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The Ecology and Control of Potato Whitegrubs of India

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Abstract Whitegrubs are the most destructive and troublesome soil insects, impeding potato production especially in hilly states of India. In hills, the potatoes are grown during the summer season as a rain-fed crop under long-day conditions on sloppy lands with light and loose-textured soils. There are nearly 20 species of whitegrubs which attack potato in different parts of India. The most widely distributed and destructive species in India are *Brahmina coriacea*, *Holotrichia longipennis*, *Anomala dimidiata*, *Melolontha indica*, *Lepidiota mansueta* and *Holotrichia serrata. H. serrata* is found throughout Karnataka, Maharashtra, Tamil Nadu, Andhra Pradesh, Bihar and Uttar Pradesh, whereas *B. coriacea* and *H. longipennis* are restricted to the northern parts of India. The economic importance of chaffers is primarily due to feeding activity of the third instar grubs. The infected tubers have scooped out holes or half-eaten tubers which are rendered unfit for marketing. The damage to potato tubers has been reported to vary from 8.5 to 75.0% especially in hilly regions of the country. In India, the biology of *B. coriacea*, *H. longipennis*, *A. dimidiata*, *Anomala lineatopennis* and *H. serrata* has been studied and all species complete a life cycle in 1 year. Some species like *M. indica* and *L. mansueta* are expected to require 2–3 years to complete their development. The whitegrubs are polyphagous, and no single method of control provides permanent solution for the whitegrub problem. Hand collection of adults at the time of emergence has been practised as a measure of control. The beetles can be conveniently killed by spraying the host trees with some potent contact insecticides

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when consistent beetle emergence is there. Soil application of chlorpyriphos 20EC at 2.5 kg a.i./ha and phorate 10G at 3.0 kg a.i./ha has been reported effective against whitegrubs. Applying the preventive insecticide around the third week in June will have the insecticide in place when eggs begin to hatch. The cultural practices to be followed in the integrated management of whitegrubs include repeated ploughing, hoeing and forking to expose the grubs and fall/spring ploughing to expose the pupae and hibernating adults.

Keywords *Brahmina coriacea* · *Holotrichia longipennis* · *Holotrichia serrata* · *Lepidiota mansueta* · Potato · Whitegrubs

Introduction

The superfamily Scarabaeoideae contains an immense number of species whose larvae live in the soil and are commonly known as 'whitegrubs' (Gardener 1935). Most of the whitegrubs are similar in shape and colour and have fleshy curved bodies with brown heads and well-developed legs which are hardly used for locomotion (Mehta et al. 2010). They can be easily distinguished from similar-looking grubs by the presence of two rows of minute hairs on the undersurface of the last segment (Khan and Ghai 1974). They live concealed and suddenly increase their population in places having enough food and least disturbance of soil.

Whitegrubs have always existed in nature, and the earliest record of damage to crops by whitegrubs in India is that of Stebbing (1902) from Punjab. More than 1000 species of whitegrubs are known from the Indian subcontinent, of which over 40 species attack a wide range of crop plants (Veeresh et al. 1991). There is no record of serious damage until the later part of the 1950s. Because of revolutionary changes in agriculture in India during the 1960s, whitegrubs attained the status of a serious pest (Yadava and Sharma 1995). The first major epidemic of whitegrubs in India was reported in sugarcane from Bihar during 1956 (Gupta and Avasthy 1956). Now, they have been included in the category of five national pests in India (Misra and Chandla 1989) and are reported from every state, causing damage to a wide variety of cultivated crops.

Due to large-scale deforestation, the beetles have moved into areas near the agricultural fields for feeding on shrubs/fruit trees etc. and have resulted in egg laying in the cultivated areas (Yadava and Sharma 1995). Adult food is the chief environmental factor affecting the beetles' behaviour and is one of the most important considerations in the distribution of both beetles and grubs (Veeresh 1978; Veeresh 1988). The abundance and distribution of the whitegrubs depend upon the species involved, the preferred host and its location in relation to emergence place (Veeresh 1988). Whitegrubs form a major group of insect-pests damaging potato, and there has been a greater emphasis to check the peril of whitegrubs in potato. In this paper, an account is given of the life history and biology of leading species of potato whitegrubs in India. Tuber damage and crop loss estimates are presented based on available literature. The factors which affect abundance and pest status of whitegrubs are discussed along with benign management strategies.

Importance of Whitegrubs in Potato Production in India

In India, potato is cultivated in almost all states under very diverse agro-climatic conditions. More than 85% of potatoes in India are grown in the Indo-Gangetic Plains of north India from October to March during winter under short-day conditions. Hilly areas account for less than 5% of production. In the plateau regions of south-eastern, central and peninsular India, which comprise about 6% of the potato-growing area, potato is mainly a rain-fed crop or is irrigated as a winter crop. In the Nilgiri and Palini hills of Tamil Nadu, the crop is grown year round under both irrigated and rain-fed conditions. Most potatoes are produced by large-scale commercial farmers (Pandey and Kang 2003).

The problem of whitegrubs is quite serious in hilly states where the potatoes are grown during the summer season as a rain-fed crop under long-day conditions (Misra and Chandel 2003). In most parts of north-western Himalaya, potato cultivation is done on sloppy lands with light and loose-textured soils and high rainfall. The potato fields are normally situated in the vicinity of fruit orchards in Himachal Pradesh, Jammu and Kashmir, Uttarakhand and other hilly parts of India. The adults of whitegrubs (chaffer beetles) prefer to feed on fruit trees during night (Chandel et al. 1997) and enter into nearby potato fields where they lay eggs in the soil during May–June (Chandel et al. 1995). These conditions are conducive for the development and multiplication of whitegrubs (Singh et al. 2002). Veeresh (1988) reported that the presence of host plants in certain localities tends to attract more beetles, and the concentration of grubs occurs around these plants. It is common to see a field having heavy concentration of whitegrubs while the immediate neighbouring fields being completely free from them. In India, 24 species of whitegrubs have been recorded to damage potato (Table 1) from the states of Himachal Pradesh, Uttarakhand, Jammu and Kashmir, Tamil Nadu, Karnataka and NE India representing seven smaller states (Misra and Chandel 2003). The most widespread and destructive species are *Brahmina coriacea*, *Brahmina flavosericea*, *Melolontha indica*, *Anomala dimidiata*, *Holotrichia longipennis*, *Holotrichia sikkimensis*, *Holotrichia seticollis*, *Phyllognathus dionysius* (Chandel et al. 2013) and *Lepidiota mansueta* (Bhatacharyya et al. 2011). The tuber damage often exceeds 50% in endemic areas (Chandel and Chandla 2003).

Whitegrubs were reported earlier on forest plants (Beeson 1941); however, no record exists of any whitegrub damage to potato tubers until the 1960s. The first record of whitegrubs causing damage to potato in India is from Himachal Pradesh by Sharma and Bhalla (1964). They mentioned two species viz., *B. coriacea* (Hope) and *Lachnosterna* (=*Holotrichia*) *longipennis* Bl. causing damage to several crops including potato in Himachal Pradesh. The whitegrubs appeared in epidemic form in potato in the Shimla hills of Himachal Pradesh during the 1980s. The Shimla hills are highly favourable for multiplication of whitegrubs because plenty of fruit (apple orchards) and forest trees exist in the vicinity of potato fields. The adults of whitegrubs (chaffer beetles) prefer to feed on foliage of pome and stone fruits (Chandel et al. 1997). Recognizing the potential impact of *B. coriacea* on potato production, the then Director of Agriculture, Himachal Pradesh, got the attention of State Agriculture University in 1984 towards the increasing problem of whitegrubs in potato (Misra and Chandel 2003). According to an unpublished report prepared by scientists of Himachal Pradesh Agricultural University and CPRI, Shimla, there was up to 85% tuber damage to potato crops at the Potato Development Station, Shillaroo, located in Shimla hills of Himachal Pradesh.

Table 1 Different species of whitegrubs damaging potato in India

Taxon	Place of occurrence	Reference(s)
(A) Subfamily: Melolonthinae		
1. *Brahmina coriacea* (Hope)	Himachal Pradesh	Sharma and Bhalla (1964)
2. *Brahmina crinicollis* Burmeister	Himachal Pradesh	Bhalla and Pawar (1977)
3. *Brahmina flavosericea* Brenske	Himachal Pradesh	Mehta et al. (2008)
4. *Melolontha indica* Blanchard	Himachal Pradesh	Bhalla and Pawar (1977)
5. *Holotrichia longipennis* Blanchard	Himachal Pradesh, Uttarakhand	Misra and Chandla (1989); Rai and Joshi (1988)
6. *Holotrichia sikkimensis* Brenske	Himachal Pradesh	Pathania et al. (2012)
7. *Holotrichia repetita* Sharp	Karnataka	Veeresh et al. (1991)
8. *Holotrichia rustica* Burmeister	Karnataka	Veeresh et al. (1991)
9. *Holotrichia serrata* (Fabricius)	Karnataka	Veeresh et al. (1991); Butani and Jotwani (1984)
10. *Holotrichia conferta* Sharp	South India	Butani and Jotwani (1984)
11. *Holotrichia excisa* Moser	Tamil Nadu	Regupathy et al. (1997)
12. *Holotrichia nototiocollis*	Tamil Nadu	Regupathy et al. (1997)
13. *Holotrichia* sp.	North-eastern India	Anonymous (1989)
14. *Holotrichia seticollis* Moser	Himachal Pradesh, Uttarakhand	Chandel et al. (1997); Musthak Ali (2001)
15. *Lepidiota mansueta*	Assam	Bhatacharyya et al. (2011)
(B) Subfamily: Rutelinae		
16. *Anomala dimidiata* Hope	Himachal Pradesh	Misra and Chandla (1989)
17. *Anomala polita* (Blanchard)	Himachal Pradesh	Misra and Chandla (1989)
18. *Anomala rugosa* Arrow	Himachal Pradesh	Misra and Chandla (1989)
19. *Anomala rufiventris* Redtenbacher	Uttar Pradesh	Rai and Joshi (1988)
20. *Anomala* sp.	Karnataka	Lingappa and Giraddi (1995)
21. *Anomala communis* Brenske	Tamil Nadu	Regupathy et al. (1997)
22. *Anomala nathani* Frey	Tamil Nadu	Regupathy et al. (1997)
(C) Subfamily: Dynastinae		
23. *Phyllognathus dionysius* Fabricius	Himachal Pradesh	Misra and Chandla (1989); Pathania et al. (2012)
(D) Subfamily: Cetoniinae		
24. *Chiloloba acuta* (Weidemann)	Karnataka	Puttaswamy and Visweswaragowda (1977)

Nature of Injury of Whitegrubs in Potato

All whitegrubs are polyphagous. They can feed on any root or underground stem (Veeresh 1988). Being polyphagous, the whitegrubs feed on roots of a wide variety of cultivated plants. In general, underground parts of all plants are subjected to grub feeding and show different types of damage (Yadava and Vijayvergia 2000). Initially, young grubs feed on mother tubers, roots of developing potato plants. But, after tuber formation, the older second and third instar grubs feed on the tubers (Mehta et al.

2010). The second instar grubs produce smaller holes in tubers and can go unnoticed by consumers; however, the third instar grubs (Fig. 1) make large, shallow, circular or irregular cavities into potatoes. Such infested tubers with scooped out holes or half-eaten tubers (Fig. 2) are rendered unfit for marketing (Chandel et al. 2003). It is of common occurrence to see heaps of potatoes, separated from marketable lots, damaged due to grubs (Fig. 3) in the upper Shimla hills. Singh and Verma (1982) reported that in some worst-affected areas located in dry temperate zones, even the seed tubers are eaten away before they give rise to plants. The full-fed grubs of *B. coriacea*, *Holotrichia* spp. and *Anomala* spp. are smaller in size (ca. 30–40 mm), and they make several cavities on the tubers (Mehta et al. 2008). However, in case of larger whitegrubs like *Melolontha* spp., the larvae are about 70 mm in body length, and they make a single large hole in the tubers which are filled with soil (Pathania et al. 2012). As such, potato plants are completely tolerant to whitegrub attack, and the potato plants are not liable to be killed in the presence of a large population of whitegrubs. Chandel et al. (2003) reported up to 20 grubs of *B. coriacea* attacking a single potato plant in Shimla hills, and the potato plants continue to grow normally even in such heavily infested fields, without manifestation of injury on aerial parts. However, Bhatacharyya et al. (2011) reported that the entire potato plant dries up due to feeding of *L. mansueta* grubs on fibrous roots in Assam. In Karnataka, *Anomala bengalensis* and *Anomala* sp. have been found cutting roots of potato plant in a 40–45-day-old crop in the Hassan area damaging about 6% of plants (Trivedi 1987). Puttaswamy and Visweswaragowda (1977) reported that *Chiloloba acuta* damages young shoots of potato in Karnataka. Contrary to their harmful effects, the whitegrub-infested tubers are preferred for seed by farmers. Perhaps, infested tubers produce better sprouts resulting into good crop stand.

Economic Importance of Whitegrubs in Potato

The economic importance of chaffers is primarily due to feeding activity of the third instar grubs. There exists a highly positive correlation (r=0.948) between the population of the third instar grubs and tuber damage (Anonymous 2004). Chandel et al. (2008) reported that with unit increase in population of the third instar grubs of *B. coriacea*, the tuber damage will increase by 12.17%. There is lesser problem of whitegrubs in Indo-Gangetic Plains of India, because in plains, potato is grown during short-day conditions of winter (Chandel et al. 2013). Most species of whitegrubs construct earthen cells during winter, and the grubs

Fig. 1 Third instar grubs of *B. coriacea*

Fig. 2 Half-eaten whitegrub-damaged tubers

remain inactive without any feeding leading to complete asynchrony between pest biology and phenology of potato crop (Yadava and Sharma 1995). Whitegrubs attract greater attention in the hilly states of India, where they have long been present. In Himachal Pradesh, Sharma and Bhalla (1964) recorded serious damage by grubs of *B. coriacea* and *H. longipennis* in several field crops including potato. Rajendran and Chandla (1986) recorded high incidence of *B. coriacea*, *L. longipennis* and *M. indica* in certain villages of Shimla, Mandi and Kullu districts of Himachal Pradesh. Veeresh (1988) observed that 10–20% of the tubers in the harvested potatoes in upper Shimla hills of Himachal Pradesh are half-eaten tubers due to damage of whitegrubs. Chandla et al. (1988) reported that potatoes are being severely attacked by *Lachnosterna* (=*Brahmina*) *coriacea* in Shimla hills of Himachal Pradesh and found 56.3% tuber damage on number basis.

Whitegrubs are responsible for causing 40 to 90% losses in yield in endemic areas situated in higher hills of Uttar Pradesh, Himachal Pradesh, Jammu and Kashmir and north-eastern states (Misra 2000). Misra (2003) conducted field experiments on management of whitegrubs in potato fields of Shimla hills and reported up to 64.58% damaged tubers at the Potato Development Station, Shillaroo, in untreated fields. Chandel et al. (2005) observed 34.35% infestation of potato tubers due to grubs of *B. coriacea* at Fagu in the Shimla district of Himachal Pradesh. There was 42.10 and 42.16% tuber damage on number and weight basis at the Potato Development Station, Shillaroo, in the Shimla district during 2009. The corresponding tuber damage at the Potato Development Station, Kheradhar, in the Sirmaur district has been recorded to be

Fig. 3 Separated lot of whitegrub-infested tubers in Shimla hills of HP

15.08 and 15.83%, respectively (Anonymous 2010). Bhatacharyya et al. (2011) reported 25.0–48.0% yield losses due to attack of *L. mansueta* in the Jorhat district of Assam. In other areas of Assam, where *Anomala* sp., *Adoretus* sp. and *Apogonia* sp. attack potato, 10–20% tuber infestation is common. There are reports of about 25–30% tuber damage from the Twang area of Arunachal Pradesh (Chand 2010), and the predominant species in this area is *L. mansueta*. In Meghalaya, *Holotrichia* spp. are inflicting tuber damage to the tune of 10.5–75% (Misra 2000). Trivedi (1987) found up to six grubs per plant during the monsoon season in Karnataka, and the plant damage was about 6% in 40–45-day crops. In the Kashmir region of Jammu and Kashmir, Zaki et al. (2007) reported 13.3% tuber infestation at the Potato Development Station, Gulmarg.

Life History and Distribution of Potato Whitegrubs in India

Most species of whitegrubs complete their life cycle in 1 year. Some species like *M. indica* and *L. mansueta* are expected to require 2–3 years to complete their development. In species with a 2-year life cycle, the larvae seldom cause damage in the first year; it is during the second year that most damage is caused to plants by the larvae. All scarabaeids undergo three larval stages and spend more than half of their lifetime as larva (Ritcher 1958); as such, it is the larval stage which is encountered more often. Amongst Indian whitegrubs, the biology of *B. coriacea*, *H. longipennis*, *Holotrichia serrata*, *A. dimidiata* and *Anomala lineatopennis* has been studied by various workers and all species are univoltine. The general development cycle of whitegrubs vis-à-vis potato crop in hilly states of India is depicted in Fig. 4. In India, infestation of whitegrubs is widespread in the states of Himachal Pradesh, Uttar

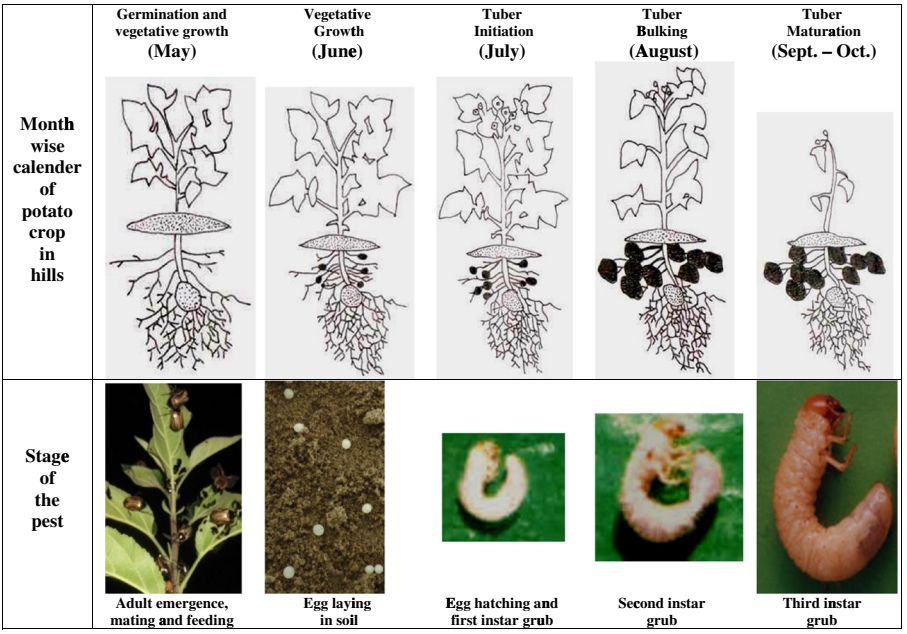

Fig. 4 Generalized development cycle of whitegrubs in relation to stages of potato crop in hilly states of India

Pradesh, Jammu and Kashmir, Tamil Nadu, Karnataka and north-eastern states (Fig. 5). More damage occurs in north-western hills and north-eastern hills as compared to southern parts of India.

Chandel et al. (1995) studied the biology of *B. coriacea* in mid-hills of Himachal Pradesh and reported that eggs hatch in 9–12 days during April–July. Development of the first and second instars requires 14.4 and 20.0 days, respectively. Most of the grubs attain the third instar by September and occupy 37.2 days. Fully fed grubs construct earthen cells and remain in earthen cells for 176–241 days. Chandel et al. (2008) reported that almost all grubs moult to the third instar by the end of September, and the third instar

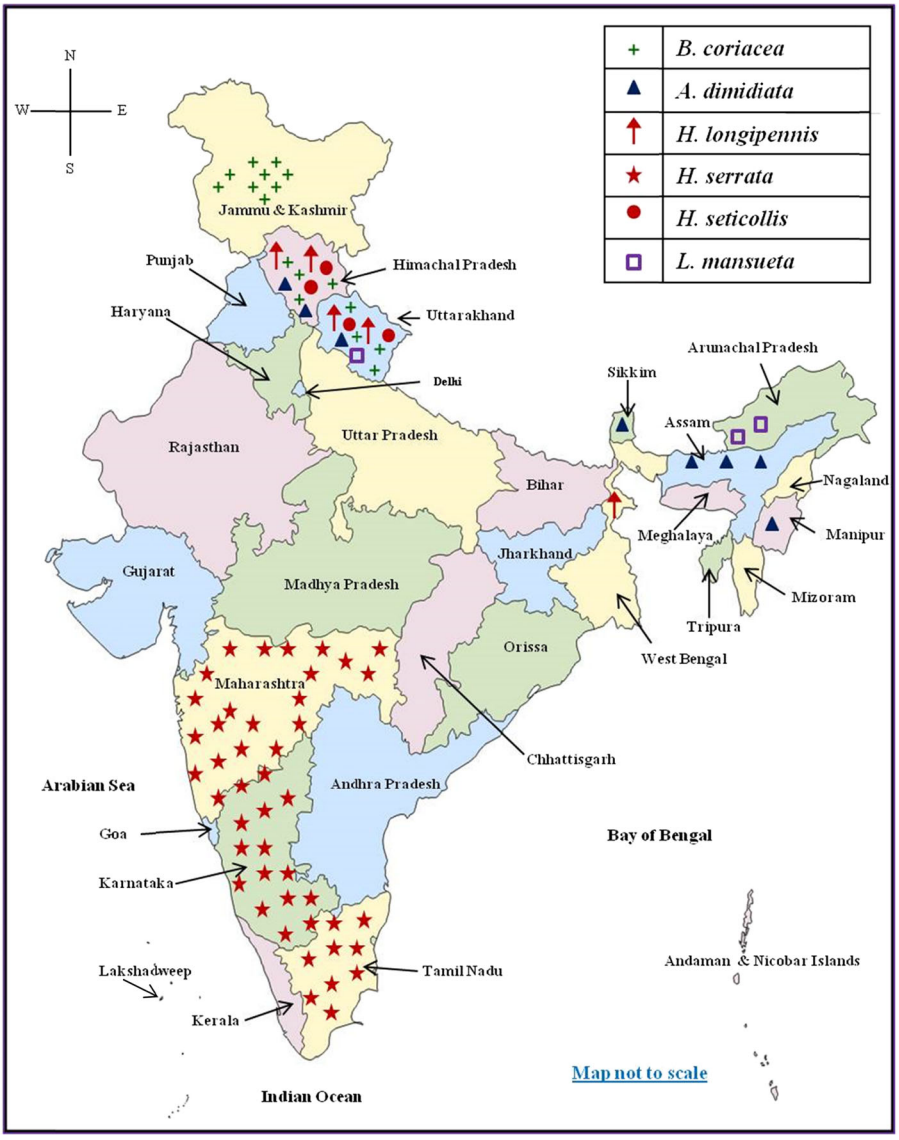

Fig. 5 Distribution map of predominant species of whitegrubs in potato crop in India

grubs are responsible for nearly 90% tuber damage in potato fields. Formation of pupae begins in April (Chandel et al. 2003), and pupal period ranges from 19 to 24 days (Chandel et al. 1995). In higher hills, the life cycle is prolonged due to harsh climate conditions. During winter, even when the fields remain covered with snow, the whitegrubs are present in the upper soil layer inside the earthen cells (Chandel et al. 2003). In north-western Himalaya, adult emergence begins in the third week of May, and peak population occurs between 15 and 20 June. Generally, no adults of *B. coriacea* are evident on flight trees beyond the third week of July (Chandel et al. 2003).

H. longipennis causes severe damage to potato in Uttarakhand (Mehta et al. 2010). The beetle emergence takes place during May–September, and the peak population occurs during June–July (Gupta et al. 1977; Mehta et al. 2010). In the Garhwal region of Uttarakhand, this species constitutes 55.8% of the total beetle population (Sushil et al. 2006). In Himachal Pradesh, *H. longipennis* accounts for nearly 10% of beetle population (Mehta et al. 2010). The biology of *H. longipennis* has been studied in Uttarakhand (Haq 1962; Shah and Shah 1990; Mishra and Singh 1993). The female beetles lay eggs in June–July (Mishra and Singh 1993), and the incubation period varies from 12 to 15 days. The first and second instar grubs occupy 41.8 and 45.6 days, respectively (Mishra 2001b). The third instar grubs occupy 216–228 days, and the fully fed third instar grubs move downwards for overwintering. Haq (1962) reported that the third instar grubs of *H. longipennis* are present at a depth of 2–3 in. up to the middle of November, and then they migrate deep into the soil up to a maximum of 10 in. and remain there till the end of February. Total larval period varies from 294 to 323 days. Pupae are formed in April and adult emergence starts by the end of May (Mishra 2001b).

A. lineatopennis is distributed in Himachal Pradesh and Uttarakhand causing damage to potato (Musthak Ali 2001). In Uttarakhand, *A. lineatopennis* completed a generation in about 320 days. Eggs hatch in 7–11 days, and larval period varies from 276 to 313 days (Mishra et al. 1998). The duration of the third instar grubs ranged from 202 to 223 days, and overwriting takes place deep into the soil in hard-earthen cells. The hibernating grubs become active with the rise in temperature, and pupa are formed in April (Mishra 2001a). Adults have been recorded to feed on apple, peach and apricot (Musthak Ali 2001).

In India, *A. dimidiata* is distributed in Himachal Pradesh, Uttarakhand, Haryana, Punjab, West Bengal, Sikkim, Assam, Meghalaya and Manipur (Chandra and Uniyal 2007). The adults are highly phototactic and get attracted to light in large numbers. *A. dimidiata* constitutes 27.6% of total beetle population in Uttarakhand (Sushil et al. 2006), whereas in Himachal Pradesh, its relative proportion is about 10% (Chandel et al. 1997). The biology of *A. dimidiata* has been studied in Uttarakhand by Mishra (2001a). The beetles of *A. dimidiata* emerge from the soil in the beginning of June, and adults feed on apple, walnut, plum, apricot, peach, *uttish*, tun, poplar, bhimal, hisalu and gulbahar (Musthak Ali 2001). Sushil et al. (2006) reported that walnut, wildrose and *uttish* are the most preferred hosts of *A. dimidiata* beetles. The peak emergence of beetles occurs in the first fortnight of July; however, emergence continues till the beginning of September (Garg and Verma 1993). Females lay eggs deep in the soil, and the incubation period varies from 12 to 21 days. The duration of the instars is about 15 and 38 days for the first two stages and 256 days for the third instar overwintering grubs (Mishra 2001b). Maximum grub population and damage are from July to September (Yadava and Sharma 1995).

P. dionysius is distributed in Himachal Pradesh, Uttar Pradesh, Haryana, Sikkim West Bengal, Maharashtra, Tamil Nadu, Orissa and Karnataka (Chandra and Uniyal 2007). In Himachal Pradesh, adult emergence takes place in May (Mehta et al. 2008). Adult beetles have been recorded on *Ficus* spp. (Musthak Ali 2001). The grubs of *P. dionysius* inflict damage to potato in the sub-tropical mid-hill zone of Himachal Pradesh. The adults are shining, chestnut-red beetles measuring 16–23 mm long. The eggs are laid during June and July and hatch in 5–8 days. The larvae feed during July, August and September. They then pupate, the pupal period being 8 days only. The beetles rest in the soil till May, when they become active, burrow out, fly, mate and lay eggs.

H. seticollis is an important species in the hilly tracts of Uttarakhand (Yadava and Sharma 1995). The grubs cause heavy damage to all rainy season crops including potato. Chandel et al. (1994a, b) also reported this species from Himachal Pradesh. The beetle emergence may start in the month of May after the area receives a good amount of precipitation. The emergence may vary in different localities depending on the amount of rain and may be observed till the end of August. Immediately after the emergence, adults mate on host trees like walnut. Females may lay 10–20 elongate white eggs, and the incubation period ranges from 9 to 11 days. The newly hatched grubs measure about 8.32 mm in length. The average length of the second and third instar grubs is about 17.8 and 35.5 mm, respectively. The fully fed third instars grubs transform into pupae in the beginning of October at a depth of 30–50 cm inside earthen cells. Pupal period ranges from 15 to 20 days. The adults remain in the soil until their emergence, which is triggered by pre-monsoon rains during May. The beetles are dark brown in colour and medium (ca. 15–16 mm long). There is a single generation in a year (Yadava and Sharma 1995).

L. mansueta has been observed to cause substantial damage in the Ganges basin of Uttarakhand and Uttar Pradesh. In Assam, this species has appeared as a key pest of potato in Brahmaputra basin areas (Mathur et al. 2010). Bhatacharyya et al. (2011) reported its biennial life cycle from north-eastern parts of India. Adults emerge from the soil for mating during early April to mid-May. Egg laying starts in mid-April and continues till mid-May (Bhatacharyya et al. 2013). The eggs hatch in 42–48 days. The duration of the first and second instar grubs varies from 35 to 45 days and from 55 to 63 days, respectively. The development of the third instar is prolonged for about 2 years. The third instar grubs occupy 545–563 days. The pupal period is relatively short, and adults come out of pupae in 4–5 weeks. The adults are unique in having atrophied mouth parts. Both male and female beetles are non-feeding in habit, and they come out of the ground only for mating.

H. serrata is prevalent in Karnataka, Maharashtra, Andhra Pradesh, Tamil Nadu, Kerala, south Rajasthan, the tarai belt of Uttarakhand and south Bihar (Mathur et al. 2010). The emergence in north India begins in late May, and the beetles are active until August (Majumdar and Teotia 1965). In Karnataka, the beetles start emerging from the first week of April, and the adult activity is stopped before the end of May (Veeresh 1977). The adults are attracted to neem, palas, babul, guava and grapevine. Besides potato, the grubs cause extensive damage to vegetables, pulses, oilseed, cereals, millets, tobacco, sugarcane and sorghum (Yadava and Sharma 1995). Veeresh (1977) studied the biology of *H. serrata* in Karnataka. A gravid female lays up to 40 eggs in her lifetime. Eggs hatch in 12–15 days, and the first instar larva comes out of the earthen

cell if there is sufficient moisture. Under drought, it remains inside the cell until favourable conditions occur. The first, second and third instar grubs are 10.8-, 20.0- and 47.0-mm long, respectively, and the average duration of each instar is 22.5, 35.0 and 124.5 days, respectively. The grubs become full grown in October, stop feeding, burrow deeper in the soil and construct earthen cells for pupation. The pupal stage continues for 15.5 days. Adults are 22.4-mm long and 14.0 mm in body width (Yadava and Sharma 1995).

Holotrichia repetita damages potato in Tamil Nadu and Karnataka. The adults prefer to feed on *Cinnamomum* and *Ficus* spp. *Anomala rufiventris* is found in Himachal Pradesh (Sharma and Bhalla 1964), Uttarakhand (Sushil et al. 2006), West Bengal, Manipur, Meghalya and Sikkim (Musthak Ali 2001). Adult beetles cause damage to fruits and foliage of pome and stone fruits (Sharma et al. 1971). The adults are very dark bronzy green, with the sternum and legs greenish black and the abdomen beneath deep mahogany red. The beetles are 16.0–22.0 mm (Chandra and Uniyal 2007). *Anomala polita* has been recorded as a pest of field crops and fruits in Himachal Pradesh (Bhalla and Pawar 1977) and Uttarakhand (Sushil et al. 2006). Misra and Chandla (1989) described *A. polita*-infesting potato in Himachal Pradesh.

Holotrichia excisa is distributed in Western Ghats and Nilgiri hills of Tamil Nadu. The adults feed on *Fageura zeylarica*, *Olea dioica*, *Clerodendrum viscosum*, *Solandra guttata* and *Aporosa lindleyana* (Musthak Ali 2001). Regupathy et al. (1997) reported this species causing damage to potato in Tamil Nadu. *Holotrichia rustica* is distributed in Karnataka and Madhya Pradesh (Kulkarni et al. 2009); however, potato is damaged by this species only in Karnataka (Veeresh et al. 1991). The beetles after emergence settle on the bushes of *Ziziphus jujuba*, *Ziziphus mauritiana*, *Ziziphus xylopyrus*, *Acacia leucophloea* and *A. catechu*. Lingappa and Giraddi (1995) reported *Holotrichia conferta* as an important pest of potato in Karnataka. *M. indica* is distributed in Himachal Pradesh (Mehta et al. 2008) and Tamil Nadu (Chandra and Uniyal 2007). The adults feed on rose and neem in Nilgiri hills of Tamil Nadu (Musthak Ali 2001). In Himachal Pradesh, the adult emergence takes place in July, and the beetles were observed feeding on wheat spikes (Chandel et al. 2010). The life cycle is biennial.

Management of Whitegrubs

The adults and grubs cause different types of damage; therefore, integration of mechanical with chemical control in combination with cultural practices has been found most effective in the management of whitegrubs (Singh et al. 2002). The adults are so mobile; therefore, controlling one life stage will not necessarily preclude the problems caused by the other (Misra and Chandel 2003).

Management of Beetle Population The adult beetles are usually associated with wild plants rather than crops. These beetles can be conveniently killed by spraying the host trees with some potent contact insecticides. Night surveillance should be done in the endemic areas to ensure consistent beetle emergence before spraying the host plants. Chemical control options used by the Indian farmers include spraying methyl parathion, carbaryl or monocrotophos (Chandel et al. 1994b; Chandla et al. 1988; Anonymous 2000). Dimethoate has been shown to be extremely effective against the beetles of

B. coriacea in Himachal Pradesh (Anonymous 2002). Hand collection of adults at the time of adult emergence has been practised as a measure of control and is reported from several endemic pockets. The beetles exhibit distinct preference for certain hosts in a particular locality. Adult host plant as an attractant has been successfully used while collecting adults as a measure of control (Veeresh 1977). At Fagu in the Shimla district of Himachal Pradesh, about one lakh beetles of *B. coriacea* were collected and killed in an endemic area of about 20 ha of potato fields, and the pest was brought under control in 3 years of operation (Anonymous 2004). In the Jorhat district of Assam, farmers from 10 whitegrub-endemic villages participated in mass campaign programmes organized between 2010 and 2012 against *L. mansueta* during April–May. About 42,000 beetles of *L. mansueta* were collected and destroyed during these campaigns (Bhatacharyya et al. 2011). Adult collection as a successful measure of control has to be done from the very first day of the first summer rains. Otherwise, desired results are difficult to achieve. The collection can be done by shaking the twigs of most preferred host plants after 2030 h (Mehta et al. 2010). The collected beetles can be killed in the water mixed with kerosene (Chandel and Kashyap 1997). The adults of certain species like *A. dimidiata* and *A. lineatopennis* are highly attracted to light, so light traps can be useful tool for monitoring.

Management of Whitegrubs in Potato Fields Potato whitegrubs typically are controlled by applying a soil insecticide. Long residual chlorinated insecticides like aldrin, DDT and heptachlor dusts were standards for grub control during the 1970s and 1980s (Singh 1964; Pushkarnath 1966; Rataul and Misra 1979). Most of these fast-acting, persistent insecticides were restricted or banned for agricultural usage during the 1990s in response to the environmental concerns and the food safety. These restrictions, and the relative ineffectiveness or slower activity of alternative products, have left the potato growers with few options for remedial whitegrub control in India. Trivedi and Rajagopal (1999) reported that whitegrubs in potato can be effectively managed by deep ploughing during summer months, exposing larvae and pupae to the natural predators, flooding fields for 7–10 days, effective crop rotation and using well-rotten FYM.

Chemical Control Chlorpyriphos, phorate and carbofuran are widely used for preventive control of potato whitegrubs in India. Chandla et al. (1988) reported that the grubs of *B. coriacea* in potato fields can be controlled effectively by application of phorate 10G or carbofuran 3G at 2.5–3.0 kg a.i./ha in furrows at the time of planting. However, Chandel et al. (2008) reported that insecticides applied during early April at sowing time did not give desirable results as the beetles lay eggs in May–June, and by that time, the insecticides get dissipated. In mid-hills of Himachal Pradesh, soil drenching with chlorpyriphos at 5 kg/a.i. has been found to be effective resulting in 83.30–100.00% mortality of eggs and grubs of *B. coriacea* (Chandel et al. 1993). Sharma and Chandla (2013) reported that phorate 10G at 10 kg/ha at planting followed by spray of chlorpyriphos (0.1%) on ridges at earthing up in June resulted in 90% reduction in tuber damage by grubs of *B. coriacea*. Recent studies conducted in Shimla hills have shown clothianidin 50 WDG to be more effective at a very low dose (120 g a.i./ha) than conventional granular insecticides like phorate and carbofuran. The clothianidin granules can be applied preventively at earthing up in June (Anonymous

2014). Seed treatment has also been found effective in the management of whitegrubs in potato. Chandel et al. (2008) dip treated seed size tubers in insecticide solution for 30 min and observed 80.1–93.6% control of *B. coriacea* grubs with chlorpyriphos (0.1%) and imidacloprid (0.05%). Das (1999) suggested the use of quinalphos 5G and carbaryl (Sevin 10%) at 20 kg/ha for effective management of whitegrubs in potato. In Karnataka, potato whitegrubs are controlled by soil application of phorate 10G or carbofuran 3G at 20–25 kg/ha immediately after pre-monsoon rains during April–May. Chlorpyriphos 20EC at 5 L/500 L of water can also be substituted in place of granules (Lingappa and Giraddi 1995). In Tamil Nadu, soil application of methyl parathion (2% dust) at 50 kg/ha, if given a fortnight after the first summer rain, has been reported effective. However, in endemic areas, the use of phorate 10G or quinalphos 5G during August–December coinciding with rainfall is suggested (Regupathy et al. 1997). Whitegrubs have a stage of vulnerability when they are most susceptible to an insecticide application. Missing the appropriate treatment window can lead to little or no insect control. To obtain the best results, insecticide application should occur soon after adult emergence and should coincide with egg laying or egg hatching (Chandel et al. 2008). At this time, most eggs should have hatched, and the small grubs will be feeding near the soil surface where they are more easily controlled. Damage from the grubs will not become apparent until later in the season when whitegrubs are larger. If the field has a history of whitegrub problem, a preventive treatment may be the best approach. Applying the preventive insecticide around the third week in June will have the insecticide in place when eggs begin to hatch.

Cultural Management There are certain cultural practices which are highly effective in suppressing whitegrubs. Chandel and Kashyap (1997) suggested that the best way to clean grubs out of a field is to pasture the land with pigs, as when pigs are allowed to forage on heavily infested land, they will usually root out and eat the grubs. As a rule, adults do not deposit eggs in clover and alfalfa unless there is a considerable admixture of grasses or other weeds. Thus, grub populations could be reduced by rotating these crops with potato (Chandel and Chandla 2003). Chandel et al. (2008) found highly positive correlation between population of the third instar grubs of *B. coriacea* and tuber damage in Shimla hills of Himachal Pradesh. In the summer crop of potato, especially in hilly states, the most critical period in the dynamics of the whitegrub infestation lies between August and September and timely harvest can avoid huge losses.

Biological Control Whitegrubs are naturally infested by various entomopathogenic fungi. *Metarhizium anisopliae* (Metsch.) and *Beauveria bassiana* (Bals.) tested in combination with insecticides are known to reduce the incidence of whitegrubs in potato in Himachal Pradesh (Chandel and Mehta 2005). Pathogenicity of *M. anisopliae* and *B. bassiana* is affected by soil temperature and water content. Infected beetles do not die for several days, so there is potential for auto-dissemination within populations.

The entomopathogenic nematodes *Steinernema carpocapsae* (Weiser), *Steinernema feltiae* (Filipjev), *Heterorhabditis indica* Poinar and *Heterorhabditis bacteriophora* Poinar can be an effective biological insecticide for controlling whitegrubs in potato. Chandel et al. (2005) observed less *B. coriacea* grubs in *H. indica*-treated potato fields in Shimla. There was less than 20% reduction in tuber damage after application of

H. indica in potato. The efficacy of nematodes for grub control may be enhanced by using them in combination with certain insecticides. *H. indica* interacts synergistically with imidacloprid. Sluggishness of imidacloprid-treated grubs of *B. coriacea* facilitates host attachment and subsequent penetration of infective juvenile nematodes. Apply nematodes with sufficient water and ideally keep soil moist for 1–2 weeks after treatment. To avoid heat and direct sunlight exposure of the nematodes, apply in early morning or late in the day.

Selvakumar et al. (2007) isolated *Bacillus cereus* from atrophied pupae of *A. dimidiata* from Almora, and its strain WGPSB-2 has been able to cause 92 and 67% mortality in the second instar larvae of *A. dimidiata* and *H. seticollis*, respectively.

Several species of predatory birds prey upon both the grubs as well as beetles. Amongst the avian predators, Indian myna (*Acridotheres tristis* L.) and jungle crow (*Corvus macrorhynchos* Wagler) are the major predators feeding on whitegrubs at the time of ploughing (Singh et al. 2003). Spotted owlet (*Athene brama*) settles on walnut trees during night and preys upon beetles (Mishra 2001a). These important predatory birds need to be maintained in the potato ecosystem and be exploited using appropriate management practices.

Integrated Pest Management Techniques Recommended Against Whitegrubs in Potato

It is very difficult to control whitegrubs by applying a single control measure. The adults are so mobile; therefore, controlling one life stage will not necessarily preclude the problems caused by the other. Management of whitegrubs is feasible by integrating all the components of pest suppression in a befitting manner. In endemic localities, the management programme should be practised on an area basis. Individual efforts may not be very successful.

Collection and Destruction of Adult Beetles The adult emergence is synchronous; thus, the collection and killing of beetles have been found to be one of the most effective techniques. This management strategy based on large-scale beetle collection is highly cost-effective and area-wide mass campaigns can be organized in endemic locations. Adult collection has to be done from the very first day of the first summer rains. Light trap, though a tool for population monitoring, can be used in reducing the population for more strongly phototactic species like *A. dimidiata* and *A. lineatopennis*.

Spraying Insecticides on the Adult Flight Trees Most of the scarab beetles come out of soil immediately after the first good pre-monsoon shower. The emerged beetles congregate on some preferred host for mating and feeding. These beetles can be conveniently killed by spraying the trees with insecticides. The beetles which settle on treated hosts would be killed before they return to the soil the next morning for egg laying.

Ploughing Soils Fields having a history of whitegrub attack should be tilled several times in April–May or in September. Tilling or discing soil macerates grubs and exposes them to predators such as birds.

Use of Soil Insecticides The insecticides should be applied in endemic localities to bring down the population below the economic threshold level. Species-specific action thresholds for insecticide application should be worked out. The most effective insecticides are chlorpyriphos or phorate and are recommended for soil application against neonate tiny grubs. The older grubs are hard to control as they move deep into the soil, and the insecticides usually do not penetrate the soil well enough to kill the grubs.

Biological Control Entomopathogenic fungi and nematodes can effectively combat an infestation of whitegrubs. Entomopathogenic fungi include *M. anisopliae* and *B. bassiana*, and usually, the fungi are used in combination with farm yard manure. The strains of nematodes which are available for field application are *S. carpocapsae*, *S. feltiae*, *H. indica* and *H. bacteriophora*. The soil must be well soaked before applying nematodes as they need water for transport down to the root system. They start to work 48–72 h after application, and nematodes will die without moisture.

The Importance of Harvesting Date in Avoiding Whitegrub Infestation Farmers want the potato skins to be fully mature before harvesting. Sometimes, harvesting is delayed by environmental factors such as late rains. Early harvesting of potato before the 15th of September in summer-planted crop is very useful.

Conclusion

The most important control measures for the whitegrubs are based upon observations regarding their life cycle; therefore, a thorough knowledge of the pest biology is necessary before developing management practices to control them. The vulnerable period for potato to whitegrubs' injury occurs during tuber maturation stage from September to October, and the greatest damage is done by the third instar grubs. Soil sampling should begin early in the predicted grub activity period (late July). Since whitegrubs do not distribute themselves uniformly throughout a field, it is essential that the entire potato field may be surveyed in a consistent uniform pattern. Ploughing infested fields when most of the grubs are pupating will kill many of the pupae and newly transformed adults. The hand collection of beetles on their preferred hosts in May–June is quite effective. This subsequently reduces the number of eggs laid in the fields. The beetles can be killed by spraying the host trees with recommended insecticides. The adult control methods are very useful as larval populations are largely regulated by the size of the adult population. In chemical control of grubs, the time and method of application decide the efficacy of the control. Soil treatment with granular insecticide can reduce whitegrub populations in endemic fields. The application should occur when the grubs are immature, as the mature grubs often are deep in the soil and are very resilient. Application of phorate/carbofuran granules or chlorpyriphos about 45 days after transplanting at earthing up in June has been effective in suppressing whitegrubs in potato. The most critical period in the dynamics of whitegrub infestation lies between August and September, and timely harvest before September can avoid huge losses in summer potato.

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