, Vijaylakshmi U. 1959. A note on the occurrence of certain parasitic fungi on insect-pests of sugarcane. *Curr Sci.* 28:295.
- Rath AC. 1992. *Metarhizium anisopliae* for control of the Tasmanian pasture scarab, *Adoryphorus couloni*. In: Jackson TA, Glare TR, editors. *Use of Pathogens in Scarab Pest Management;* Andover, MA: Intercept; p. 217–227.
- Redmond CT, Potter DA. 1995. Lack of efficiency of *in vitro* and putatively *in vitro* produced *Popillia japonica* against field population of Japanese beetle (Coleoptera: Scarabaeidae) grubs in Kentucky. *J Econ Entomol.* 88: 846–854.
- Ritcher PO. 1958. Biology of Scarabaeidae. *Annu Rev Entomol.* 3:311–334.
- Ruiz-Vega J, Aquino-Bolanos T. 2002. Recursos para el control integ- rado de gallina ciega Phyllophaga spp en maiz de temporal. In: Baez-Sanudo R, Juvera-Bracamontes JJ, editors. *Memorias del XXV Cong- reso Nacional de Control Biologico.* Texcoco, Mexico: Sociedad mexicana de Control Biologico; p. 211–213.
- Samson RA. 1981. Identification: Entomopathogenic Deuteromycetes. In: Burges HD, editor. *Microbial control of pests and plant diseases 1970–1980;* New York, NY; Academic press, London; p. 93–106.
- Sharma A, Thakur DR, Chandla VK. 2009. Use of *Steinernema* and *Heterorhabditis* nematodes for the control of white grubs, *Brahmina coriacea* (Hope) (Coleoptera: Scarabaeidae) in potato crop. *Potato J.* 36(3–4):160–165.
- Sharma A, Chandla VK, Thakur DR. 2012. Biodiversity and pathogenicity potential of mycoflora associated with *Brahmina coriacea* in potato fields of North Western Indian hills. *J Entomol.* 9(6):319–331.
- Sharma A, Thakur DR, Kanwar S, Chandla VK. 2013. Diversity of entomopathogenic bacteria associated with the white grub, *Brahmina coriacea* (Hope). *J Pest Sci.* 86:261–273.
- Sharma PM, Sharma AN, Hussaini SS. 2011. Entomopathogenic nematodes, a potential microbial biopesticide: mass production and commercialization status- a mini review. *Arch Phytopathol Plant Prot.* 44(9):855–870.
- Sharpe ES, Detroy RW. 1979. Fat body depletion, a debilitating result of milky disease in Japanese beetle larvae. *J Invertebr Pathol.* 34:92–94.
- Shinde VKR, Mathur YS, Bareth SS. 1995. Evaluation of Steinernematodes against phytophagous scarabs. V National Symposium on Soil Biology and Ecology, Santiniketan. Nov 2-4, SA-4.
- Shinde VKR, Sharma SK. 1971. Bacteria pathogenic to *Lachnosterna consanguinea* Blanch. (Coleoptera: Scarabaeidae). *Madras Agric J.* 58:114–116.
- Singh M, Gupta PR. 2006. Occurrence of entomopathogenic nematodes in H.P., India and their pathogenicity against various insect species. *Pest Manage Econ Zool.* 14(1&2):179–189.
- Singh SP. 1978. Occurrence of *Metarhizium anisopliae* (Met.) Sorokin on white grubs in potato fields. *Curr Res.* 7(10):173.
- Singh SP. 1991. Bio control of Crop Pests. *Indian Farming.* 41(5):18–23.
- Srikanth J, Easwaramoorthy S, Santhalakshmi G. 2010. Field efficacy and persistence of *Beauveria brongniartii* (Sacc.) Petch applied against *Holotrichia serrata* F. (Coleoptera: Scarabaeidae) infecting sugarcane in southern India. *Sugar Cane Int.* 28(4):151–156.
- Stebbing EP. 1902. Departmental notes on insects that affects forestry. 1:1–149.
- SubbaRao A, Veeresh GK. 1988. Virulence of various strains of *Bacillus popilliae* to third instar grubs of *Holotrichia serrata* F. *J Soil Biol Ecol.* 8:95–97.
- Sushil SN, Mohan M, Selvakumar G, Bhatt JC, Gupta HS. 2008. Isolation and toxicity evaluation of bacterial entomopathogens against phytophagous white grubs (Coleoptera: Scarabaeidae) in Indian Himalayan hills. *Int J Pest Manage.* 54(4):301–307.
- Suzuki N, Hori H, Ogiwara K, Asano S, Sato R. 1992. Insecticidal spectrums of a novel isolate of *Bacillus thuringiensis serover japonensis*. *Biol Cont.* 2:138–142.
- Thurston GS, Kaya HK, Gaugler R. 1994. Characterizing the enhanced susceptibility of milky disease-infected scarabaeid grubs to entomopathogenic nematodes. *Biol Cont.* 4(1):67–73.
- Toth T. 2006. Collection of entomopathogenic nematodes for the biological control of insect pests. *J Fruit Ornamental Pl Res.* 14(Suppl. 3):225–230.
- Tulloch M. 1976. The genus *Metarhizium*. *T Brit Mycol Soc.* 66:407–411.
- Vanderberg JD, Jackson MA, Lacey LR. 1998. Relative efficacy of blastospores and aerial conidia of *Paecilomyces fumosoroseus* against the Russian wheat aphid. *J Invertebr Pathol.* 72:181–183.
- Veeresh GK, Kumar ARV, Ali ATM. 1991. Biogeography of pest species of whitegrubs of Karnataka. In: Veeresh

- GK, Rajagopal D, Vikraktamath CA, editors. Advances in management and conservation of soil fauna; Bangalore, Oxford and IBP Publishing Company Pvt. Ltd; p. 191–198.
- Veeresh GK 1988. White grubs. In: Veeresh GK, Rajgopal D, editors. Applied Soil Biology and Ecology. 2nd ed., New Delhi: IBH; p. 243–282.
- Veeresh GK, Vijayendra M, Vijaymohan M, Rajann C. 1982. Bio ecology and management of Areca white grubs, *Leucopholis* spp (Coleoptera: Scarabaeidae: Melolonthinae). J Soil Biol Ecol. 2:78–86.
- Veeresh GK. 1977. Studies on root grubs in Karnatka, UAS (Bangalore), Monograph series no. 2, p. 87.
- Vyas RV, Parasharya BM, Yadav DN. 1988. Dispersal of milky disease organism *Bacillus popilliae* var *holotrichae* of white grub (*Holotrichia consanguinea*) through birds. Indian J Agric Sci. 58:243–244.
- Wang Y, Campbell JF, Gaugler R. 1995. Infection of entomopathogenic nematodes *Steinernema glaseri* and *Heterorhabditis bacteriophora* against *Popillia japonica* (Coleoptera: Scarabaeidae) larvae. J Invertebr Pathol. 66: 178–184.
- Wouts WM, Mracek S, Gerdin S, Bedding RA. 1982. *Neoplectana Steiner*, 1929 a junior synonym of *Steinernema Travassos*, 1927 (Nematoda: Rhabditida). Syst Parasitol. 4:147–154.
- Wright RJ, Villani MG, Agndelo-Silva F. 1988. Steinernematid and Heterorhabditid nematodes for control of larval European chafers and Japanese beetles (Coleoptera: Scarabaeidae) in potted yew. J Econ Entomol. 81:152–153.
- Wu S, Youngman RR, Kok LT, Laub CA, Pfeiffer DG. 2014. Interaction between entomopathogenic nematodes and entomopathogenic fungi applied to third instar southern masked chafer white grubs, *Cyclocephala lurida* (Coleoptera: Scarabaeidae), under laboratory and greenhouse conditions. Biol Cont. 76:65–73.
- Yadava CPS, Sharma GK. 1995. Indian White grubs and Their Management. Technical Bull, Indian Council of Agricultural Research, New Delhi, No. 2, p. 26.
- Yadava CPS, Vijayvergia JN. 2000. Integrated management of white grubs in different cropping systems. In: Upadhayay RK, Mukerji KG, Dubey OP, editors. IPM systems in Agriculture; New Delhi, India: Aditya Books Pvt. Ltd; p. 105–122.
- Yamanaka S, Takeuchi K, Tanabe H. 1995. Host finding ability, vertical migration and infectivity of *Steinernema glaseri*, *S. anomali* and *S. kushidai* (Nematoda: Steinernematidae). Jpn J Nematol. 25:24–32.
- Young EC. 1974. The epizootiology of two pathogens of the coconut palm rhinoceros beetle. J Invertebr Pathol. 24:82–92.
- Yu H, Zhang J, Huang D, Gao JG, Song F. 2006. Characterization of *Bacillus thuringiensis* strain Bt 185 toxic to Asian Cockchafer *Holotrichia parallela*. Curr Microbiol. 53:13–17.
- Yubak Dhoj GC, Keller S, Nagel P. 2004. Microbial control of white grubs with entomopathogenic fungi and its value in Integrated Pest Management in Nepal. Tribhuvan Uni J. 24:37–47.
- Zimmerman G. 1993. The entomopathogenic fungus, *Metarhizium anisopliae* and its potential as a bio control agent. Pestic Sci. 37:375–379.