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Review

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A REVIEW ON THE BIOLOGY AND MANAGEMENT OF POTATO TUBER MOTH

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The potato tuber moth (PTM; caused by *Phthorimaea operculella)* is one of the most serious insect pests that causes damage to crop production and storage of potatoes. It causes damage to the potato, while larvae of *P. operculella* feed on and grow in the leaves and tubers of potatoes, resulting in direct product losses. The larvae construct tunnels through tubers and mine leaves, stems, and petioles, resulting in uneven galleries. Foliar damage to the potato crop does not normally result in major output losses, although contaminated tubers may have lower marketability and storage losses of up to 100%. Light watering every 4 days and mulching with neem leaves during the last 4 weeks before the harvest was found to be a successful treatment. Spraying a thin layer of testing natural oils also acts as a defensive layer, which causes confusion or disturbance to the searching neonate larvae. The pest is tough to eradicate, so producers rely heavily on insecticides and biological approaches. Potato tuberworm damage was reduced by rotating esfenvalerate and indoxacarb treatments before and after vine kill. At 5 g/kg potato tuber in farmer rustic storage, *Acorus calamus* dust exhibited great efficiency in preventing PTM tuber damage. In different regions of the world, parasitoids such as *Copidosoma* spp. and *Apanteles* spp. are significant in PTM management. Pheromone traps are used for pest population monitoring as well as pest management in the field and during storage.

Key words: tuber, foliage, larvae, storage, insect, potato

The primary center of the origin and diversity of the potato crop and its wild relatives is western South America (de Haan & Rodriguez, 2016). Cultivated in all continents except Antarctica, the potato (*Solanum tuberosum* L.) is one of the five most important crops in the world (Vernon & van Herk

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2013). Between 8,000 and 5,000 BC, the potato was the earliest cultivated vegetable in modern-day southern Peru and extreme northern Bolivia. Potato (*S. tuberosum* L.) is the fourth important crop after wheat, rice, and maize and one of the most essential cash crops for developing countries like Nepal to address food security and poverty reduction.

In developing nations, the Asia-Pacific area produces more than 80% of potatoes, with China producing the most. In the 1990s, potato output grew at a remarkable pace, with China's production nearly doubling during the decade to reach about 70 million tons per year by the turn of the century. Potato output grew at the quickest pace in the Democratic People's Republic of Korea, where the government made potatoes a cornerstone of its food security plan (Basnet *et al.* 2022a). India is the greatest producer of potatoes in South Asia and the world's third largest producer. Due to its popularity as a vegetable in urban diets and the growing demand for western-style fast food, potato consumption has increased. India is a major supplier of potatoes to neighboring nations' developing processing industries (Ezeta 2008).

Potato tuber moth (PTM) red ant, green peach aphid, white grubs, leaf miner fly, cutworm, cotton bollworm, semi-looper, *Epilachna* beetle, black blister beetle, flea beetle, wireworm are the pests attacking potato (Giri *et al.* 2013). Among the pests attacking potatoes, the PTM is extremely prevalent in the field and during storage. It causes a loss of stored potato tubers from 23% to 47%. The PTM's larval stage is the most dangerous, which means that the more the number of larvae, the more damage and loss occur of the potato crop (Alvarez *et al.* 2005). Post-harvest losses were considerably high in South-Asian countries; India and Bangladesh incurred 24% and 20% losses in 2005, while in Nepal, it was as high as 25%. Losses in storage are caused by one of the notorious pests, the PTM *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae), which is one of the major hosts of potato along with other various solanaceous crops like tomato, eggplant, and others (Basnet *et al.* 2022b). The PTM is a devastating pest in tropical and subtropical areas. It is an eminently damaging and widespread pests of solanaceous crops, particularly potato *S. tuberosum* L. (Kroschel & Sporleder 2006). A considerable shift in global climate will influence agriculture and the worldwide food supply (Puri *et al.* 2022). When potato cultivars were transferred from India to Kathmandu for adaptation research under the Indian Aid Mission program in the early 1960s, the PTM must have been introduced. In Nepal, PTM has been documented in more than 15 districts, including high altitudes (Aryal & Simkhada 2020). *P. operculella,* like its major host, the potato, is thought to have originated in western South America (Rondon 2010). In South Central Asia, it is believed that *P. operculella* was brought from Italy to Bombay, India, in 1906 (Lefroy 1907).

The larvae move up to 0.15 miles in between crops and foliage in order to infest tubers or plants, while long distance move is probably the result of the movement of infested tubers (Alvarez *et al.* 2005). *P. operculella* is likely to cause economic loss in locations where it has established itself and produces more than four generations each year (Sileshi & Teriessa 2010). Vegetable cultivation is progressively becoming a significant contributor to Nepal's gross domestic product (GDP) (Thapa *et al.* 2022). In Nepal, pre-harvest damage in tuber and foliage is less than 5%, and postharvest damage in tuber is 40 – 100%, and it can cause yield reduction up to 100% (Giri *et al.* 2009). In order to increase the production of potato, damage caused by *P. operculella* should be reduced. Although *P. operculella* is most commonly associated with potatoes, it can also be found in other solanaceous plants like eggplant (*Solanum melongena* L.), tomato (*Solanum lycopersicum* L.), black nightshade (*Solanum nigrum* L.), silver leaf nightshade (*Solanum elaeagnifolium* Cav.), chili pepper (*Capsicum frutescens* L.), tobacco (*Nicotiana tabacum* L.), cape gooseberry (*Physallis peruviana* L.), and field ground cherry (Rondon 2010a).

Many traditional insecticides have been replaced by novel chemical insecticides that have strong insect pest control capabilities at low rates or dosages, high selectivity, increased specificity to the target pests, minimal toxicity to non-target species, and are environmentally benign. Because of these properties, many of the new insecticides are thought to be safer, more appropriate, and better suited for integrated pest management (Casida & Quistad 1998). So, this study was conducted to gain knowledge on

the efficiency of different novel chemical insecticides for the management of PTM.

The production and productivity of potato are harmed by the attack of many insect pests, among which *P. operculella* is one of the most troublesome pests which affects negatively the production of potato by feeding on tubers in the field and during storage (Basnet *et al.* 2022b). The most damaging stage of this pest is the larval stage. Larva mines the leaves, stems, and petioles and excavates tunnel through tubers (Larraín *et al.* 2009). Furthermore, potato tubers infested by larvae contain holes and excreta of the larva, making them unfavorable for consumption and selling.

P. operculella that was originated in the Andean region has now become an invasive pest globally (Kroschel *et al.* 2013). *P. operculella* was reported in 1966 in Kathmandu valley for the first time in Nepal. Its distribution and severity have been reported from various western and central hills and terai districts of Nepal. *P. operculella* was introduced in Nepal during the early 1960s, when potato cultivars were transferred from India to Kathmandu for adaptative research under the Indian Aid Mission Program (Joshi 2004). Preharvest damage in tuber and foliage is less than 5% and postharvest damage in tuber is 40% –100% and it can cause yield reduction up to 100% (Giri *et al.* 2013). Chemical management is the most common approach used for PTM. The use of chemical insecticides without knowing their effectiveness has led to its high reproductive capacity, and adaptability to seasonal change, which have resulted in difficulty in controlling this pest (Atanasova *et al.* 2014).

The relevance of PTM, as well as the control strategies employed to prevent production losses through synthetic fungicides and other organic amendments are discussed in this paper. This review paper's goal is to give information on the causes and effects of the signs and symptoms of PTM, as well as its management strategies. This data would be useful for entomologists, farmers, and academics, who can use it as a guide to safeguard potatoes in the field.

Insect pest of potato

Insect pests are very common causes of crop damage and storage in the world. However, the study of the impact of numerous pests on agricultural output has remained largely separate from the current debate on how species diversity affects ecosystem productivity. Many pests including insects, mites, slugs and nematodes attack many varieties of potatoes grown throughout the world. Insect pests and their relative importance vary from region to region with the highest number of economically important pest species occurring in the potato agro ecosystem in the neo-tropics, countries of potato origin (Kroschel & Canedo 2008).

The loss of potato to insect pests is estimated to be 16% worldwide (Oerke *et al.* 2012). Tuber yield and quality reduction range between 30% and 70% for various pests (Raman & Booth 1983). Potato crop losses due to pests and diseases throughout the cropping season and storage are considerable, reaching up to 32% in developing nations (Kroschel & Sporleder 2006). National productivity in Nepal is poor due to a variety of factors, including insect infestations. In Nepal, more than 40 insect pest species have been linked to potato production (NPRP 2008).

Potato tuber moth

P. operculella is a significant insect pest that attacks potatoes and is found all over the world (Larraín *et al.* 2007). It originated in South America, the home of the potato, where it adapted well to this crop and specialized in the detection of high glycol alkaloid levels (Goldson & Emberson 1985). *P. operculella* is a significant potato pest. The PTM is a pest that wreaks havoc on tubers. The larvae of *P. operculella* feed on and grow in potato leaves and tubers, causing direct losses of edible items (Larraín *et al.* 2009). The damage produced by the PTM during storage, according to research, is extensive and varies depending on the original infestation degree (Von Arx *et al.* 1987). In Nepal, it is the most prevalent pest of stored potatoes (Tiwari *et al.* 2006). *P. operculella* is an invasive potato pest that originated in the Andean area and co-evolved with its feeding source, the potato (Kroschel *et al.* 2013).

P. operculella is a worldwide potato pest that may be found in both tropical and subtropical climates (Haines 1977; Keller 2003). More than 90 nations have recorded sightings of the moth (Jürgen Kroschel & Sporleder 2006). It has been discovered

in at least 25 states in the USA, from the Atlantic to the Pacific coasts. This pest is found in areas where solanaceous plants, such as potatoes, are produced. Many countries have temperate climates, notably New Zealand, have recorded economically important outbreaks of *P. operculella* (Cameron *et al.* 2002). Australia (Symington 2003), Southwestern Europe (Povolný & Hula 2004), and most recently, the Pacific Northwest of the USA (Jensen *et al.* 2005) have also recorded outbreaks. However, until 2002, when serious *P. operculella* damage was observed in a field near Hermiston, Oregon, it was not a big worry for producers in the Pacific Northwest (Rondon *et al.* 2007). The distribution and intensity of pests have been documented in Nepal's western and central hill and plain areas (Joshi 2004).

Host range of PTM

P. operculella was renamed *Gelechia operculella* in 1873 (Zeller 1875). In 1902 and 1931, the genus was amended, and in 1964, it was placed in the genus *Phthorimaea* (Rondon 2010a). PTM are most frequently linked with potatoes, but they have also been recorded feeding on tomatoes, eggplants (*S. melongena* L.), peppers (*Capsicum* spp.), tobacco, and wild solanaceous plants including Jimson weed and datura (*Datura stramonium* L.) (Gill *et al.* 2012). The PTM is only found in the *Solanaceae* family of plants (Hanafi 2005). The larvae of *P. operculella* are oligophagous, meaning they only consume plants of the *Solanaceae* family (Chumakov & Kuznetsova 2009).

Life cycle and biology of PTM

The PTM has four stages of development: adult, egg, larva, and pupa (Hanafi 2005). Adult moths are typically tiny (about 0.94 cm in length) and have a wingspan of around 1.27 cm. PTM has black markings on its forewings (two to three dots on males, "X" on females). Both pairs of wings have fringed borders. PTM moths can discover tubers and lay eggs by crawling through soil fissures or burrowing short distances through loose soil (Rondon 2010a). PTM eggs are smaller than 0.0508 cm in diameter, round, transparent, and vary in colour from white to yellowish brown. PTM larvae are typically light brown with a brown head. Mature larvae (about 96 cm long) might be pink or greenish in hue (Hanafi 2005). Temperature has a significant impact on the hatching time (Rondon 2010b). Larvae change colour from white to yellow to pink to green as they grow. For up to 2 weeks before pupation, the larvae eat their host plants (Gill *et al.* 2014). Males can be distinguished from females in the fourth larval stage by the presence of two elongated yellowish testes in the fifth and sixth abdominal segments (Rondon 2010a).

For concealment, the pupa is developed in a silk cocoon that is coated with earth particles and detritus. Pupation can occur amid dead potato leaves, in the soil, or on potato tubers that have been kept (Hanafi 2005). Pupae require 10 to 30 days to fully grow, depending on the environmental circumstances (Gill *et al.* 2012). Mating begins as the adults emerge, and females seek a host to deposit eggs within a few hours of mating, depending on temperature (Hanafi 2005). The newly laid eggs are bright yellow, and later become dark brown before hatching. Eggs from the same egg mass hatch almost simultaneously (Vernon & van Herk 2013). The life cycle is complete in a short period (22 – 30 days) in summer ranging from egg to adult and is usually long in winter up to 2 – 4 months. The optimum temperature required for moth development ranges from 22°C to 26°C and the air humidity required is 70 – 80% (Abewoy 2018).

Nature of damage

Insect pests are the major cause of damage to crop production and storage worldwide. *P. operculella* is one of the biggest insect pests causing harm to potatoes, infesting them both in the field and during storage. The larval stage is the most damaging stage of the pest which attacks potatoes both in the field and in store (Evans *et al.* 1992). Adult female of *P. operculella* lays eggs on the leaves, and soon after hatching, the larvae start to mine into leaves. One-third to one-half of the leaf is injured by the larva of *P. operculella* in its larval life if it continuously feeds the leaves; but where necessary, it mines the petiole and kills the entire leaf. Larvae do not bore tubers through the stem. Mines in the leaf, petiole, and tunneling in the stems are common injuries made in field condition (Raman 1980; Kroschel & Canedo 2008).

In warm and dry climates, *P. operculella* not only attacks the leaf, but also causes extensive damage

during storages of potatoes. The losses are more pronounced in tubers. The tubers get infested in the fields, and adults lay eggs near the eyes. Larvae give irregular galleries and tunnels of different depths that are responsible for both losses in weight and quality of the potatoes (Raman 1980). *Fusarium* sp. and *Erwinia* sp. are responsible for secondary infestation (Chandel *et al.* 2020), which results in rots and ooze (Sileshi & Teriessa 2001). Contaminated tubers have minimal value as food or seed (Ojero & Mueke 1985), and infested seed is a major source of *P. operculella* infection in freshly planted potato crops. Tubers do not always show sign of damage at harvest, but may be the source of harboured eggs and early instar larvae, which may result in severe postharvest losses of stored potatoes in the absence of adequate control measures (Kroschel & Canedo 2008). If infested tubers are stored without proper precautions, the entire stock of stored tubers may be destroyed. In rustic non refrigerated stores, infestations of *P. operculella* can wipe out an entire crop in as little as 2–4 months (Von Arx *et al.* 1987).

Losses caused by PTM

P. operculella is a severe potato pest that is toxic in stores and is found in tropical and subtropical areas (Guerra *et al.* 2007). *P. operculella* causes large losses in potato crops in both storage and field conditions, and it is also an important postharvest pest of potato crops (Lal 1987; Joshi 1989). To minimize the loss that happens during transportation, the market should be located near the production region (Chaulagain *et al.* 2021). Damage caused by *P. operculella* to potatoes in the field and during storage is a significant barrier to potato production and storage. Losses in yield owing to plant debilitation are not the major worry with *P. operculella* until infestations of potato plants are severe. When tubers become exposed to and are infected by *P. operculella* before or during harvest, the most economic harm occurs at the end of the growing season (Lacey *et al.* 2008). The amount of *P. operculella* in the leaves can impact the amount of *P. operculella* in the tubers (Lagnaoui *et al.* 1996), and damage to stored potatoes can be a total loss when tubers are left untreated (Hanafi 1999). *P. operculella* has been found to cause 30–70% losses in the country stores in India (Basnet *et al.* 2022b). By the infestation of five pairs of *P. operculella* on the haulm of potato plant, the yield is reduced to 30% in Nepal (Joshi & Sitaramaiah 1979). Potato harvested in some pocket areas in Khumaltar, Kathmandu, showed 100% losses due to an outbreak of *P. operculella* (Joshi *et al.* 2004). Although yield loss from field infestation is uncommon, quantity and quality losses in storage are significant in warm and dry climates, where losses can exceed 100% if not managed (Lagnaoui *et al.* 2000). Unhealthy plants are more frequently damaged by *P. operculella* than healthy plants (Lal 1987). By field infestation of *P. operculella,* 87% of potato tubers were lost and rotting was positively correlated with tubers' infestation in storage (Sileshi & Teriessa 2001). Yield losses have been recorded as 46–60% under field conditions and 60–70% in unprotected storage in Indonesia (Douches *et al.* 1998). In Nepal, it is reported that tuber yield loss due to *P. operculella* infestation of potato crops ranges from 45 ± 3.2% to 78.9 ± 10% (Aryal & Simkhada 2020).

P. operculella damage in February planting was 24–27.5% of tuber weight at harvest (Abdallah 2017). In Chile, Fenemore (1980) investigated 20 potato cultivars for resistance to *P. operculella* infection. He discovered that between 28.7% and 61.6% of these cultivars were infested. The average loss was projected to be 321.75 $/ha based on potato prices at the time. Rondon *et al.* (2007) reported that potatoes from many farms in Oregon's Columbia Basin were rejected for market owing to *P. operculella* infection, resulting in a $2 million loss in 2003. *P. operculella* can cause 50% yield losses related to grade-outs (Doğramaci & Tingey 2007), and a greater prevalence of tuber infection can leave potatoes wholly unmarketable in the United States-SA. According to Basavaraju *et al.* (2009), in India, yield losses owing to PTM infestation varied from 6% to 9% depending on the location. According to Tsedaley (2015), in Ethiopia, *P. operculella* is the most major impediment to potato production, causing up to 42% losses in storage. In the Andes, field losses can exceed 30%, but the most economically important harm comes when contaminated tubers are transported to potato shops in Bolivia, where re-infestation occurs (Kroschel *et al.* 2016).

Potato crop losses have been found to be ranging from 50% in Yemen and Peru to 86% in Tunisia,

Algeria, and Turkey, 90% in Kenya, and 100% in India and the Philippines (Alvarez *et al.* 2005). In Egypt, the PTM has destroyed up to 100% of potato plants in the field and during storage (Ahmed *et al.* 2013). The PTM is a tomato pest that wreaks havoc on leaves, stems, and immature fruits.

Management practices of PTM

Cultural methods

P. operculella is a major pest of solanaceous crops, such as potatoes, throughout the world. Cultural method of pest control involves modification of cultivation practices, such as elimination of cull piles and volunteers, soil moisture and vein clearing, rolling and covering hills, crop rotation, and so on, which were done earlier for reducing the *P. operculella* population (Rondon *et al.* 2007). Farmers employ a variety of cultural methods to reduce tuber damage and increase potato output and quality (Hanafi 1999). Cultural practices include removal of infested seed tubers, planting the tuber deep (at least 10 cm), regular mounding of the soil cracks, and harvesting potato soon after the crop maturity reduces the population of *P. operculella* (Rondon *et al.* 2007). It is important to keep tubers under at least 5 cm deep in the soil (Alvarez *et al.* 2005; Chumakov & Kuznetsova 2009). Another cultural method of controlling *P. operculella* is irrigation, which continually keeps the soil moist and the soil surface sealed. It is very important to manage volunteer plants and cull piles to remove the potential food sources and habitat of *P. operculella* (Alvarez *et al.* 2005; Chumakov & Kuznetsova 2009). Tubers get exposed and infected by *P. operculella* before or during harvest when deep planting and ridging are not done (Oatman & Platner 1974; Guenthner 2003). The pupal stage of *P. operculella* survives in soil. The timely collection and destruction of pupa can help reduce the pet population (Rondon *et al.* 2007). Potato loss can also be reduced by drying the seed for a few days in the shade before storing it and after pre storage treatment using local techniques or a combination of chemical insecticides (Adhikari *et al.* 2021). PTM may be controlled by harvesting potatoes as soon as the crop reaches maturity. While moth populations are sustained in plant and tuber detritus in the field in the absence of the main crop, quick field cleaning is an important preventative action (Basnet *et al.* 2022a). To reduce overwintering of potato tuberworm, cull heaps should be eliminated. Avoid leaving harvested tubers in the field overnight because they might serve as egg-laying sites for the PTM (Gill *et al.* 2012).

When compared to crops planted 3 weeks later, planting in the second week of November resulted in less insect damage and a much higher overall yield in Sudan. Insect damage varied from 3.3% (planting 10 cm deep and hilling up three times) to 16% (planting 5 cm deep and hilling up once). Irrigation and mulching both decreased bug damage dramatically. The most successful treatments were light watering every 4 days and mulching with neem leaves during the last 4 weeks before harvest (Ali 1993).

Botanical methods

All natural insecticides derived from plants are botanicals. The use of botanical in crop protection has now become popular in the world of agriculture as an alternative to the use of toxic, persistent, and synthetic compounds (Herman *et al.* 2005a). Botanical insecticides are one of the most important elements of current pest management technology since they are the safest, easiest, and slow but efficient methods of managing the majority of dangerous pests, including PTM (Basnet *et al.* 2022b). A study of the literature (Das 1995) found that 35 plant species are effective against the PTM in nonrefrigerated storage or in lab (Guerra *et al.* 2007). Dried chopped leaves and flowers of *Minthostachys* species were shown to lessen the amount of tuber damage in stores by nearly 80% and essential oils reduced the number of eggs produced by almost 80% when compared to the control treatments. According to Moawad and Ebadah (2007), in PTM, cardamom oils at 0.02% and 0.05% concentrations reduced the proportion of egg hatchability the most (67.5% and 86.7%, respectively). The use of vegetable oils also helps to avoid the assault. *P. operculella* fertility was lowered by orange peel oil (Sharaby 1988). Salem (1991) discovered that neem seed extract was efficient in suppressing *P. operculella* on potatoes in an Egyptian shop; after 6 months of treatment with 100 ppm neem, storage loss was only 25% (compared to 10% with carbaryl).

In potatoes preserved for 4 months, Raman (1988) found *Eucalyptus globulus*, *Lantana ca-*

mara, and *Minthostachys* sp. to be beneficial in dried, shredded, and powder form. Pradhan (1988) recommended 300 – 330 g/crate/8 kg chopped and dried leaves of *Eucalyptus* spp., *Artemesia vulgaris*, or *Chenopodium botrys* to protect potato tubers against PTM. Muna (*Minthostachys* spp.), eucalyptus (*E. globulus*), chilca (*Baccharis* spp.), curry plants, Indian pivets, *L. camera*, pangam leaves, *C. botrys*, *Mentha arvensis*, and *Ar. vulgaris* are beneficial for suppressing PTM (Rivera & Retamozo 2000; Niroula & Vaidya 2004). Ghanam (2017) discovered that clove flower powder was the most efficient against *P. operculella* larvae, while for treating the potato tuber affected by *P. operculella* eggs, santonica flower powder and black pepper seed powder are added last. Sharaby *et al.* (2009) also discovered that dusting potato tubers with *Allium cepa* bulb powder (50% concentrated combined with talcum powder) reduced egg deposition and adult emergence. Larval penetration into treating tubers was considerably decreased by *Al. cepa*, *Pelargonium graveolens*, and *Cymbopogon citratus*. *Pelargonium* or *Allium* combined with talcum powder provided effective protection over a lengthy period of time (30 – 40 days). *Acorus calamus* lives for a long time, resulting in a high percentage of larval mortality and lesser adult emergence in the first generation. For the management of PTM in storage potatoes, *Ac. calamus* appears to be the best alternative to chemical insecticides, and it is advised to apply 5% w/w weekly (Basnet *et al.* 2022b).

According to Bowers and Nishida (1980), spraying a small coating of testing natural oils may operate as a protective layer, causing uncertainty or disruption to the hunting neonate larvae. Spraying Neemerich oil (*Azadirachta indica*) over potato tubers had ovicidal and larvicidal effects against PTM, according to Rama (1989). Spraying 1.0% natural and commercial oils of *Mentha citrate, Cymbopogon citratus, Myristica fragrans*, and á-ionone on potato tubers reduced the percentage of larval penetration of PTM and caused failure of many of them to complete their development to the adult stage, according to Sharaby *et al.* (2009). It was also demonstrated that the volatile oils of the oils listed may effectively minimize infestation by PTM by decreasing the life span of adults and lowering their fertility. As a result, the majority of exposed females die before producing eggs and some fail to lay their entire load of eggs. According to Moawad & Ebadah (2007), spraying potato tubers with natural treatment like blending cardamom oil (1.5%) with talcum powder (larval penetration was 13.3%) was the most effective technique to repel PTM. They also discovered that no adults could emerge from larvae fed cardamom-treated tubers at a concentration of 1.5%. According to Sharaby *et al.* (2009), various natural essential oils, such as peppermint, camphor, and pineapple, were shown to be larvae repellents.

Chemical methods

P. operculella is a noxious pest of potato both in the field and under storage conditions. The use of repellent plants can be an environmentally sound alternative to the application of chemical insecticides (Guerra *et al.* 2007). The indiscriminate use of insecticides has become one of the most serious problems in Nepal. The chemical control of *P. operculella* is a common practice in Kathmandu valley. The management of pests and diseases in potato crop involves 15% of the total cultivation cost (Joshi 2004). The use of agrochemicals on potatoes against *P. operculella* may be hazardous to consumers (NPRP 2008). Thus, it is necessary to develop the safe use of insecticides. Chemical control is effective, quick, secure, and economical, but it has some major drawbacks: negative impact on products and the environment; the constant danger of intoxication for humans and animals; the presence of residues in different parts of the plants; and appearance (Bhandari *et al.* 2022). Dusting healthy tubers with fine wood ash-controlled infestations for long periods. Seed potatoes were adequately protected by 5% malathion dust and 1.5% quinalphos dust. Potatoes kept in gunny bags impregnated with solutions of malathion 50 EC and azadirachtin 1,400 ppm were also free of damage. Although *Bacillus thuringiensis* (Bt) treatment reduced infestation and rotting, the proportion of tuber damage remained significant. In Tunisia, a country in North Africa, Das *et al.* (1998) found that deltamethrin was effective in reducing pest damage. After 3 months of storage, the treatment showed no significant effect on sprouting.

Farmers use deltamethrin, methyl parathion, dichlorovos, and dimethoate to control *P. operculella* in stored potatoes in Kathmandu valley (Joshi

2004). Damage caused by *P. operculella* to tubers can be efficiently controlled with a variety of insecticides (Abdel-Salam *et al.* 1972). Chemical control has shown variable success in controlling foliage infestation, but not tuber damage (Bacon 1960; Bacon *et al.* 1972; Foot 1974). One of the reasons behind insecticide being not effective toward adult *P. operculella* is the internal feeding habits of larvae. Also, there is some evidence of insecticide resistance of *P. operculella* population to pyrethroids (Georghiou, 1980; Raman & Booth 1983; Collantes *et al.* 1986). Because the larvae spend the majority of their lives inside the tubers, traditional management approaches are ineffective (Haiba 1994). The chemicals registered for control of *P. operculella* include systemic granules applied at planting and foliar sprays. Because of the toxicity, tunneling organophosphate, carbamate, and pyrethroid insecticides, chemical treatment of *P. operculella* has been difficult (Bacon 1960; Shelton & Wyman 1979; Shelton *et al.* 1981; Collantes *et al.* 1986). The commonly used chemicals belong to organophosphate and carbamate groups, but their replacement is done by less-harsh insecticides (Basnet *et al.* 2022a). Clough *et al.* (2010) recently discovered that rotating esfenvalerate and indoxacarb administration before and during vine kill reduced potato tuberworm damage. For efficient control, such application times are crucial (Rondon *et al.* 2007; Clough *et al.* 2010). In addition to chemical management, it is strongly suggested that potatoes be harvested immediately after vine kill since the danger caused by potato tuberworm damage increases if the tubers are left in the field (Rondon 2010a).

Adult potato tuberworm moths rest on the underside of potato leaves throughout the day and become more active in the evening (Thontadarya 1977). As a result, pesticide treatments should be timed to coincide with the peak of insect activity in the evening. The insecticides chlorantraniliprole and spinetoram have lately given a more focused and integrated pest management (IPM) friendly option for lepidoptera control in potatoes. They have been demonstrated to be particularly effective against potato tuberworms (Lawrence 2009; Dobie 2010). The widespread use of traditional insecticides (organophosphates, organochlorines, carbamates, and synthetic pyrethroids) has resulted in the emergence of severe pesticide resistance, a secondary pest epidemic, a direct threat to users, and negative impacts on the environment target species.

Only use insecticides in the field to control PTM if the moth capture in pheromone traps exceeds the relevant action level. In potato stores, *P. operculella* is controlled by dusting malathion or carbaryl powder on the potatoes (Sporleder *et al.* 2008). *P. operculella* is efficiently controlled in the field and stored in Ethiopia with the systemic pesticide diazinon 60% EC (Getu & Girma 1994).

Biological controls

The PTM, which originated in the Andes but is now found in all potato-growing regions save the coldest north temperate latitudes, is responsible for the majority of potato losses (Rondon 2010a). Under current pest management schemes in potatoes, the impact of natural enemies on *P. operculella* is unknown, especially in areas where an intense agricultural production system is based on regular broad-spectrum pesticide treatments on a calendar basis (Koss 2003). However, the literature contains a wealth of information about the biology and potential of natural enemies such as parasitoids, predators, and diseases. Biological control agents have the benefit of having no preharvest periods, and are therefore safer for the application staff, food supply, and nontarget species (Rondon 2010a). In different regions of the world, parasitoids such as *Copidosoma* spp. and *Apanteles* spp. are significant in PTM management (Abewoy 2018). The following are the most often utilized moth parasites (Sporleder & Carhuapoma, 2016): *Apanteles subandinus*, *Bracon gelechiae, Chelonus kellieae, Chelonus phthorimaeae, Copidosoma koehleri, Copidosoma desantisi, Orgilus lepidus, Orgilus jennieae, Orgilus parcus*.

Bt has been recognized as one of the most virulent against *P. operculella*, while *Bt kurstaki* (Btk) has been identified as one of the most virulent against *P. operculella*. After 168 h, Niroula and Vaidya (2004) found that three concentrations of *Lindera neesiana* and *Ac. calamus* were effective in PTM control, with *L. neesiana* causing 66.7%, 70.0%, and 83.3% adult mortality and *Ac. calamus* causing 56.7%, 66.7%, and 70% adult mortality in three concentrations of 0.05% w/w, 0.5% w/w, and 5%, respectively. Similarly, *Ac. calamus* dust applied at 5 g/kg potato tu-

ber in farmer rustic storage protected tuber damage from PTM for 4 months, which was followed by Btk (Z-52-strain, Biolep) (air-dried mixture @ 35 g/L, water, and 35 g talcum powder) applied at 6 g/kg tuber and *Artemisia* chopped leaves applied at 20 g/kg tuber (Basnet *et al.* 2022a). When compared to farmers' practice, *Ac. calamus*-treated potato tubers had reduced infestation during all observation periods, and the farmers in the communities had a favorable attitude toward the product because it was available locally in Nepal (Aryal & Jung 2019).

Pheromone control

Pheromone traps are employed for pest population monitoring as well as management in the field and during storage (Chernii *et al.* 1994). Mulumba and Lal (2008) many of which depend on the quantity and quality of soil organic matter. The equilibrium level of soil organic matter depends on the balance between input through plant residues and other biosolids and output through decomposition, erosion and leaching. However crop residues have numerous competing uses such as fodder, fuel and construction material. Similarly, costs are incurred in its application and these increase with mulch level. Therefore, it is necessary to establish optimum mulch application rates. Empirical data on soil organic matter in relation to input residue of residue are needed to understand management impact on soil quality. Long-term field plots were setup in 1989 to study the effects of mulching on soil physical properties of a Crosby silt loam (Aeric Ochraqualf or stagnic luvisol discovered a substantial positive relationship between adult moth pheromone captures, foliar larval numbers, and PTM plant infection. *P. operculella*'s sex pheromone has been identified as a combination of trans-4, cis-7-tridecadienyl acetate (PTM1) and trans-4, cis-7, cis-10 tridecatrienyl acetate (PTM2) (Persoons *et al.* 1976). Herman *et al.* (2005b) tested delta design DeSIRe, a green plastic funnel, water, and A-traps, in New Zealand and discovered that DeSIRe sticky traps collected 17 moths per day, but funnel traps caught just two moths per day, a difference of nearly eight times. Herman *et al.* (2005a) came to the same conclusion, claiming that a 1:1.5 blend of the DeSIRe sticky trap was best for commercial application (PTM1: PTM2). When Larraín *et al.* (2007) evaluated different dosages of PTM sex pheromone combination (PTM1: PTM2, 1: 1.5) per trap, they determined that pheromone dispensers filled with rates of 0.2 and 0.5 mg per trap collected the most PTM males per trap. In a potato field, a mixture of pure pheromones and the contact insecticide cyfluthrin, which was made using plant oils and ultraviolet (UV) absorbers, was sprayed in 100 L droplet sizes and proved to be effective, with male PTM mortality of 100% after 3 – 4 days (Aryal 1981).

The components of the PTM sex pheromone have been discovered as (E4, Z7)-tridecadienyl acetate (PTM1) (Roelofs *et al.* 1975) and (E4, Z7, Z10)-tridecatrienyl acetate (PTM2) (Roelofs *et al.* 1975; Persoons *et al.* 1976). Blends ranging from 9:1 to 1:9 were investigated after these two compounds were produced (Voerman & Rothschild 1978; Raman 1988). The majority of chemical mixtures were successful in trapping male PTMs. Raman (1988) and Tamhankar & Harwalker (1994) both examined a water trap and a funnel trap and saw no significant difference in moth capture. Water traps, on the other hand, collected more moths than sticky traps, according to Bacon *et al.* (1976) maintained by flux from the atmosphere, are present in the surface mixed layer and penetrate into the thermocline to depths of about 500 m. Dissolved 210Po is ordinarily present in the mixed layer at less than equilibrium concentrations, suggesting rapid biological removal of this nuclide. Particulate matter is enriched in 210Po, with 210Po210Pb activity ratios greater than 1.0, similar to those reported for phytoplankton. Box-model calculations yield a 2.5-year residence time for 210Pb and a 0.6-year residence time for 210Po in the mixed layer. These residence times are considerably longer than the time calculated for turnover of particles in the mixed layer (about 0.1 year. Raman (1988) concluded that pheromones from PTMs might be a very beneficial tool in a PTM IPM program.

CONCLUSIONS

The PTM is a serious major pest in areas where the climate favors its development and where its host plants are grown on a large scale. The PTM is a heat-loving species, which means that its range is

limited in the north. The moth can develop in numerous generations in the fields under good conditions throughout the warm season in new places, but it dies later during the wintering stage. Insect pests alone are responsible for a 16% loss in potato production throughout the world. *P. operculella* is a significant economic pest in both tropical and subtropical nations. If left unchecked, this bug can cause complete tuber destruction in storage. The larval stage, which feeds on leaves in the field and tubers in storage, is the most harmful and can be controlled by chemical method; but it is hazardous to the environment. Innovative chemical insecticides, which are less likely to trigger secondary pest outbreaks and are safer and which fit well into Integrated Pest Management, can overcome the downsides of toxic insecticides. The natural management of the PTM population is another option for managing the pest. To limit the effect of this insect pest, we must establish an integrated pest management strategy that includes suitable cultural practices, the use of pheromone traps, biological control, host plant resistance, botanicals, and the administration of chemicals at the right rate and timing. Integrating a variety of management approaches reduces the likelihood of pesticide resistance, as well as the insecticide's impact on the environment, nontargeted creatures, useful insects such as natural enemies, and human dangers.

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