

Review on Potato Late Blight and Potato Tuber Moth and Their Integrated Pest Management Options in Ethiopia

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Abstract

Potato is the fourth major crop of the world after rice, wheat and maize. However, in Ethiopia, the yield per unit area of potato is very low compared to those of other countries. There are many factors that reduce the yield of the crop among which the diseases like late blight and insect like tuber moth which play an important role in reduction of the yield. Hence, the objective of this review is to review the importance of these late blight and tuber moth of potato and their management in Ethiopia. In Ethiopia, late blight is occurs throughout the major potato production areas and researches have made estimates of losses ranging from 6.5 to 61.7%, depending on level of susceptibility of the varieties. Different types of management options like cultural, Fungicide Use, biological and Resistant Cultivars are the major management practices which can help in reducing late blight effect. However, because of its new strain development, there is no single effective management strategy of this disease. Therefore adopting integrated disease management approach is the most effective, environmentally safe and low costly to the users. In addition to late blight, potato tuber moth can also cause significant yield loss to potato. Potato tuber moth is the most important constraints of potato production in Ethiopia and it causes up to 42% yield loss in storage. Using different integrated pest management approaches including appropriate cultural practices, using pheromone traps, using biological control, host plant resistant, using botanicals and appropriate rate and time of chemical applications are used for reducing the damage of potato tuber moth.

Keywords: Biological control; Botanicals; Cultural control; Host resistance; Pheromone traps; Potato late blight; Potato tuber moth; Yield loss

Introduction

Potato (*Solanum tuberosum* L.) is a global crop planted in a wider range of altitude, latitude, and climatic conditions. Potato, is also known as white or Irish potato, is the most important and useful member of the family *Solanaceae* and is grown in tropics as well as sub-tropics during the cool as well as dry seasons under irrigation [1]. Nutrition analysis showed that potato is a healthy food in terms of vitamins, minerals, proteins, antioxidants, essential amino acids and carbohydrates [2]. Potato is one of the most widely grown food crops after the three cereals like maize, rice and wheat [3]. In Eastern Africa, potato is the best crop for food and nutrition security where food security is a key priority for the over 200 million people whose number is predicted to double by 2030 [4]. Under such increasing pressure on the fixed land, increasingly degraded environment, and uncertainties resulting from climate change, producing crops like potato with high plasticity to environmental regimes and higher yield per unit area is indispensable. However, existing climate change may also increase the risk of epidemic disease development for potato production particularly of late blight of potato that may result in yield reductions [5,6].

Experimental

Late blight of potato, caused by *Phytophthora infestans* (Mont. De Bary), is among the most important diseases, being especially

devastating in the major potato growing areas. Serious economic consequences often result from complete or partial devastation of infected fields. It is the most widespread throughout the world and causes serious tuber losses globally [7-9]. Worldwide losses due to late blight are estimated to exceed \$5 billion annually and thus the pathogen is regarded as a threat to global food security [10]. Late blight is not only the most serious fungal disease, but it also occurs almost everywhere where potatoes are grown and is especially important in the traditional potato growing areas. If not controlled, losses may reach 100% [11] and even lower infection levels may make the crop unfit for storage [12]. In the highlands of Ethiopia, late blight and bacteria wilt (*Ralstonia solanacearum*) are the most important potato diseases that cause an estimated yield loss of up to 70% [13].

Potato tuber moth (PTM), *Phthorimaea operculellais* one of the major potato pests worldwide [14]. It is a host specific pest of solanaceous crops, high adaptability to daily and seasonal changes, high reproductive potential, resistance to some insecticides and high potential to destroy potatoes in storage [15,16]. Moawad and Ebadah [17] reported that *P. operculella* causes serious damage to stored potato through its larval tunnelling and feeding, which lead to partial or complete rotting by subsequent infection of fungi and bacteria. It is a caterpillar insect pest that attacks potato plants in field and storage causing great damage to foliage and tubers and it is one of the pests that causes the most extensive damages in the field and storage of potatoes, especially in warm dry climates [18]. The larvae of this insect mine into the leaves and stems of young plants, and bore into the tubers as soon as they are formed. During storage, the damaged tubers rot and become unsuitable for human consumption. The adult moth flies from the infested tubers in the storage and from neglected small

lots in warehouses or farms to the fields where it causes pre-harvest infestation.

Even though, in most potato growing areas of Ethiopia the crop is attacked by a number of insect pests, the major one is *P. operculella* [14,19]. *P. operculella* is the most economic pest on potato production in Ethiopia, hence yield loss recorded up to 42% and 8.7% in store and in the field, respectively [20]. Similarly, Lagnaoui et al. [21] 100% yield loss due to *P. operculella* when tubers stored at warm condition. Therefore, the objective of this paper is review the importance of potato late blight and potato tuber moth and their management options.

Major Diseases and Insects of Potato in Ethiopia

In Ethiopia, the yield per unit area of potato is very low compared to those of other countries like Rwanda, Egypt and Kenya. There are many factors that reduce the yield of the crop among which the diseases like late blight (*Phytophthora infestans*), bacterial wilt (*Ralstonia* (*Pseudomonas*) *solanacearum*) and viruses play an important role [22]. In the highlands of Ethiopia, late blight and bacteria wilt (*Ralstonia solanacearum*) are the most important potato diseases that cause an estimated yield loss of up to 70% [13].

Potato late blight (*Phytophthora infestans*)

Economic importance of potato late blight: Among all the crops grown worldwide, potato (*Solanum tuberosum* L.), is known to suffer the greatest losses from disease attack. Late blight of potato, caused by *Phytophthora infestans* (Mont. De Bary), is among its most important diseases, being especially devastating in the major potato growing areas. Serious economic consequences often result from complete or partial devastation of infected fields [23]. It is the most widespread throughout the world and causes serious tuber losses globally [8,9]. The potential economic and social impact of this disease is best illustrated by the well-publicized role it played in the Irish Famine in the middle of the 19th century when it destroyed a large portion of the potato crop, either by eliminating foliage prior to the harvest or by causing massive tuber rot in storage. Because of the famine, millions of Irish died or emigrated [24]. Late blight may cause total destruction of all plants in a field within a week or two when weather is cool and wet [25-27]. The disease is also very distractive to tomatoes and some other members of the family solanaceae. Late blight may kill the foliage and stems of potato and tomato plants at any time during the growing season. It also attacks potato tubers and tomato fruits in the field, which rot either in the field or while in storage [27].

The average global crop losses of all diseases combined was approximately 12.8% of the potential production but potato alone was subjected to 21.8% loss [28]. In Ethiopia, the disease caused 100% crop loss on unimproved local cultivar, and 67.1% on a susceptible variety [29]. Late blight is a major limitation to potato production in high humid elevations; with estimate average yield losses of about 30-75% on susceptible varieties [30]. According to Fekede et al. and Binyam et al. [31], reports, in Ethiopia late blight of potato causes tuber yield losses of 21.71-45.8% and 29-57% depending on the resistance level of the cultivars, respectively (Figure 1). Generally, potato yield loss attributed primarily to late blight is dependent on variety susceptibility or tolerance/resistant and disease management practices.



Figure 1: Late blight affected potato leaf and tuber.

Host ranges of phytophthora infestans: *P. infestans* has been reported to cause infection on a large number of species. Erwin and Ribeiro [7] listed 89 host species, but more than 25% of these were included because artificial inoculations resulted in lesions. In agriculture, the two most important hosts are potato (*Solanum tuberosum*) [32] and tomato (*Lycopersicon esculentum*) crops [33] but pear melon (*Solanum muricatum*, “pepino”) and other solanaceous species in the genus *Solanum* can be also attacked [34].

Epidemiology and life cycle of late blight: The development of late blight epidemics depends greatly on the prevailing humidity and temperature during the different stages of the life cycle of the fungus. The fungus grows and sporulates most abundantly at a relative humidity near 100% and at temperatures between 15 and 25°C [27]. At temperatures of 13-21°C, sporangia germinate by means of a single germ tube. Night temperatures of 10 to 16°C accompanied by light rain, fog or heavy dew and followed by days of 16 to 13°C with high relative humidity are ideal for late blight infection and development [35,36]. Temperatures above 30°C slow or stop the growth of the fungus in the field but do not kill it, and the fungus can start to sporulate again when the temperature becomes favourable, provided, of course, that the relative humidity (near 100%) is sufficiently high [27]. The first symptoms of late blight in the field are small, light-to-dark green, and circular-to irregularly shaped, water-soaked lesions [36]. These usually first appear on the lower leaves where the microclimate is more humid [37]. However, they may occur on upper leaves if weather conditions are favourable and the pathogen has been carried into the field by air currents [36,37]. In moist weather, the lesions enlarge rapidly and form brown, blighted areas with indefinite borders. The fungus may appear as a white, mildew-like growth at the edge of the lesion, primarily on the underside of the leaf. This white growth distinguishes late blight from several other foliar diseases of potatoes [27].

Phytophthora infestans can survive in living host tissue, such as in seed tubers, cull piles, and volunteer potatoes that over-winter in the field, on other solanaceous plants and in the soil [36]. It usually survives from year to year in infected tubers placed in storage, in piles of cull potatoes or in infected tubers missed during harvest that remain unfrozen over the winter (volunteer potatoes). In the spring, the pathogen can be transmitted from infected tubers in cull piles or volunteers to potato foliage by airborne spores. Infected seed-potatoes are also important sources of the disease. Some infected tubers may rot in the soil before emergence, and not every plant that emerges from an infected tuber will contract late blight. Sporangia of *P. infestans* may be spread from infected plants in one field to healthy plants in surrounding fields by wind, splashed rain, mechanical transport and animals [35-37]. A few days after infection, new sporangiospores emerge through the stomata of the leaves and produce numerous sporangia, which are spread by the wind and infect new plants. In

favourable weather, the period from infection to sporangia formation may be as short as 4 days and, therefore, a large number of asexual generations and new infections may be produced in one growing season. The sporangia, when ripe, become detached and are carried off by the wind or are dispersed by rain; if they land on wet potato leaves or stems, they germinate and cause new infections [27].

Sporangia of *P. infestans* germinate either directly with a germ tube or indirectly, by liberating zoospores. Germ tubes can also form secondary sporangia, which may serve to increase the longevity of the spore. Sporangia may germinate at temperatures between 7 and 13°C when free water is present on leaves and form 8-12 motile zoospores per sporangium. These swim freely in water films, attach to the leaf surface and infect the plant. Encysted zoospores infect leaves by penetrating the leaf surface with a germ tube, either through stomata or by means of direct penetration [35,36]. The germ tube penetrates directly or enters through stomata, and the mycelium grows profusely between the cells, sending long, curled haustoria into the cells. Older infected cells die while the mycelium continues to spread into fresh tissue. In any case, as the disease develops, established lesions enlarge and new ones develop, often killing the foliage and reducing potato tuber yields [27].

Management methods of late blight: Effective management of late blight requires a comprehensive approach, integrating many strategies and tactics. This is especially important to manage strains that are very aggressive and not especially sensitive to some fungicides. Worldwide losses due to late blight are estimated to exceed \$5 billion annually and thus the pathogen is regarded as a threat to global food security [10]. In the past few decades, the frequency and severity of the disease have increased in many parts of the world including Ethiopia and have been a serious threat to potato production [38]. Despite the fact that much of the success in controlling the disease has been due to the application of large quantities of chemical fungicides, their extensive use is causing a serious pollution problem in the environment [39]. Further, the chemical control of late blight is becoming more difficult due to the appearance of new and more aggressive *P. infestans* strains. Integrated management of late blight through the use of resistant potato clones, fungicides, and cultural measures appear to offer the best option for disease management in the tropical highlands of Africa. In Ethiopia, the following management methods (control strategies) were research results used to manage potato late blight.

Cultural control: Cultural control involves all the activities carried out during agronomic management which alter the microclimate, host condition and pathogen behaviour in such a way that they avoid or reduce pathogen activity. Planting time should be scheduled, especially in places where planting is made under irrigation, to avoid the period of higher incidence of the disease. This is not always possible in continuous production areas. Soils must have good drainage and adequate aeration, in order to avoid moisture on foliage and ground. Avoid potato monocropping to escape primary inoculum likely to be present in plants or tuber debris infected during the previous season. It is advisable to use resistant varieties. Combining varieties should be avoided in order to achieve adequate agronomic management of the crop and better disease control. Nevertheless, some authors recommend the mixture of varieties to reduce disease severity and obtain adequate yields, particularly the combination of susceptible and resistant varieties. Use of healthy seed tubers for planting must be guaranteed. Sometimes seed can be infected with *P. infestans* without blight symptoms. So far, there is no evidence that infected seed can be "cleaned" or healed with fungicides [40].

Bekele and Tharmmasak [41] had done a research on the effect of intercropping on potato late blight, *Phytophthora infestans* (Mont.) de Bary development and potato tuber yield in Ethiopia. The result prevailed that, all potato-garlic ratios exhibited superior performance when compared to the fungicide unsprayed treatment. Among the proportions, 75% garlic with 25% potato (3:1) intercropped plots showed significantly ($p < 0.05$) low disease development and high tuber yield. Moreover, at 3:1 combination of garlic to potato the land equivalent ratio (LER) was greater than 1 and the monetary values were high at both testing sites. Significant ($p < 0.05$) differences were also observed among potato varieties concerning the disease development and tuber yield. The findings of this study suggested garlic as a potential intercropping plant for the management of potato late blight disease under Ethiopian condition.

Host resistance: Host resistance to late blight is significance in integrated late blight management due to its long-term economic benefits for farmers. It also minimizes changes in the population structure of *P. infestans*, decreasing the likelihood of fungicide resistance [42,43]. The use of resistant varieties is among the most effective and environmentally safe means of managing the disease. Use of resistant varieties is one of the main components of late blight management and is especially effective under tropical conditions. According to Binyam et al. [31], onset of the potato late blight disease was delayed almost by 20 days on the moderately resistant varieties as compared to the moderately susceptible and susceptible varieties.

In Ethiopia, several new potato cultivars with resistance to late blight have been released to potato growers. However, a number of these cultivars have lost their resistance over time as virulent pathotypes emerged [44]. In Ethiopia Before, few years' 29 varieties have been released officially to the Ethiopian market. Most of these originate from EIAR-CIP breeding program including three varieties with different late blight resistance in their trails. The varieties Jalane, high level of resistance and Gudene moderate resistance were released by Holota agricultural research center in 2006. Further the local variety, white flower, highly susceptible to late blight.

Biological control: Several commercial formulations of bio-control agents have been tested for efficacy against late blight. Of many trials involving different microorganisms, including *Trichoderma harzianum*, *Bacillus subtilis*, *Streptomyces* sp., *Coniothyrium minitans* and a pool of undetermined effective microorganisms (EM 5), the most effective was the *B. subtilis* based-product Serena deer. Curiously, bacterial cells were not directly responsible for the inhibition of *P. infestans*. A cell free culture extract contained metabolites that were active against *P. infestans*. Caution must be exerted when using bio-control agents capable of producing metabolites with antibiotic activity. *B. subtilis*, an ubiquitous bacteria, can produce antibiotic compounds and little is known about the persistence of these molecules on plant products or in the environment.

Ephrem et al. [45] had done a research on biocontrol activity of *Trichoderma viride* and *Pseudomonas fluorescens* against *Phytophthora infestans* under greenhouse conditions in Ethiopia. The result, in *in vitro* antagonism test carried out between *T. viride* and *P. infestans*, showed a radial growth inhibition of the pathogen by 36.7% and a complete overgrowth of *T. viride* on *P. infestans* later, whereas *P. fluorescens* inhibited the radial growth of the pathogen by 88%. In Foliar spray of the suspensions, *T. viride* was found to be more efficient than *P. fluorescens* and mixed culture. This study revealed that the foliar application of *T. viride*-ES1 has good potential in controlling the late blight disease of potato.

Chemical method: Chemical control involves the use of chemical products capable of preventing infection or of slowing down the disease once it has started. Products used to control late blight are classified as contact, translaminars and systemic. Contact fungicides act on plant surface and stop germination and/or penetration of the pathogen, reducing primary sources of the disease. They are also known as protectant or residual fungicides. Copper fungicides and dithiocarbamates are among the most important. They only protect the area where fungicide is applied; leaves formed after application of the product will not be protected against the pathogen. Systemic products are absorbed through the foliage or roots. Translocation takes place from bottom to top, sometimes the other way round, internally through xylem and phloem. They are able to protect leaves formed after the application. They inhibit some or various specific phases of pathogen development. The constant use of certain products has caused the appearance of pathogen strains resistant to these fungicides. Translaminars are products capable of moving through the leaf but not from leaf to leaf. For this reason, leaves formed after the product has been sprayed will not be protected against the pathogen [40].

Bekele and Hailu [46] had done a research on the efficacy and economics of fungicide spray in the control of late blight of potato in Ethiopia. The result showed that, Ridomil MZ-63.5% WP that is both systemic and protectant in action gave the best control (78.8%). On the other hand, Chlorothalonil, Mancozeb and Brestan 10 did not differ significantly in respect to disease control, and gave 59.3, 43.0 and 46.8% control, respectively. However, the three fungicides significantly ($P < 0.05$) controlled late blight when compared to the control plot. They conclude that, the fungicides Chlorothalonil 50% EC and Brestan 10 can be used to control late blight. Overall, Ridomil MZ 63.5% WP gave effective control of late blight and the best return. Binyam et al. [31] also reported that, reduced rates of Ridomil application resulted in better management of potato late blight with the highest marginal rate of return. Therefore, those potato growers who can afford to buy it can use it as an alternative fungicide in late blight control.

Integrated late blight management: Effective control of late blight requires implementing an integrated disease management approach [35-37]. Integration of different management options, including cultural practices (good crop husbandry), resistant varieties and fungicides is required to control late blight. Late blight of potatoes can be controlled successfully by a combination of sanitary measures, resistant varieties, and well-timed or scheduled chemical sprays [27]. In integrated management of disease, the host resistance contributes to reducing the number of sprays required to keep late blight below an economic threshold level. Integration of late blight management has often been thought as one of the better disease management options in tropical regions where fungal inocula are abundant in most months of the year [30]. These include: variation of frequency of application based on host resistance of potato varieties (reduced fungicide use), early planting and improved variety (early and mid-maturity, tolerant variety [47].

For effective control of late blight, integrated management must be adopted by all producers, including large and small-scale farmers. In Ethiopia for the past 10 years integrated disease management of late blight (IDM-LB) has been adopted as a strategy. Integrated disease management of late blight includes host resistance in combination with cultural practices such as early planting dates and reduced dose and rate of fungicide use. Experimental plots with IDM-LB yielded 50% and 75% more than late planting (planting during the month recommended for potato growing) alone [48]. According to Binyam et

al. [16], cost effective management of late blight was obtained by integrating potato varieties with the lowest rate of Ridomil application. The integration of reduced rate of Ridomil application and moderately resistant potato varieties, in the management of potato late blight is very important in reducing environmental pollution and input cost of the fungicide, and increase in production and profitability of high quality potato tuber yield.

Potato tuber moth (PTM)

Importance of potato tuber moth: The potato tuber moth (PTM) *Phthorimaea operculella* Zeller (Lepidoptera: Gelechiidae), a cosmopolitan dominant pest in sub-tropical and tropical areas, and it is responsible for very important losses in potato production [49]. It is ubiquitous pest on all continents except in the arctic [50]. PTM is most serious on potato, but has also become increasingly important on tobacco [51] and tomato [52]. The larvae cause direct damage to the tubers by infesting them underground and control using chemical insecticide sprays is difficult with uncertain results [18]. *Phthorimaea operculella* causes serious damage to stored potato through its larval tunnelling and feeding, which lead to partial or complete rotting by subsequent infestation by fungi and/or bacteria [17]. The PTM is the single most significant insect pest of potato (field and storage) in North Africa and the Middle East [53]. Tuber infection by various other insects and secondary diseases that subsequently attack damaged tubers can cause dramatic losses. Annual losses in storage alone range from 30% to 70% in India and similar losses occur in the Middle East, North Africa, and South America [54,55]. In the absence of adequate control measures, storage losses in India have been reported to vary between 25% and 100% [48,55].

P. operculella is considered the most damaging insect pest of potatoes in developing countries in the tropics and subtropics regions [56-58]. Potato tuber worm can cause significant economic damage. Potato tuber worm infestations accounted for losses of 42% of the stored crop in Ethiopia and 86% of the stored crop in Tunisia [20]. In 2003, economic losses due to potato tuber worm damage were approximately 2 million US Dollar in Oregon, and have increased significantly in 2004 and 2005 [14].

Host plants: *P. operculella* also known as potato tuber moth or tobacco split worm. It is an oligophagous pest of crops, feeding on the *Solanaceae* family only. *P. operculella* larvae are primarily feeding on potatoes, followed to other plants such as tomatoes, tobacco, eggplants, peppers and wild solanaceous plants or *Datura* [15]. Potato tuber moth is most serious on potato, but has also become increasingly important on tobacco [51] and tomato [52]. The most commonly attacked plants of economic importance are potato, tobacco, eggplant [59].

Damage symptoms of *P. operculella* on potato: *P. operculella* is one of the serious pests on the potato production in the worldwide (Rondon et al., 2007a) and it is both a pre and post-harvest problem. *P. operculella* larvae may cause economic losses in potato production into two ways: first, when farmers observe *P. operculella* infestation in his field, he may force to sell his product prematurely in low price. Second, it's reduced both seed and ware quality which lead to low market price. The larvae feed and create mining on potato leaves, stems, petioles, and tubers in the field and in the store. As a result, the newly hatched larvae eating the leaf tissue without damaging the epidermis [14,60]. Hence, infested plants can be known by larvae make mines symptom in the leaves, stems and webbing together of adjacent leaves [15].

Rapidly moving larvae penetrate the tubers, form galleries coated with silken threads. Larval excrement is pushed out and ejects frass through the holes, which can be noted immediately after larvae start mining activity (Figure 2). The larvae tunnel deep into the flesh creating dirty looking or black tubers filled with larval excrement. Therefore, the presence of even one larva is enough to spoil and destroy a tuber which can release an bad odor and rendering them unmarketable and unfit for human consumption or seed purpose [61,62].



Figure 2: Feeding damage of *P. operculella* on potato.

Life cycle and ecology of *P. operculella*: Potato tuber moth (*Phthorimaea operculella*) a complete metamorphosis pest and has four life stages: adult, egg, larva and pupa. Adult's *P. operculella* have silvery-gray in color, have a narrow body, and are approximately 10 mm in length. Forewings have dark spots, with folded external edge and a fringe longer than it is wide. The forewings have dark spots as shown "X" pattern for females and 2-3 dots on males and both pairs of wings have fringed edges Plate 2 [63]. It is mostly active during the night such as mating and oviposition and poor fliers behaviour [64].

P. operculella females begin laying eggs 2 days after emerging from their cocoons and can live 30 days. Laying eggs prefer on the lower sides of plant leaves and sometimes on leaf stalks, stems, exposed potato tubers, lumps of soil in the field, on potato tubers at the buds and on bags in store houses [14,15]. *P. operculella* female can crawl through soil cracks or burrow short distances through loose soil to find tubers on which to deposit eggs [14]. Female fecundity is 150-200 eggs, with 165 on average [15]. Once the eggs hatch, the larvae feed on the foliage or tubers depending on where the eggs were deposited. The larvae mature in 16 to 24 days (Alvarez et al., 2005) or 11-14 days, while larvae pass through 4 instars, the pupal stage lasts 6 to 9 days.

Its egg is smooth, oval, translucent, and range in color from white or yellowish to light brown, about 0.4-0.6 mm in length and 0.4 mm in width. Freshly laid eggs are white, turn to yellowish to brown, and finally turn black just prior to hatching. The larvae are white or yellow with a brown head and mature or older larva color changes from white or yellow to pink. Larvae feed on leaves throughout the canopy, but prefer the upper foliage. Plate 3 *P. operculella* larvae form tunnels under the epidermis of leaves and stalks. One larva makes 3-4 tunnels, gradually filling them with excrement and creates twisting tunnels in tubers [15]. *P. operculella* Pupae are smooth and brown and are often enclosed in a covering of fine sediment. About 5.5-6.5 mm in length

and it develops in a silky cocoon of grayish silvery color that reaches 10 mm in length. Larvae close to a population drop from the infested foliage to the ground and may burrow into the tuber to complete its life cycle. Moreover, pupation occurs inside hidden cocoons located in various shelters such as under dust, on bags/sacks, in floor cracks. Rarely *P. operculella* pupae can be found on the surface of the tubers, most commonly associated with indentations on the tuber eyes, but usually are not found in the tubers.

The life cycle complete in short period in summer ranging from egg to adult 22-30 days and long in winter to 2-4 months. The optimum temperature requires for moth development is ranging from 22-26°C and the air humidity levels of 70-80%. However, considering temperature factors Pucci et al. [65] indicated that if the ambient temperature is at 25°C or higher, they will stop ovipositing. *P. operculella* does not normally enter diapause in ontogenesis. This allows it to continuously reproduce and has overlapping generations when, suitable temperature and food is available such as potato tubers in seed or ware potatoes storehouses [15,66].

Management practices: Cultural Control: Cultural control is a good practice for the supporting and reducing of *P. operculella* damage to potato tubers and improves the yield and quality of potato. Weeds and any volunteer plants can act as alternate hosts for *P. operculella*, and should be eliminated from fields and surrounding areas. Moth populations are maintained in plant and tuber debris in the field in the absence of the main crop. Therefore, timely field cleanliness and discard infested tuber seeds are an important preventive measure. Alvarez et al., Chumakov and Kuznetsova outlined healthy seed tubers planting and good coverage of potato seeds with soil 1 to 2 inches of which, significantly reduces tuber infestation by *P. operculella*. Cull piles should be destroyed to reduce overwintering stages of *P. operculella*. After harvesting tubers soon transported overnight in the field as to prevent these potatoes could act as egg laying for *P. operculella*.

Continuous cropping of host plants increases infestation levels, which provide more favorable conditions for the reproduction of *P. operculella* linked with that particular host. Therefore, crop rotation helps to reduce and disturb the population build-up of *P. operculella* in the field and preventing it from attacking the following year's crop [67]. The rotation of crops has proved to be the most cultural control measure against those pests, which are mono phagous or restricted feeders, slow breeder and having a longer duration of feeding phase [68]. Another important aspect is keeping the soil moist *via* overhead irrigation prevents soil cracking. The daily irrigation probably closed soil cracks, reducing tuber moth access. PTW also may have died from soil oxygen reduction due to water saturation, and/or their mobility may have been reduced by wet soil, decreasing their ability to find a tuber to infest.

Host resistance: Host plant resistance is a key component of any integrated pest management (IPM) program. Resistant crop varieties, as a cultural management practice, are often used as a foundation for sound IPM strategies. Host plant resistance work in potato, thus far, has not yielded any material with appreciable levels of resistance [21]. The first line of defense in the control of insect pests is often host plant resistance. Several wild species of potatoes with high glandular trichomes and low concentrations of glycoalkaloids were used in breeding experiments to develop insect-resistant cultivars. In field experiments, glandular trichome clones showed a high level of resistance to potato pests, including PTM [69]. The cultivation of resistant varieties could reduce the chemical application and increases

the effectiveness of alternative control methods [70]. It is known that some varieties such as earliness and deep tuberization that are set deeper in the hills have less potential for tuber infestation.

Biological control: Biological control is one of the first assessments for a successful integrated pest management program, following establishment of a monitoring program, should be to determinate the role of natural enemies. *Parasitoid wasps* such as, *Copidosoma* spp. and *Apanteles* spp. are important in PTM control in other parts of the world. A few parasitoid wasps have been collected from PTW in the Pacific Northwest, but the importance of parasitoids in potato fields is unknown. Also unknown is the role of common predators such as lady beetles, big-eyed bugs, and ground beetles in controlling PTW. Choose insecticides that preserve natural enemies. Insect diseases caused by bacteria, viruses, and nematodes have been developed to control insect pests, including PTW. Microbial control of PTW is not yet developed for commercial use, but has potential in the future.

The biological control agents, *Bacillus thuringiensis* (Bt) and *granulosis virus* (GV), have also been used in different regions of the world to control PTM. Due to the success achieved with Bt, a variety of endotoxin genes are currently being used to genetically transform potato to develop PTM-resistant lines [71]. Some of these potato lines have shown a high level of resistance to PTM during experimental field trials [69]. The two larval parasitoids (*Orgilus lepidus*, and *Apantelessubandinus*) of PTM and aphids were present in all areas where potatoes were grown and that they exerted considerable control pressure on these two key pests [72]. Mortality of potato tuber moth larvae in detached-leaf bioassays on the transgenic plants was 80% to 83% after 72 h of feeding, compared to 8% on the non-transgenic 'Spunta' [73].

Storage management: *P. operculella* is a year round problem under storage conditions due to continuous reproduction favoured by suitable environmental condition and food availability [65,66]. Hence, the length of the life cycle of *P. operculella* is highly dependent on temperature and high accumulation of tubers on the shelf [19]. Therefore, a frequent monitoring store of potatoes is importance by using pheromone traps based on signs of rot and insect damage. This storage observation helps to prevent the spread and development of *P. operculella* and to decide control options. Cultural control under storage is the most important option involves removal of damaged tubers and sanitation of storage facility walls, floors, and ceiling [60]. In addition to this, treat tubers and facility with recommended chemicals, if this pest was detected in the previous year. However, pyrethroids chemicals are good for potatoes stored for seed purpose but Bt spray can be used on tubers which are mainly used for human consumption [63].

Chemical control: The base line of pest management should be based on field-specific information. *P. operculella* populations vary greatly from field to field as well as area to area. Therefore, crop field should be monitored regularly by using through pheromone traps to determine *P. operculella* populations and helps to know time of insecticide applications [74]. Insecticides for control of PTM in the field should be applied only if the moth catch in pheromone traps exceeds the appropriate action threshold. *P. operculella* control in potato stores practiced by applying dust chemicals on the potatoes with malathion or carbaryl powder [75]. In Ethiopia the systemic insecticide diazinon 60% EC used effectively to control *P. operculella* in the field and storage [76]. Rondon et al. and Gill et al. recommended the exact insecticide application on *P. operculella* to reduced yield damage of potato when the moth catch of pheromone traps exceeds

15-20 adults per trap each night. Insecticides can control *P. operculella*, but the treated potato tubers in contact with systemic insecticides, can be used only as seed because of the health hazard from residues if used in ware [77].

Integrated Pest Management (IPM): Integrated Pest Management is a broad-based approach that integrates a range of practices for economic control of pests with, least possible hazard and environmentally sounds. Before applying IPM program comprehensive information on the life cycles of pests, ecology and plant pest interaction required. It uses all suitable pest control techniques in a compatible manner to reduce pest populations below economic injury levels. In IPM a variety of complementary pest control measures: cultural practice, host resistance varieties, biological control, botanical and the last option chemical control that should be both economic control and environmentally sound [53]. IPM in potatoes is similar to that of other crops and there are beneficial species used for biological control that occur in potato crops worldwide. Cultural control and selective pesticide applications [72] are very important in IPM program for *P. operculella* management.

Results, Discussion and Conclusion

Potato (*Solanum tuberosum* L.) is the fastest growing major crop in the developing world with important economic impact on many resource-poor farming families. However, in Ethiopia, the yield per unit area of potato is very low compared to those of other countries. There are many factors that reduce the yield of the crop among which the diseases like late blight and insect like tuber moth which play an important role in reduction of the yield. Therefore understanding its development, epidemiology and life cycle are most important in selecting and implementing its effective management strategy. In the case of late blight, there are different types of management options of which can help in reducing its effect. However, because of its new strain development, there is no single effective management strategy of this disease. Therefore, adopting integrated disease management (IDM) approach is the most effective, environmentally safe and low costly to the users.

Potato tuber moth is the most important constraints of potato production in Ethiopia and it causes up to 42% yield loss in storage. Chemical management of *P. operculella* is challenging because of the protected tunnelling behaviour of larvae in foliage and tubers. Because of this, the pest has developed resistance to many traditional organophosphate, carbamate, and pyrethroid insecticides. So that, in order to reduce the impact of this key insect pest we have to develop an integrated pest management approach: including appropriate cultural practices, using pheromone traps, using biological control, host plant resistant, using botanicals and appropriate rate and time of chemical applications. Integrating of many management options helps in reducing the risk of pesticide resistance development, reduce the impacts of the insecticide to environment, non-targeted organisms, beneficial insects such as natural enemies and human hazards. Therefore, developing integrated pest management strategies are needy and vital in relative to single management tactics.

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