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Integrated Management of Potato Tuber Moth (Phthorimaea operculella) (Zeller) in Field and Storage

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ABSTRACT
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 tunneling behavior 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. It is very important to store our products at appropriate storage conditions in order to reduce the damage from insect pests as well as other organisms. Field as well as storage sanitation is the best and most effective way of reducing the damage of potato tuber moth and can improve the quality of our products. The development of an appropriate integrations of management options is very important rather than dealing with conventional use of insecticides.
Keywords: Biological control, Botanicals, Insect pest, Pheromone traps, Tunneling behavior, Yield loss

1. INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of mankind's most valuable food crops (FAO, 2004), and the most important vegetable crop in terms of quantities produced and consumed worldwide (FAO, 2005). Ethiopia has possibly the highest potential for potato production of any country in Africa (FAO, 2008). A number of production problems account for the low yield of potato production in Ethiopia including, absence of well adapted varieties, sufficient and high quality seed potatoes, adequate storage and marketing facilities, problems of disease, especially late blight, early blight, bacterial wilt and tuber rots (APR, 1979/80) and insects including potato tuber moth are economically important (Olanya *et al*., 2004). The potato tuber moth, *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelichiidae) is a major pest of potato (*Solanum tuberosum* L.) worldwide (Fenemore, 1988). It is one of the most damaging potato pests in tropical and subtropical areas (Lagnaoui *et al*., 2000). Potato tuber moth (PTM) is one of the most important constraints to potato production worldwide (Rondon *et al*, 2007). Larvae develop in foliage and tubers of potato causing direct losses of edible product (Larrain *et al*., 2007).

The moth has high reproductive potential and is apparently developing resistance to some insecticides. It can cause damage to foliage and to tubers in the field, but has especially high potential to destroy potatoes in storage, sometimes to nearly total loss (Lutaladio *et. al.* 1995). The principal economic damage occurs toward the end of the growing season when tubers become exposed and are infested by PTM prior to or during harvest (Lacey *et al*., 2007). Infested tubers may result in rejection of entire loads if the level of infestation is high (Jensen *et a*l., 2005). The main damage caused by this insect is to stored tubers; in warm climates losses can reach 100% (Lagnaoui *et al*., 2000). It leads to partial or complete rotting by subsequent infestation by fungi and / or bacteria. In this case, the infested tubers become completely unmarketable (Moawad and Ebadah, 2007).

Potato tuber moth (PTM), *Phthorimaea operrculella,* is a caterpillar insect pest that attacks potato plants in field and storage causing great damage to foliage and tubers (Ibrahim *et al*., 2001) 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 (Larrain *et al*., 2007). 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 (Haiba and Abd-El Aziz, 2008). Conventional control methods are not very successful because the larvae pass a major portion of their life inside the tubers (Haiba, 1994). Hence, considering the importance of this key insect pest, the present review initiated with the objective, to review the importance of potato tuber moth in field and storage, and its management options.

2. POTATO TUBER MOTH (PTM)

2.1. Importance of Potato Tuber Moth

The potato tuber moth (PTM) *Phthoritnaea 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 (Das *et al.,* 1982). It is ubiquitous pest on all continents except in the arctic (Visser, 2004). PTM is most serious on potato, but has also become increasingly important on tobacco (Van Vuuren *et al*., 1998) and tomato (Gilboa & Podoler, 1994). The larvae cause direct damage to the tubers by infesting them underground and control using chemical insecticide sprays is difficult with uncertain results (Larraín *et al*., 2009). *Phthorimaea operculella* causes serious damage to stored potato through its larval tunneling and feeding which lead to partial or complete rotting by subsequent infestation by fungi and / or bacteria (Moawad and. Ebadah, 2007). The PTM is the single most significant insect pest of potato (field and storage) in North Africa and the Middle East (Fuglie *et al.*, 1992). The larvae mine the foliage, stems, and tubers in the field and tubers in storage. 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 (Raman and Palacios, 1982; Saxena and Rizvi, 1974). In the absence of adequate control measures, storage losses in India have been reported to vary between 25% and 100% (Nirula, 1960; Saxena and Rizvi, 1974; CIP, 1988).

P. operculella is considered the most damaging insect pest of potatoes in developing countries in the tropics and subtropics regions (Fenemore, 1977, 1980, 1988). Potato tuberworm can cause significant economic damage. Potato tuberworm infestations accounted for losses of 42% of the stored crop in Ethiopia and 86% of the stored crop in Tunisia (Roux *et al*., 1992; Sileshi and Teriessa, 2001). In 2003, economic losses due to potato tuberworm damage were approximately 2 million US Dollar in Oregon, and have increased significantly in 2004 and 2005 (Rondon, 2007).

2.2. Identification and Biology

Potato tuber moth (*Phthorimaea operculella*) has four life stages: adult, egg, larva, and pupa (Rondon *et al*, 2007). The adult has a narrow silver-grey body approximately 8 mm long, with grey-brown wings spanning 12mm speckled with small dark spots (Dimsey, 2008). Forewings have dark spots (two to three dots on males and a characteristic "X" pattern on females). Both pairs of wings have fringed edges (Rondon *et al*, 2007). The moths are active mainly at dark, but during the day can be seen flying sporadically within potato crops (Foot, 1998). The moth is distinguished from other solanaceous-feeding moths by a costal hair pencil on the hind wings of the male (Meyrick, 1885). Females begin laying eggs 2 days after emerging from their cocoons, and will deposit 50-100 eggs over two weeks. Oval eggs are laid on the underside of leaves and on exposed potato tubers. When the eggs are first laid they appear a pearly white colour, but change to yellow when mature, and black just prior to hatching (Foot, 1998). Moths can crawl through soil cracks or burrow short distances through loose soil to find tubers on which to deposit eggs. Eggs are less than 0.02 inch, spherical, translucent, and ranging in color from white or yellowish to light brown. Larvae usually are light brown with a brown head. Mature larvae (approximately 3⁄8 inch long) may have a pink or greenish color (Rondon *et al*, 2007).

The larva (caterpillar) on hatching is 1-2 mm long and grows through four instars (stages) to reach a length of 15-20 mm (Foot, 1998) or about 12 mm (Dimsey, 2008). Young larvae are grey or yellow-white colour; whilst mature, healthy larvae are display a pink or green colour. All instars have a dark brown head. The pupa is formed in silk cocoon covered with soil particles and debris for camouflage. Pupation (change from a larva to a pupa) occurs among dead potato leaves, on the soil, or on stored potato tubers (Dimsey, 2008; Foot, 1998).Larvae feed on leaves throughout the canopy but prefer the upper foliage. They mine the leaves, leaving the epidermal areas on the upper and lower leaf surface intact. Larval feeding results in necrotic areas on leaves. Leaf damage is unremarkable and not always visible without careful scouting. Larvae close to pupation drop from infested foliage to the ground and may burrow into tubers. Exposed tubers are most vulnerable to PTM damage. Larvae can move via cracks in the soil (Rondon *et al*, 2007). Ultimately, larvae spin silk cocoons and pupate on the soil surface or in debris under the plant. Pupae occasionally are found on the surface of tubers, most commonly associated with indentations on the tuber eyes, but they usually are not found inside tubers. PTM pupae (approximately 3⁄8 inch long) are smooth and brownish and often are enclosed in a covering of fine sediment. Preliminary studies in Oregon indicate that PTW adults potentially can emerge from soil at depths up to 4 inches. Once adults emerge, mating occurs. Within a few hours, depending on temperature, females seek a host on which to lay eggs (Rondon *et al*., 2007.

2.3. Host Plants

The potato tuber moth is an oliphagous insect confined to species in the family Solanaceae, including both cultivated and feral plants (Broodryk, 1971; Fenemore, 1988). The cash crops attacked by *P. operculella* include *Solanum tuberosum*, *Nicotiana tabacum*, *Solanum melongena,* and *Solanum lycopersicum* (Fenemore, 1988), while some of its weed host species include *Solanum dulcamara*, *S. rostratum,* and *Datura stramonium* (Potato Association, 2008).

Potato tuber moth is most serious on potato, but has also become increasingly important on tobacco (Van Vuuren *et al*., 1998) and tomato (Gilboa & Podoler, 1994). The range of hosts is limited to the family Solanaceae. The damage has also been reported on eggplant and other solanaceous crops and weeds (Rahalkar *et al*., 1985). The most commonly attacked plants of economic importance are potato, tobacco, egg plant, and, occasionally, tamarillo leaves. The native weed poroporo may be heavily attacked (Foot, 1998). It cans also attack "Apple of Peru" (*Nicandra physaloides*) and Thornapple (*Datura stramonium*) (Anonymous, Undated).

2.4. Symptoms and Damage

On leaves, damage is caused by the tunnelling of the caterpillars between the upper and lower epidermis of the leaves. The mines have a blotchy appearance, and are often associated with brown and dying bits of tissue. As the caterpillars increase in size, they tend to mine near the leaf base, and even down into the petiole and stem, which becomes blackened. In young plants this may result in withered and dying shoots. In potatoes, towards the end of the season, the caterpillars move down the plant towards the exposed tubers in the soil. Here the first sign of infestation is the appearance of grey or whitish frass on the surface of the tubers, usually near the "eyes". Infestation can continue in the potato store and infested potatoes soon become filled with unsightly black tunnels. In tobacco, damage is most serious to the transplanted crop in hot, dry conditions (Anonymous, Undated).

Potato tuber moth (PTM) suffers extensive damage on both foliage and tubers. This is caused by the larvae, which normally spend their entire lives in either one of these food sources; the only exception to this is when infested foliage is destroyed, forcing larvae to abandon it and search for tubers (Foot, 1998). Foliage damage includes transparent blisters, eaten out patches on leaves and cavities in leaf stalks. The tops of heavily infested potato plants die prematurely, which causes yield reduction. Tubers developing under these plants become infested by larvae from the top of the plant, or by new larvae developing from eggs laid on the tubers (Dimsey, 2008). Tuber-mining larvae usually enter through the "eyes" from eggs laid nearby, and make slender, dirty-looking tunnels throughout the tuber. An infested tuber can be identified by mounds of frass (droppings) at the tunnel entrances. High levels of tuber infestation occur in the field during summer, and stored potatoes can suffer severe damage all the year round (Dimsey, 2008; Foot, 1998). The larvae tunnel through tubers allowing the entry of fungal and bacterial pathogens (Hanafi, 1999). Egg laying on the tubers and development of the larvae continues as potatoes are harvested and put into storage (Dimsey, 2008).

2.5. Life Cycle and Clemet

The life cycle of potato tuber moth can be completed within 20 to 30 days and there may be as many as 12 generations in a single year (Raman, 1980). Adult tuber moths live for 10 to 15 days and during this time the females lay clusters of eggs on potato plants (leaves, stems, and tubers), storage containers (sacks, boxes, etc.), and dirt or debris surrounding tubers (Raman, 1980). Larvae typically emerge from the eggs after 5 days of incubation (Goldson and Emberson, 1985) and begin feeding on leaves, stems, and tubers. Larval mining on the plant results in the loss of leaf tissue, death of growing points, and weakening or breakage of stems (Raman, 1980), all of which can reduce yield. Tuber mining results in tubers that are not marketable or consumable and renders tubers susceptible to infection by potato pathogens (Alvarez *et al*., 2005). After 8 days of feeding, the larvae pupate and emerge as adults after 6 to 9 days (Alvarez *et al*., 2005). *P. operculella* does not have true diapause and can produce as many 18 generations in a year when environmental conditions in the field and in non-refrigerated storages are favorable (Kabir, 1994).

Potato tuber moth lay tiny; pearly white eggs singly or in clusters of up to six on sheltered spots on the plants, on the ground near the plants, or on exposed potatoes. These hatch in about a week, and the newly hatched larvae wander around briefly before eating their way into leaves, stems or tubers. The rest of the larval development (passing through four instars) takes place within the plant tissues, and occupies up to three weeks (depending on temperature). The caterpillars then leave the plant, moving down to the soil, and spin a loose cocoon encrusted with soil and leaf fragments either here or just below the skin of a tuber. Pupal development takes about a week, but may be much longer in the winter months. During the summer season, the whole cycle occupies about a month, but may extend to ten weeks in the winter, with no diapauses (Unknown, Undated). The moths are very short-lived (Anonymous, Undated).

Potato tuber moth prefers hot dry summers. Temperature is reported to be critical for rapid increase of PTM. Average daily temperatures between 20-25 $^{\circ}$C are optimum for potato tuber moth development (Raman, 1988). As many as 6-8 generations may occur in the field during summer. As the temperature declines in autumn, so does the population and the moth life cycle lengthens to a maximum of 20-24 weeks over winter (Dimsey, 2008). As a result generations are not distinct, and between December and April every stage of the life cycle may be present in abundance. In midsummer a complete generation spans 4-5 weeks: eggs hatch in 2-6 days, larvae mature in 16-24 days, pupae hatch after 6-9 days, and adult females begin to lay eggs after 2-4 days. As the temperature drops in autumn the population declines, and the duration of the life cycle gradually lengthens until in winter it spans 20-24 weeks. By August-October the overwintering population consists almost entirely of pupae. These hatch in November with the onset of warm, dry conditions, to begin the next summer population explosion. In stored potatoes the population continues to breed all the year round, the length of the life cycle depending on storage temperature (Foot, 1998).

3. GENERAL MANAGEMEN PRACTIECIES

The most effective management program combines cultural, biological, and chemical approaches. A number of insecticides have proven effective in controlling PTM. Since this pest prefers foliage rather than tubers, and tuber infestation is reduced when a full or partial canopy is present, early use of insecticides may not be warranted (Rondon *et al*., 2007).

3.1. Cultural Control

Many cultural practices that are used by farmers to improve the yield and quality of potato can also limit the development of potato tuber moth (PTM) and minimize damage to tubers (Fuglie *et al.*, 1993; Hanafi, 1998). Cultural methods reported to reduce PTM include: farmers should avoid planting seed tubers infested with tuber moth and when crop rotations are being planed, potato field should be located as far as possible from previous potato plantings. Any volunteer potato plants growing in uncultivated areas and other crops should be destroyed (Hanafi, 1999), which are source of next year's populations (Rondon *et al*., 2007) is very important in rescuing the population and damage of PTM. Another important aspect is Keeping the soil moist via overhead irrigation prevents soil cracking. This is especially important later in the season when vines are beginning to die. In research at Oregon State University, applying 0.1 inch of water daily through a center pivot irrigation system from the time of vine kill until harvest decreased PTM tuber damage and did not increase fungal or bacterial diseases. 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 (Rondon *et al*., 2007).

PTM prefer green foliage to tubers for egg laying and feeding. When foliage starts to decline, tuber infestation increases. Adults move into the soil via soil cracks to find shelter from the light and to lay eggs on tubers, while larvae do so to find food. Thus, the length of time between desiccation and harvest is crucial. The longer dead vines and undug tubers remain in the field, the greater the likelihood of tuber infestation. Tubers that are exposed or close to the surface are at high risk for PTW damage. Do everything possible to maintain more than 2 inches of soil over the tubers during the season. Covering hills with 1 to 2 inches of soil immediately after vine kill significantly reduces tuber infestation. A rotary corrigator can be used. Research at Oregon State University found that rolling of potato hills in sandy soil caused soil to slough off the hill, resulting in increased PTM damage. Thus, rolling is not recommended in areas with sandy soils.
(Rondon *et al*., 2007).

3.2. Pheromone Control

Potato tuber moth pheromones have been used extensively in monitoring adult male moth (Raman, 1982; Von Arx *et al*., 1987; Hanafi, 1998). In areas where the tuber moth is a problem, it is best to use pheromone traps to base control decisions on moth catches and the growth stage of the crop (Hanafi, 1999). The use of synthetic sexual pheromones to interfere with reproduction offers a non-traditional way to manage pest control that does not use insecticides. Sexual pheromones are species-specific and highly selective, and since they are not toxic and do not represent health risks to humans and animals, they are valuable tools in integrated pest control management (Larraín *et al*., 2009). The use of pheromone traps for mass trapping is an insect control method that has been sufficiently researched (El-Sayed *et al.,* 2006). Pheromone interferes with insect mating, reducing the future larvae population and subsequent damage. Traps can also be used with the degree-day calculation method for decision-making on the application of insecticides in pest control (Kumral *et al*., 2005).

Sexual pheromones have shown to be a tool to reduce the reproductive potential of numerous insect species, and are particularly important in the integrated management of pests, as their active ingredients affect specific insects only (Larrain *et al*., 2007). In addition, the PTM sex pheromone has been used as a tool for monitoring PTM populations under field and storage conditions. Pheromone traps are used to indicate the time at which insecticide applications are required, according to PTM population densities. In turn, the reduction of insecticide usage helps to protect the natural enemies of PTM in the field (Raman, 1988).

3.3. 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 (Rondon *et al*., 2007).

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 (Mohammed *et al*., 2000). Some of these potato lines have shown a high level of resistance to PTM during experimental field trials (Mohammed, 2003). The two larval parasitoids (*Orgilus lepidus*, and *Apanteles subandinus)* 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 (Horne & Page, 2009). 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' (Douches *et al*., 2002).

There are a number of indigenous wasp parasitoids which will attack potato tuber moth and which can reach quite high levels by the end of the season. These, however, would not be sufficient to keep the pest from causing significant damage in heavy infestations. During the "sixties", a highly effective parasitic wasp (*Copidosoma koehleri*) was introduced from South America and soon spread through the potato-growing areas. It lays its eggs in the moth eggs, and these sub-divide and multiply within the growing caterpillar until they fill its body in the last instar and emerge as adults wasps, ready once again to parasitize new eggs. Of course, parasitic control of the pest will be disrupted with the use of harsh insecticides (Anonymous, Undated).

Bacillus thuringiensis kurstaki (Bt), an aerobic soil bacterium, produces an insecticidal crystal protein during sporulation (McGaughey and Whalon 1992, Barton *et al*., 1987). These insecticidal crystal proteins have to be ingested by the insect where they bind to specific receptors in the midgut of target pest species and cause death (Gill et al. 1992). These Bt Crystal proteins are nontoxic to humans, animals, birds, and most beneficial insects and have been used as biological insecticides to control agricultural insect pests for >30 yr (Koziel *et al*., 1993). The genes (*cry* genes) which encode Bt crystal proteins have been cloned, sequenced, and transformed into various crops and are now available commercially (Barton and Miller 1993). Transformation of potato with a wild type *cryIA-Bt* toxin gene resulted in potato tuber moth mortality of only 20-60% (Hudy, 1998). A *Bt-cry5* toxin gene, with activity against both Lepidoptera and Coleoptera (Tailor *et al*., 1992), was codon-modified to increase its expression level in the plant. Douches *et al*. (1998) transformed this gene into potato to obtain control of potato tuber moth. Detached-leaf bioassays with *Btcry5* potato lines demonstrated a high expression level of *Bt-cry5* protein in the leaves and up to 96% mortality of potato tuber moth with larvae in foliar assays (Westedt *et al*., 1998, Li *et al*., 1999). The use of chemical insecticides in PTM control was dangerous for humans and generates potatoes unfit for consumption (Von AIX *et al.,* 1987). Among the possible alternatives to chemicals, one of the most credible is the granulosis virus (Baculoviridae, Eubdculovirkke) isolated from this insect and already applied in several countries (Raman *et al.,* 1987).

3.4. 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 (Lagnaoui *et al*., 2000). 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 glycoalkaloides were used in breeding experiments to develop insect-resistant cultivars (Raman, 1988a). In field experiments, glandular trichome clones showed a high level of resistance to potato pests, including PTM (Mohammed, 2003).

The cultivation of resistant varieties could reduce the chemical treatments and increases the effectiveness of alternative methods of control. It is known that some cultivar trials, such as earliness and deep tuberization can hinder field infestation. But not factor of resistance in the tubers of *s. tubersum* varieties proved efficacious (Arnone *et al*., 1998). Resistant clons were selected from primitive cultivars and wild solanum species are at the International Potato Center of Lima (Peru) and were used as parents in a breeding program giving rise to genotypes with tuber resistance to the peruvion population of potato tuber moth (PTM) (Ramon & Palacios, 1982; Chavez *et al*., 1988; Ortiz *et al*., 1990). Varietal selection offers some opportunity to reduce potato tuber moth (PTM) damage. Varietal differences in susceptibility to PTM damage may be due to differential feeding by larvae or to adult egg-laying preferences. Also, varieties that are set deeper in the hills have less potential for tuber infestation (Rondon *et al*., 2007)

3.5. Botanical Control

In the continuous search for new pest control agents, plants are considered one of the most important sources (Moawad and Ebadah, 2007). Plant extracts were used as toxicants, oviposition repellents, growth regulators or antifeeders for many insects (Ismail, 1994; Nassar *et al*., 1997). Storing potatoes with lantana leaves nearly eliminates damage by *Phthorimaea operculella* (Zeller), the potato tuber moth (Lal, 1987). Many studies are available in reducing the PTM damage or killing the different of the insect stages of insect using the plant preparation as recorded by (Pandey *et al*., 1982; Chouvalitwongporn and Vattanatangum, 1985; Raman *et al*., 1987; Sharaby, 1988; Kashyap *et al*., 1992; Moawad, 1995). Moawad and Ebadah (2007), the higher concentration of the cardamon oil, resulted in the lower percentage of egg hatchability with the highest % in reduction eggs hatchability of 67.47% and 86.74%. The use of attractant or repellent volatile plant compounds offers a promising alternative and sustainable control measure to potato tuber moth (Das *et al*., 2007).

Neem extracts have a wide range of effects against insect pests, including repellence, feeding, oviposition deterrence, toxicity, sterility and growth regulatory activity (Jacobson, 1989; Schumutterer, 1990; Ascher, 1993; Van Randen and Roitberg, 1996). Neem extracts either from leaves or seed is very important in reducing damage due to the potato tuber moth, *Phthorimaea operculella,* during storage. In India, in simulated storage trials as well as in actual storage trials conducted in a warehouse, a 4 month protection was achieved against the pest when harvested potato and the covering material was sprayed with 5 and 10% 'enriched' neem seed extract (Sharma *et al*., 1984). Serious potato tuberworm damage to stored potato was averted also in the Sudan by spraying potato with a 2.5% neem leaf or seed extract prior to bagging (Siddig, 1987).

3.6. Chemical control

As far as insecticidal control is concerned, there are many chemicals registered for use. These include systemic granules applied at planting and foliar sprays. The commonly used chemicals have mostly been from the organophosphate and carbamate groups, but newer and less harsh insecticides are steadily replacing these (Anonymous, Undated). Susceptibility of potatoes to the potato tuber moth as well as to important diseases such as the late blight and bacterial wilt attracts large-scale use of chemical pesticides making it the second highest consumer of agricultural pesticides worldwide, after cotton (Das *et al*., 2007). Insecticides remain the chief means of control for potato tuberworm (Alvarez *et al*., 2005). Insecticides for control of PTM in the field should be applied only if the moth catch in pheromone traps exceeds the appropriate action threshold. It is extremely important to control this pest prior to harvest. Insecticide sprays are directed toward the newly hatched larvae and for this reason it is especially important that sprays are properly calibrated and the correct nozzles are used to ensure coverage. Potato producing farmers in North Africa use generally three to four insecticide applications (mainly pyrethroid) to control PTM during the spring and fall crops (Hanafi, 1999). Raman, (1988), available means to control the potato tuber moth and avoid major crop losses have left farmers with no alternatives to chemical control and, in some cases, the pesticides are applied directly to the potatoes in storage. The general utility of insecticides, however, is limited by high cost, persistence of residue in tubers and the environment, and development of insecticide-resistant pests (Douches *et al*., 2002). Chemical management of *P. operculella* is challenging because of the protected tunneling behavior of larvae in foliage and tubers and because this pest has developed resistance to many traditional organophosphate, carbamate, and pyrethroid insecticides (Bacon 1960; Shelton and Wyman 1979; Shelton *et al*., 1981; Collantes *et al*., 1986).

3.7. Integrated Pest Management (IPM)

IPM is based on a more complete understanding of insect ecology and plant-pest relationships (Dolucchi, 1987). In IPM a variety of complementary pest control measures including varietal resistance, cultural practices, and biological control are combined in such a way that is both environmentally sound and economically viable (Fuglie *et al*., 19912). IPM requires an integrated set of control options for all pests, both major and minor, that are encountered in any crop. Potato crops are no different and there are beneficial species that occur in potato crops worldwide, cultural options that are available and also selective pesticide options (Horne & Page, 2009) are very important in IPM of potato tuber moth management. A reduction in insecticide use would provide considerable economic, health and environmental benefits. Varying degrees of success have been achieved with suitable alternative control measures such as the use of natural enemies (Cruickshank and Ahmed, 1973; Callan, 1974; Mitchell, 1978), microbial control (Reed, 1969), resistant varieties (Raman and Palacios, 1982; Temerak, 1983; Nayar, 1987), genetically engineered potatoes expressing the *Bt* gene (Jansens *et al*., 1995; Peferoen *et al*., 1990) and the use of pheromones (Roelofs *et al.,* 1975; Persoons *et al*., 1976). In addition, the use of attractant or repellent volatile plant compounds offers a promising alternative and sustainable control measure to PTM (Das *et al*., 2007).

According to CIP- Kenya progress report (Undated), the KARI has conducted trials to develop Integrated Pest Management (IPM) strategies to control PTM, especially since treatment with commercial insecticides can be very dangerous. Several potentially effective components have been identified, including a mixture of *Bacillus thuringiensis* (Bt) var. kurstaki and fine sand, which protected stored potatoes for three months. Other materials being evaluated in mixtures include the granulosis virus, neem tree extract, lantana (shrubs and herbaceous perennials of the family *Verbenaceae*), and pyrethrum (a naturally occurring insecticide harvested from Chrysanthemum flowers widely grown in East Africa).

4. CONCLUSION

Potato tuber moth (PTM) is one of the most important constraints to potato production worldwide. In Ethiopia it causes up to 42% yield loss in storage. Chemical management of *P. operculella* is challenging because of the protected tunneling behavior of larvae in foliage and tubers and because this pest has developed resistance to many traditional organophosphate, carbamate, and pyrethroid insecticides. So that in order to reduce the impact of this key insect past 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. It is very important to store our products at appropriate storage conditions in order to reduce the damage from insect pests as well as other organisms. Field as well as storage sanitation is the best and most effective way of reducing the damage of potato tuber moth and can improve the quality of our products. Problems helps in making base control decisions, to interfere with reproduction like insect mating, reducing the future larvae population and subsequent damage. However there is no single effective management of this important pest. So that development of an appropriate integrations of management options is very important rather than dealing with conventional use of insecticides.

5. REFERENCES

Alvarez, J.M., E. Dotseth, and P. Nolte, 2005. Potato tuberworm a threat for Idaho potatoes. University of Idaho Extension Bulletin CIS1125: Jan 2005. Available at/http://www.info.ag.uidaho.edu/pdf/CIS/CIS1125.pdf.

Anonymous. Undated. Potato tuber moth (Lepidoptera: Gelechiidae). Pests of Field Crop Southern Africa. At (http://www.pestsandcrops.com/index_files/Page3212.htm).

APR (Annua Progress Report), 1979/80. Scientific Phythological Laboratory (SPL). Ambo.

Arnone, S., Musmeci, S., Bacchetta, L., Cordischi, N., Pucci, E., Cristofaro, M., and Sonnino,A. 1998. Research in *solanum* spp. Of sources of resistance to the potato tuber moth *phthorimaea operculella* (Zeller). Universta della Tuscia.

Ascher, K. R. S., 1993. Nonconventional insecticidal effects of pesticides available from the neem tree, Azadirachta indioca. Arch. Insect. *Biochem. Physiol*, **22**: 433-449.

Bacon OG. 1960. Control of the potato tuberworm in potatoes. *Journal of Economic Entomology*, **53**: 868-871.

Barton, K. A., and M. J. Miller, 1993. Production of *Bacillus thuringiensis* insecticidal proteins, pp. 297-315. *In* S. Kung and R. Wu [eds.], Transgenic plants, vol. 1. Engineering and utilization. Academic, San Diego, CA.

Broodryk, S.W., 1971. Ecological investigations on the potato tuber moth, *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae). *Phytophylactica*, **3**: 73-84.

Barton, K. A., H. R. Whiteley, and N. Yang, 1987. *Bacillus thuringiensis*Ñendotoxin expressed in transgenic *Nicotiana tabacum* provides resistance to lepidopteran insects. *Plant. Physiol*, **85**: 1103-1109.

Chouvalitwongporn, P. and Vattanatangum, A. 1985. Potato tuber moth control in Thailand. Working paper No. 85-14. CIP region VII.: 195-207 pp.

Callan E, 1974 Changing status of parasites of potato tuber moth *Phthorimaea operculella* (Lepidoptera:Gelichiidae) in Australia. *Entomophaga*, **19**: 97–101

Chavez R., P.E. Schmiediche, M.T. Jackson, K.V. Rmaman, 1988. The breeding potential of wild potato species resistant to potato tuber moth, *Phthorimaea operculella* (Zeller). *Euphytica*, **39**:123-132.

CIP (International Potato Center). Undated. International Potato Center: World Potato Atlas. History and Overview. KENYA. At http://research.cip.cgiar.org/confluence/display/wpa/Kenya.

CIP (International Potato Center). 1988. Integrated pest management for potatoes in developing countries; *CIP Circular* 16 1–8

Collantes LG, Raman KV, Cisneros FH. 1986. Effect of six synthetic pyrethroids on two populations of potato tuber moth, *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae), in Peru. *Crop Protection* 5: 355-357.

Crickmore, N., Zeigler, D.R., Feitelson, J., Schnepf, E. Van Rie J., Lereclus, D., Baum, J. and Dean, D.H. 1998. Revision of the nomenclature for the *Bacillus thuringiensis* pesticidal crystal proteins. Microbiol. Mol. Biol. Rev. Sep. **62**(3):807–813.

Cruickshank, S. and Ahmed, F. 1973. Biological control of potato tuber moth *Phthorimaea operculella* (Zell.) (Lepidoptera: Gelichiidae) in Zambia. *CIBC Tech. Bull.* **16:** 147–162
Dimsey, 2008. Potato tuber Moth. Vegetable -Matters-of- Facts. Victoria. Number 53.November 2008.
Das, G.P.L**.,** Magallona, E.D., Raman, K.V. and Adalla, C.B. 1992. Effects of different components of IPM in the management of the potato tuber moth, in storage. Agricultural Ecosystem and Environment., 41: 321-325.
Das, P. D., Raina, R., Prasad, A. R. and Sen, A . 2007. Electroantennogram responses of the potato tuber moth, *Phthorimaea operculella* (Lepidoptera; Gelichiidae) to plant volatiles. India. *J. Biosci*. **32**(2).
Deluchi, V., (ed.)., 1987. Integrated pest management quo Vadis? parasitis. Geneva. Switzerland.
Douches, D.S., Li, W., Zarka , K. and Coombs, J. Pett , W. and Grafius, E., and El-Nasr, T. 2002. Development of *Bt-cry5* Insectresistant Potato Lines 'Spunta-G2' and 'Spunta-G3'. Hortscience **37**(7):1103–1107.
Douches, D. S., A. L. Westedt, K. Zarka, B. Schroeter, and E. J. Grafius. 1998. Transformation of potato (*Solanum tuberosum* L.) with the *Bt-cry5* transgene to combine natural and engineered resistance mechanisms to control tuber moth. Hortic. Sci. 33: 1053-1056.
El-Sayed, A.M., Suckling, D.M., Wearing, C.H. and Byers, J.A. 2006. Potential of mass trapping for long-term pest management and eradication of invasive species. *J. Econ. Entomol*. **99**:1550-1564.
FAO, 2004. Agricultural data. Production and Indices Data Crop Primary. http://www.fao.org/ 15 2 2010).
FAO, 2005. FAOSTAT Agricultural Data. Agricultural production, crops, primary. Available at http://faostat.fao.org/faostat/collections?subset=agriculture Accessed on 10 February 2005; verified on 17 March 2005. United Nations Food and Agriculture Organization.
FAO (Food and Agriculture Organitiobn), 2008. Potato World: Africa—International Year of the Potato 2008. http://www.potato2008.org/en/world/africa.html. Date of accession: 12/5/2010.
Fenemore, P.G. 1977. Oviposition of potatotuber moth, *Phthorimaea operculella* (Lepidoptera: Gelechiidae) - fecundity in relation to mated state, age, and pupal weight. *New Zealand Journal of Zoology* 4: 187-191.
Fenemore, P.G..1980. Susceptibility of potato cultivars to potato-tuber moth, *Phthorimaea operculella* (Lepidoptera: Gelechiidae). *New Zealand Journal of Agricultural Research* 23 (4): 539-546
Fenemore, P.G. 1988. Host-plant location and selection by adult potato moth, *Phthorimaea operculella* (Lepidoptera: Gelechiidae): A review. J. Insect Physiol. 34:175-177.
Foot, M., 1998. Potato Tuber Moth Life Cycle. Horticulture and Food Research Institute of New Zealand Ltd. At http://www.hortnet.co.nz/publications/hortfacts/hf401015.htm.
Fuglie, H. Ben Salah, M. Essamet, A. Ben Temime, and A. Rahmouni, 1991.the development and adoption of integrated pest management of the potato tuber moth, phthorimaea poerculella (Zeller) in Tunisia. International Potato Center (CIP) apartado 5969. Lima, Peru.
Fuglie, K., H. Ben Salah, M. Essamet, A. Ben Temime, and A. Rahmouni. 1992. The development and adoption of integrated pest management of the potato tuber moth, Phthorimaea
operculella (Zeller) in Tunisia. Insect Sci. Appl. 14(4):501-509.
Gilboa, S. AND Podoller, H. 1994. Population dynamics of potato tuber moth on processing tomatoes in Isrel. *Entomologia Experimentalis et Applicata* 72 93): 197-206.
Gill, S. S., E. A. Cowles, and P. V. Pietrantonio, 1992. The mode of action of *Bacillius thuringiensis* endotoxins. Annu. Rev. Entomol. 37: 615-636.
Goldson, S.L. and R.M. Emberson. 1985. The potato moth Phthorimaea operculella (Zeller): Its habits, damage potential and management. Special Publ., Agron. Soc, N.Z., Christchurch, New Zealand, p. 61–66.
Haiba, I. M. 1994. Disinfestation of different varieties of potato naturally or artificially infested by the potato tuber moth, *Ph. Operculella* Zeller in the storage. J. Arb Nucl. Sci. and Appl. 27(3): 31-43.
Haiba, I.M. and Abd-El Aziz, M. F. 2008. Biochemical effects of potato irradiation on potato tuber moth, *Phthorimaea operculella* Zeller (Lepidoptera – Gelechiidae). Egypt. *Acad. J. biolog. Sci*., 1(2): 1- 11 (2008).
Hanafi,A. 1998. Integrated pest managemaent of potato tuber moth *Pthorimaea operculella* (zell) in potato field and storage in soyss Vallis of Morocco. In: Hanafi *et al*.(Eds). Pproceedings of the International Symposium on Integrated Production and Protaction of Horticultural Crops. Agadir. 6-9 May 1997. Pp. 452-459
Hanafi, A. 1999. Integrated Pest Management of Potato Tuber Moth in Field and Storage. Potato Research, 42, 373-380.
Horne, P. and Page, J. 2009. IPM in Australian potato crops and the threat from potato psyllid. Australia.
Hudy, P. S. 1998. Analysis of engineered (*cryIA[c]-Bt*-transgenic) and natural resistance mechanisms in potato (*Solanum* spp.) for the control of potato tuber moth (*Phthorimaea operculella* Zeller). M.S. thesis, Michigan State University, East Lansing.

Ibrahim, M.A., E.A. Metry, Y.A. Osman, T.M. Nasr El-Din, and M.A. Madkour, 2001. Genetically modified potato (*Solanum tuberosum* L.) resistant to potato tuber moth (*Phthorimaea operculella*). Egypt.

Ismail, I.A. 1994. Activity of *Azadirzchata indica* A. Juss extracts and Azadiiachin in determining oviposition by cotton bollworm, *Heliothis armigera* (Hubn.) Bull.Ent. soc. Egypt, Econ. Ser., 21: 75-79.

Jansens S, R. Cornelissen, R. de Clercq, A. Reynaerts and M. Peferoen, 1995. *Phthorimaea operculella* (Lepidoptera: Gelichiidae) resistance in potato by expression of the *Bacillus thuringiensis* Cry 1A (b) insecticidal protein; *J. Econ. Entomol* 88 1469–1476

Jensen, A., P. Hamm, A. Schreiber, S. DeBano, 2005. Prepare for tuber moth in 2005. Potato Progress 5, 1–4.

Jacobson, M., 1989. Focus on phytochemical pesticides, vol. 1: The neem tree CRC, Boca Raton. FL. Pp: 178

Kabir A. 1994. Laboratory studies on the oviposition and generation production of them potato tube moth, *Phthorimaea opeculella* (Zeller) (Lepidoptera: Gelechiidae). *Bangladesh Journal of Zoology* 22:25-28.

Kashyap N.P., Bhagat, R.M., Sharma, D.C., And Suri, S.M. 1992. Efficiency of some useful plant leaves for the control of potato tuber moth, *Pthorimaea operculella* (zell). In stores. J. Ent. Res. 16, 223-227.

Kumral, N.A., Kovanci, B. and B. Akbudak. 2005. Pheromone trap catches of the olive moth, *Prays oleae* (Bern.) (Lep., Plutellidae) in relation to olive phenology and degree-day models. J. Appl. Entomol. 129:375-381.

Koziel, M. G.,N. B. Carozzi, T. C. Currier, G.W.Warren, and S. V. Evola, 1993. The insecticidal crystal proteins of *Bacillus thuringiensis:* past, present and future uses. Biotechnol. Genet. Eng. Rev. 11: 171-228.

Lagnaoui, A., V. Cañedo and D. S. Douches, 2000. Evaluation of *Bt-cry1Ia1 (cryV)* Transgenic Potatoes on Two Species of Potato Tuber Moth, *Phthorimaea operculella* and *Symmetrischema tangolias* (Lepidoptera: Gelechiidae) in Peru. CIP Program Report 1999 – 2000.

Larraín, P. S., M., M. Guillon, J. B. Kalazich, F. S. Graña, and C. R Vásquez, 2007. Efficacy of different rates of sexual pheromone of *phthorimaea operculella* (zeller) (Lepidoptera: Gellechiidae) in males of potato tuber moth captures. *Agricultural Technic*. 67: 4.

Larraín, P. S., M. Guillon, J. Kalazich, F. Graña, and C. Vásquez, 2009. Effect of pheromone trap density on mass trapping of male potato tuber moth *phthorimaea operculella* (zeller) (Lepidoptera: Gelechiidae), and level of damage on potato tubers. Chilean journal of agricultural research 69(2):281-285.

Lacey, L.A., David, R. Horton, D. and Jones, C. 2007. The effect of temperature and duration of exposure of potato tuber moth (Lepidoptera: Gelechiidae) in infested tubers to the biofumigant fungus Muscodor albus. USA.

Lal, L. 1987. Studies on natural repellents against potato tuber moth (*Phthorimaea operculella* Zeller) in country stores. Potato Research 30(2): 329-334.

Li, W., K. Zarka, D. S. Douches, J. Coombs, W. Pett, and E. J. Grafius. 1999. Co-expression of potato PVY coat protein and cryV-Bt genes in potato. J. Am. Soc. Hortic. Sci. 123:218-223.

Lutaladio, N.B.; P.T. Ewell; H. Kidanemarian. 1995. Advances in Potato Research in Eastern and Central Africa. In: Root Crops and Poverty Alleviation: Proceedings of the Sixth Triennial Symposium of the International Society for Tropical Root Crops-Africa Branch (ISTRC-AB). October 22-28, 1995. Edited by M.O. Akoroda and I.J. Ekanayake. ISTRC-AB. Lilongwe, Malawi.

McGaughey, W. H. and M. E. Whalon, 1992. Managing insect resistance to *Bacillus thuringiensis* toxins. Science (Wash. D.C.) 258:1594-1600.

Meyrick, E. 1885. Description of New Zealand Micro-Lepidoptera. Transactions and Proceedings of the Royal Society of New Zealand 1868-1961. V.18:162-167.

Mitchell, B. L. 1978. The biological control of potato tuber moth *Phthorimaea operculella* (Zeller) in Rhodesia; *Rhod. Agric. J.* 75 55–58

Moawad, S.S. and Ebadah, I.M.A. 2007. Impact of Some Natural Plant Oils on Some Biological Aspects Of the Potato Tuber Moth, *Phthorimaea opercullela,* (Zeller) (Lepidoptera: Gelechiidae). Egypt. Agriculture and Biological Sciences, 3(2): 119-123, 2007.

Mohammed, A., 2003. Germline transformation and isolation of midgut related genes from the potato tuber moth, *phthoramiaea operculella*, (lepidoptera: gelechiidae). Texas A&M University.

Mohammed, A., D. S. Douches, W. Pett, E. Grafius, J. Coombs, Liswidowati, W. Li, And M. A. Madkour. 2000. Evaluation of Potato Tuber Moth (Lepidoptera: Gelechiidae) Resistance in Tubers of *Bt-cry5* Transgenic Potato Lines. *Entomological Society of America.* 93(2): 472-476.

Nassar, M.I., M.K. Omnia and A.H. Mohye. 1997. The potentiality of *Sorghum bicolor* and *Nerium oleander* extract in control of the Grey flesh fly *Parasarcophaga argyrostoma*. J. Egypt. Ger. Soc. Zool., 22: 235-251.

Nayar, N. M. 1987. Potato tuber moth and its management; Extension Bull. No. 26 (E) (Simla, India, CPRI)

Nirula, K .K. 1960. Control of potato tuber moth; *Indian Potato J* 2: 47–51

Olanya, O.M., J.J. Hakiza and C.C.Crissman, 2004. Potato production in the tropical highlands: constraints, fungicide use and the impact of IPM strategies. Growing potato in tropical highlands. Outlook on pest management- August. pp.182.

Oritz R., Iwanaga M., Raman K.V., Palacios M. 1990. Breeding for resistance to potato tuber moth, *Phthorimaea operculella* (Zeller), in diploid potatoes. *Euphytica* 50:119- 125.

Pandey U.K., Srivastava, A.K. Chandel, B.S. and Lekha, C. 1982. Response of some plant origin insecticides against potato tuber moth, *Gnorimoschema opercula* Zeller (Lepidoptera: Gelechiidae) infesting Solanaceous crops. J.Ent. Zool. 69. 267-270.

Peferoen M, Jansens S, Reynaerts A and Leemans J. 1990. Potato plants with engineered resistance against insect attack; in *Molecular and cellular biology of the potato* (eds) M Vayda and W Park (Tucson: CAB) pp 193–204

Persoons, C. J., S. Voerman, P. E. J. Verwiel, F. J. Ritter, W. J. Nooyen, and A. K. Minks, 1976. Sex pheromone of the potato tuber moth, *Phthorimaea operculella*: isolation, identifi cation and field evaluation; *Entomol. Exp. Appl*. 20 289–300

Rahalkar, G. W., M. R. Harwalkar, and H. D. Rananavare, 1985. *Phthorimaea operculella*. In: Singh, P.7 Moore, R.F. (eds.). Handbook of Insect Rearing Vol. 2. 443- 451. Elsevier, Amsterdam.

Raman, K.V. 1980. Potato tuber moth. Tech. Info. Bul. 3. International Potato Center, Lima, Peru.

Raman, K.V. 1988. Integrated insect pest management for potatoes in developing countries. CIP Circ. Intl. Potato Ctr., Lima, Peru. Vol. 16(1).

Raman, K.V. 1988. Control of potato tuber moth *Phthorimaea operculella* with sex pheromones in Perú. Agric. Ecosyst. Environ. 21: 85-89.

Raman, K.V., Booth, R.H. And Palacios, M. 19.87. Control of potato tuber iiioth *Plifhorhaea opercrilellq* (Zeller) in rustic potato stores. Tropical Science, 27: 175-194.

Raman, K. V. and Palacios, M. 1982. Screening potatoes for resistance to potato tuber worm; *J. Econ. Entomol.* 75 47–49.

Reed, E .M .1969. A granulosis virus of potato tuber moth; *Aust. J. Sci*. 31 300–301

Roelofs, W. L., Kochansky, J. P., Carde ,R. T., Kennedy, G. G., Henrick, C .A., Labovitz, J. N. and Corkin, V. L. 1975. Sex pheromone of the potato tuber worm moth, *Phthorimaea operculella*; *Life Sci*. 17: 699–706

Rondon, S.I. 2007. New Emerging Pests in the Pacific Northwest. Oregon State UniversityIntegrated Pest Management.

Rondon, S.I. S.J. DeBano, G.H. Clough, P.B. Hamm, A. Jensen, A. Schreiber, J.M. Alvarez, M. Thornton, J. Barbour, and M. Dogramaci. 2007. Biology and Management of the Potato Tuberworm in the Pacific Northwest. USA. Oregon State University.

Roux, O., R. Von Arx, and J. Baumgaertner. 1992. Estimating potato tuberworm (Lepidoptera: Gelechiidae) damage in stored potatoes in Tunisia. Journal of Economic Entomology 85: 2246–2250.

Saxena, A. P. and Rizvi, S. M. A., 1974. Insect pest problems of potato in India. J. *Indian Potato Assoc.* 1:45-50.

Schmutterer, H., 1990. Properties and potential of natural pesticides from the neem tree, *Azadirachta indica*. Annu. Rev. Entomd., 35; 271-97.

Sharaby, A.M. 1988. Effect of orange, *Citrus sinensis* (L.) peel oil on reproduction in *Pthorimaea operculella* (Zell.). Insect Sci. Applic, 9: 201-203.

Shelton A. M, and Wyman, J.A. 1979. Time of tuber infestation and relationships between pheromone catches of adult moths, foliar larval populations, and tuber damage by the potato tuberworm. *Journal of Economic Entomology*, **72**: 599-601.

Shelton A. M, Wyman, J.A. & Mayor, A.J. 1981. Effects of commonly used insecticides on the potato tuberworm and its associated parasites and predators in potatoes. *Journal of Economic Entomology* 74: 303-308.

Sharma, R.N., B.A. Nagasampagi, A.S. Bhosle, M.M. Mulkarni, and Tungikar, V.B. 1984. 'Neemrich': the concept of enriched fractions from neem for behavioral and physiological control of insects, pp. 115-128. *In* (H. Schmutterer and K.R.S. Ascher, eds.) Natural Pesticides from the Neem Tree (*Azadirachta indica* A. Juss) and Other Tropical Plants. *Proc. 2nd Int. Neem Conf.* , Rauischholzhausen, Germany, 1983.

Siddig, S.A. 1987. A proposed pest management program including neem treatments for combating potato pests in Sudan, pp. 449-459. *In* (H. Schmutterer and K.R.S. Ascher, eds.) Natural Pesticides from the Neem Tree (*Azadirachta indica* A. Juss) and Other Tropical Plants. *Proc. 3rd Int. Neem Conf.*, Nairobi, Kenya, 1986.

Sileshi, G., and J. Teriessa. 2001. Tuber damage by potato tuber moth, Phthorimaea operculella Zeller (Lepidoptera: Gelechiidae), in the field in eastern Ethiopia. International Journal of Pest Management 47: 109–113.

Temerak, S.A. 1983 Field management of the potato tuberworm *Phthorimaea operculella* (Zeller), infesting certain potato varieties through manipulation of different levels of irrigation; *Bull. Soc. Entomol.*

Egypt. **62**:153–160.

Van Randen, E.j. and Roitberg. 1996. The effect of egg load on super parasitism by the snobbery fly. Entomol. Exp. Appl., 79: 241-245.

Van Vuuren, J.J, A. Bennett and A.L. Bennett, 1998. Ovipisition site preferences of potato tuber moth, *phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae), a pest on tobacco, *Nicotiana tabacum* L. (Solanacaeae). *African Entomology* 6: 177-183.

Von Ars, K.: J. Goveder. M. Cheikh and A.B. Temime. 1987. lntegrated control of- potato tuber moth *phthorimaea opercrrlcllu* (Zeller). In Tunisia.Insect Science and its Applicatio. 4/69: 989-994.

Visser, D. 2004. The potato tuber moth *phthorimaea operculella* (Zeller),in South Africa: potential control measures in non-refrigerated store environments. University of Pretoria.

Westedt, A.L., D.S. Douches, W. Pett, and E.J. Grafius. 1998. Evaluation of natural and engineered resistance mechanisms in *Solanum tuberosum* for resistance to *Phthorimaea operculella* (Lepidoptera: Gelechiidae). J. Econ. Entomol. 91: 552-556.