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Emerging Challenges of Insect Pests in Some Horticultural Crops of Ethiopia

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ABSTRACT

For developing countries like Ethiopia, Agriculture is the center of sustainable development contributing the highest share of their national GDP and food requirements. By recognizing the significance of agriculture and its diversification for Ethiopian economy, growing attention has been given to improve the horticulture sector. Beside their important role in securing income generation, nutrition requirement, ecological balance and employment opportunities, some horticultural crops are currently under the risk of invasive insect pests highly hindering their production and productivity. Out of numerous invasive crop pests in Ethiopia, this paper attempts to analyze the history, distribution and economic importance of about four pests (among which three are the insects) that are hardly affecting the production of some mostly important horticultural crops since the last decade. White mango scale on Mango fruit since 2010; Tomato leaf miner on tomato crop since 2012; two spotted spider mite on potato crop since 2014 and African citrus psyllid on white sapote plant since 2018 are discussed. For proper understanding and relevant identification, the biology of each insect (pest) has been explained after accessing established literatures. Moreover, potential management options used in different parts of the world as well as in Ethiopia after its invasion for each pest has been discussed so that sustainable management strategies can be developed. There is no doubt that the paper provides highlight about the urgency of each pest and create awareness among responsible stake holders so that equal consideration is given for sustainably managing it to increase the productivity of each crop.

Key Words: Invasive pest, Tomato leaf miner, African citrus psyllid, White sapote, Red spider mite, White mango scale.

1. Introduction

More than 85% of the population in the rural parts of the Ethiopia is engaged in agricultural production as a major means of livelihood (Bezabih and Hadera, 2007). Realizing the importance of the agricultural diversification in the country, amplified attention has been given to improving the horticulture sector (Selamawit and Tesfaye, 2019). Horticultural crops play a significant role both in providing income generation and improving nutrition status. Because the horticultural crops species are so diverse the sector also helps in maintaining ecological balance, increases production intensification of the farmers and provide more employment opportunities as their management being labor intensive (Bezabih et al., 2014; Selamawit and Tesfaye, 2019). However, the agricultural productivity, in general, is low due to use of low level of improved agricultural technologies, associated risks of weather conditions and biotic factors including diseases and pests (Duressa, 2018; Selamawit and Tesfaye, 2019). The challenges of combating the crop pests are among the major constraints seriously affecting the sector's sustaining and accelerating production and productivity (Duressa, 2018).

Pathogens, weeds, and invertebrates cause significant crop losses worldwide, and they put a barrier to the achievement of global food security and poverty reduction (Oerke, 2006). It is estimated that over 40% of annual food production are lost due to pests (insects, diseases, weeds etc) in sub-Saharan Africa. Addressing field and storage agricultural losses could have a significant effect on food security and farm income without increasing pressure on land (Willis, 1997). In Ethiopia, pre and post-harvest yield losses due to various insect pests, diseases, weeds and vertebral pests such as birds and rodents are believed to be between 30 and 40% (Abdulahi, 2000).

Due to the number of factors such as climate change, population increase, expansion of agricultural lands, international trade, intensification of crop production through technologies such as pesticide usage, and many mores, the risk of invasive pests getting worsen in every parts of the world (Hellmann et al., 2008). The invasion and outbreak of insect pests on world's important crops is among the challenges of ensuring food security especially in the low income and developing countries. The establishment of different crop pests, mainly the insects out of their native boundaries, added to poor quarantine and monitoring measures in such deprived nations, make unreliable response and result in substantial yield losses which put not only the country in

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high risk position, but also the life of many individuals in danger.

Lack of awareness about the invasive pest species and associated risk factors among the government, farmers, policy makers and funding organizations; low level of institutional responses; reluctance and ignorance in the farming community and other stake holders; and national failure for responding early and consistently makes the pest cause its irresistible effect once become established. Although, there is great gap of information and studies regarding the nature, extent and importance of invasive insect pests, it is clear that numerous crop pests are importantly invaded Ethiopia so far. Documenting the history and capacity of distribution and associated problems of such important pests periodically can help in minimizing the potential risks of important invasive pests. In view of this, the effort is given to analyze the importance of major pests, mainly insects that are associated with some, among major, horticultural crops in Ethiopia in the last decade. White mango scale (*Aulacaspis tubercularis*) on Mango (*Mangifera indica*) since 2010 (Temesgen, 2014); Tomato leaf miner (*Tuta absoluta*) on tomato (Lycopersicum esculuntam) since 2012 (Muluken et al., 2014); two spotted spider mite (Tetranychus urticae) on potato (Solanum tuberosum) since 2014 (Muluken et al., 2016) and African citrus psyllid (Trioze erytreae) on white sapote (Casimiroa edulis) since 2018 (Tesfaye and Mulatu, 2019) are discussed in this paper. It is emphasized on biology, history of distribution, importance, nature of damage and potential management options employed anywhere, so that the reader can understand and incorporate to his/her possible future works. The significance of the information provided here as an asset for the future works, like developing sustainable management strategies including integrated pest management (IPM) and policy and decision making, is certainly high.

2. Materials and Methods

This study was conducted collecting through secondary datas from various sources and compared the previous studies for contentsanalysing and case studies. Accordingly results and discussion have made , conclusion is drawn.

3. Results and Discussion

3.1. Tomato leafminer (*Tuta absoluta* Meyrik (Gelechiidae: Lepidoptera)) on Tomato (*Lycopersicum esculuntam Mill*)

3.1.1. Tomato crop and its importance in Ethiopia

Tomato is greatly important both as a source of food and health care and it is mainly cultivated by smallholder farmers in Ethiopia. The crop is nutritionally low in calories but high in minerals magnesium, iron, potassium, phosphorus, sodium; vitamins A and C, niacin, riboflavin, thiamine and the valuable antioxidant lycopene and beta-carotene which play an important role in human health (Dias, 2012). It is widely consumed in every household in different forms including raw, as an ingredient in many dishes, sauces, salads, and drinks (Fekadu and Dandena, 2006). Although the crop is targeted by a vast number of insect pests and diseases, the tomato leaf miner, *Tuta absoluta* (Lepidoptera: Gelechiidae) is the leading obstruction in production and productivity of the crop especially where it recently invaded including Ethiopia (Gray et al., 2013; Duressa, 2018).

3.1.2. Biology of Tuta absoluta

Tuta absoluta is a member of the group of the insect order Lepidoptera in the family Gelechiidae. It has a life cycle with complete metamorphosis (Nicolas et al., 2010) and adults are nocturnal in habit. The moths usually remain hidden at day time, showing greater morning crepuscular activity, and disappear among crops by flying (Estay, 2000). During her lifetime a single female can lay a total of about 240 to 260 eggs on the aerial parts of the plant with but peak oviposition occurs at night (Riquelme Virgala and Botto, 2009; Fargalla and Shalaby, 2013). Dispersed eggs are laid on the underside of leaves especially at the apical shoot, stems and sepals to facilitate fast pest distribution (Cherif et al., 2013). There are four larval stages from first instar to fourth instar and the larva is the feeding stage of this pest causing 80 to 100% losses in tomato if it is not controlled (Nicolas et al., 2010). Female adult can live for 10 to 15 days while males can live for 6 to 7 days only and the insect exhibits 10 to 12 generations in a year (Derbalah et al., 2012) exhibiting high reproduction potential with whole life cycle completed within 30 to 35 days based on the environmental conditions (Harizanova et al., 2009).

3.1.3. History and distribution of Tuta absoluta

Tomato leafminer (*T. absoluta*) is native to South America, first described in 1917 by Meyrick from Peru (Nicolas et al., 2010) and recognized as the pest of tomato crop in 1980s in its native countries; detected in Spain in 2006 (Urbaneja et al., 2007) and spread to all Mediterranean countries, Northern Europe and the Middle East between 2006 and 2010 (Cocco et al., 2012). In African, *T. absoluta* was firstly reported in Algeria, Morocco, and Libya in 2008 and 2009 (Harbi et al., 2012) and continued to invade Egypt (Moussa et al., 2013) and Sudan (Mohammed et al., 2012) in 2010. It had accessed to Ethiopia in 2012 most probably from Sudan (Muluken et al., 2014) and Kenya in 2013 (Mohamed et al., 2015), Tanzania and Senegal in 2014 (Tonnang et al., 2015), Uganda in 2015 (Tumuhaise et al., 2016), South Africa in 2016 (Visser et al., 2017). Natural dispersal means such as wind and active transportation by human through local and abroad markets are suggested the main means of spread for this invasive insect species.

The distribution of *T. absoluta* in Ethiopia was offensively occupying the main tomato farming locations. Similarly, the abundance is also high when detected from moth captured using pheromone trapping method, ranging from 27 to 47 in open field and 103 to 255 in the greenhouse (Muluken et al., 2014). Following its first outbreak in the major tomato belt of Ethiopia in the Central Rift Valley (CRV),

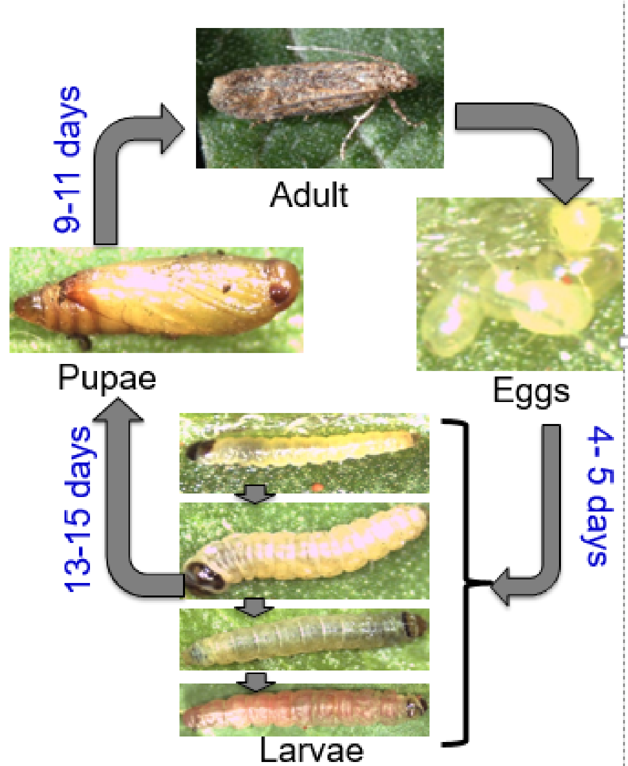

Figure 1: Life cycle of *T. absoluta* (Source: Samira et. al., 2016)

the farmers used cocktails of the insecticides available for managing other vegetable pests, but they left without success and complete failure of the crop was observed in 2013. The possible reason for its failure might be due to the insecticides used were old and broad spectrum, which is common activity in many other African countries also to indiscriminately use locally available pesticides (Ayalew, 2015). Indeed, different types of pesticides have been used for tomato leafminer, but none of them were significantly successful (Guedes and Siqueira, 2013).

3.1.4. *Host plant and damage of T. absoluta*

Although it prefers tomato, *T. absoluta* can also feed on other cultivated Solanaceae host plants including potato (S. tuberosum L.), sweet pepper (S. muricatum L.), eggplant (Solanum melongena L.), and tobacco (Nicotiana tabacum L.) as well as on non-cultivated Solanaceae plants (Nicolas et al., 2010; Mohamadi et al., 2017). The eggs after laid on the aerial parts of the host plants hatches to the feeding larvae. The larvae of infest the leaves, flowers, shoots, buds, stems and fruits. Leaf mines are irregular and may later become necrotic. The larvae usually enter the fruit under the calyx and tunnel the flesh, leaving galleries clogged with frass that cause the fruit to drop or to rot on the vine. So it cause negatively effects on plant architecture and can result in a significant reduction of fruit yield (Lietti et al., 2005; Botto, 2011; Roditakis et al., 2015)

Figure 2: Damage and symptoms of *T. absoluta* on different parts of tomato plants (Samira et. al., 2016)

3.1.5. *Management of T. absoluta*

T. absoluta was found mostly fitted with different environmental conditions (Van Damme et. al., 2015 and Tonnang et. al., 2015) and is difficult to manage by using chemical pesticides due to the larvae are endophytic in nature (protected in the leaf mesophyll or inside fruits) and its resistance ability to different pesticides used (Cuthbertson et al., 2013; Ponti et al., 2015). (Herbert et al., 2001) reported that higher levels of resistance to some insecticides including Permethrin was correlated with greater use of these compounds by tomato producers in Brazil.

Cultural control of *T. absoluta* Promoting the growth of tomato plants by improving the soil fertility with vermicompost found to affect the population growth parameters of the pest (Patriquin et al., 1995; Zink and Allen, 1998; Mohamadi et al., 2017). The studies suggested that increase in microbial populations and activities in the soils and the humic acid content of the vermicompost can be of the beneficial effects of vermicompost amendment. According to (Mohamadi et al., 2017), the tomato resistance to *T. absoluta* might be related to the promoted growth and nutrient uptake of the plant due to addition of the humic substances. The organic matter in vermicomposts can usually affect plant morphology and physiology that could provide plants with more resistance to pest attacks or made the plants less susceptible to the pests. (Yildirim and Unay, 2011) reported that tomato plants treated with humic substances were positively affected and Liriomyza trifolii (Burgess) population on the treated plants was negatively affected. (Mohamadi et al., 2017) reported reduced populations of *T. absoluta* on plant growth promoter and regulator (PGPR) treated plants which could be related to the promoted plant growth.

Biological control of *T. absoluta* The parasitoid complex of many hymenopteran species were reported for the larval stage of *T. absoluta*. Among these, the koinobiont endoparasitoid Pseudapanteles dignus and the idiobiont ectoparasitoid Dineulophus phthorimaeae accomplish over 50% of natural parasitism and exhibit promising attributes for either augmentative or conservation biological control in the native range and may also be suitable for introduction in the new regions invaded by *T. absoluta* (Cabello et al., 2009; Luna et al., 2010; **?**). The presence of one of the effective predators, namely Nesidiocoris tenuis Reuter, in Ethiopia was confirmed in tomato fields of the CRV areas in less than a year after the pest reported (Muniappan, 2014).

Chemical control of *T. absoluta* Although the identification of effective and selective insecticides were important as the integral component in the integrated management of *T. absoluta*, no insecticide had been registered for the control of this pest based on local efficacy data prior to the study of (Ayalew, 2015). An experimental study by Ayalew found that leaf infestation and fruit damage were significantly low with plots treated with Ampligo 150 ZC at 300 ml/ha and Coragen 200 SC at 250ml/ha resulting in higher marketable and total yield suggesting their good efficacy (Ayalew, 2015). Both insecticides contain the active ingredient chlorantraniliprole, a diamide insecticide which acts by modulating the ryanodine receptor (Bassi et al., 2012) and supposed to have a high efficacy against insect pests which mine in the leaf mesophyle tissue as they are capable of reaching the mining larvae in the leaf by penetrating the leaf surface. Tracer 480 SC at 150 ml/ha and Radiant 120 SC at 130 ml/ha ranked second in their overall performance in the same study (Ayalew, 2015). The active ingredient of these insecticides is spinosad which belongs to the insecticide class spinosyns and acts as nicotinic acetylcholine receptor (nAChR) allosteric modulators.

IPM strategy of *T. absoluta* Many studies reported the effect of biocontrol agents such as parasitoids, predators, microbial cells, microbial products, small RNA interference (RNAi), inheritance sterility (IS) development in insect and pest resistant plant cultivar production for suppressing of tomato leafminer population (Van Lenteren and Bueno, 2003; Abbes et al., 2012; Cagnotti et al., 2012; Camargo et al., 2016). The other options with known effects of reducing the pest numbers and plant damage include mass trapping of adult insects using pheromone traps, field hygiene including safe removal, disposal of infested plants and fruits, and removal of alternate hosts can form integral components of the IPM (Braham, 2014). Combination of cultural practices such as crop rotation with nonsolanaceous plants, destruction of infested plant material and postharvest debris, removal of wild host plant is recommended in addition the use of various botanical insecticides, synthetic insecticides as last resort, microbial agents (Bt, entomopathogenic fungi) and biological control can be used as IPM strategy.

3.2. African Citrus Psyllid (*Trioza erytreae* Del Guercio, 1918) (Hemiptera: Triozidae)) on White Sapote (*Casimiroa edulis*)

3.2.1. Overview about White sapote

White sapote (*Casimiroa edulis* L1ave and Kex) also called casimiroa or Mexican-apple is native to Northern America (Mexico) and Southern America (Costa Rica, El Salvador, Guatemala) (internet access, `https://www.growables.org/information/TropicalFruit/SapoteWhite.htm`). White sapote is an evergreen tree with spreading, often drooping branches and a broad leafy crown; it can grow up to 18 meters tall. The edible fruits are greatly appreciated and are commonly consumed. The tree is often cultivated as a fruit crop in warm temperate, subtropical and higher elevations of the tropics, and is also often grown as an ornamental (Database and Fern, 2020).

Fruits are eaten raw or cooked. A sweet flavour, though the butter-textured flesh can be resinous and the flavour is peach-like. The fruit has a remarkably high food value, almost as rich in protein, carbohydrate and vitamins as a banana and sugar content can be up to 27%. The yellow-green fruit is up to 10cm long. Some reports say that the seed is toxic if eaten raw, whilst others say that it can be roasted and eaten like nuts (Database and Fern, 2020). White sapotes are rich in carbohydrates and are a good source of vitamin C and potassium. They also contain vitamin A, calcium, B-complex vitamins, and the pigment carotene (internet access,`https://www.specialtyproduce.com/produce/Lamertz_White_Sapote_14198.php`). Commercial production of White sapote was known in New Zealand, Australia, and Israel while it has been introduced in for small scale production in South Africa, Egypt and different part of Ethiopia recently (Tesfaye and Mulatu, 2019; Mathewos et al., 2013; Reta, 2013; Emelda and Vijayalakshmi, 2012; Mesele et al., 2012).

3.2.2. Biology of African citrus psyllid

African citrus psyllid (*Trioza erytreae*) is a member of the Triozidae family in the Hemipteran insect order. African and Asian citrus psyllid (*Diaphorina citri Kuwayama*) are similar species and they can be differentiated by their wing characteristics. Adult Asian citrus psyllids have front wings that are widest near the tip and African citrus psyllids have front wings pointed at the tip.

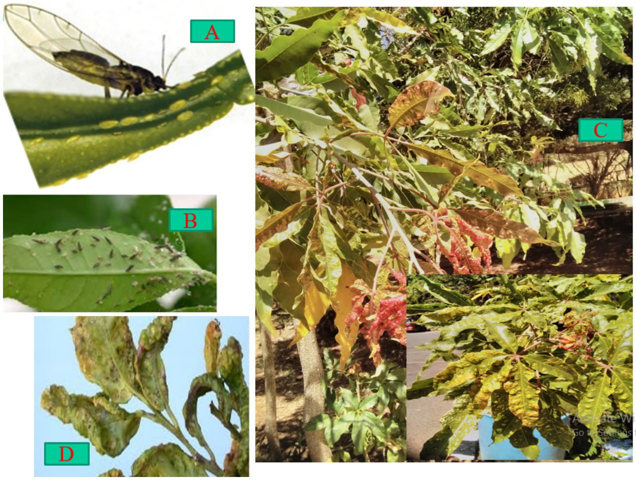

Figure 3: Adult African citrus psyllids and their damages. A: adult female with clear unspotted wing and eggs laid on margin and midrib of the leaf; B: adults and nymphs feeding together on the underside of the leaf; C: gall and deformed leaf of white sapote leaf in Haramaya university; D: citrus leaf damaged by African citrus psyllid (photo A & B from Tesfaye and Mulatu, 2019; photo C and D by the author).

Furthermore, the wings of Asian citrus psyllids are either transparent with white spots or light brown with a central beige band, while that of African citrus psyllids are all clear and unspotted (Figure 3A). In juveniles, wing pads of the African citrus psyllid are smaller than the Asian citrus psyllid. Immature psyllids are sometimes confused with aphids and whitefly pupae but, can be easily distinguished by examining the back of the abdomen. Adult aphids have two dark tubular structures called siphunculi, but the African citrus psyllid does not have siphunculi on the rear of its abdomen during any developmental stage. Adult psyllids can also be differentiated from aphids by their behavior. For example, Psyllids are very active and able to jump whereas aphids move slowly when disturbed. Whitefly pupae have fringe-like projections surrounding the body with eyes and antennae not readily viewable from a top-down view compared to immature psyllids. Psyllid nymphs have eyes and antennae that are easily seen and smaller, more conspicuous fringe-like projections surrounding certain areas of the body (Martin et al., 2019)

Adult male measures about 2.17 mm whereas females measure about 2.24 mm (Espinosa and Hodges, 2009) and they are pale green upon emergence, but the head, dorsum, antennae, tarsi and tibiae turn from brown to black as the insect matures (Mead, 1976). Males have a rounded tip on the posterior end of their abdomen while it is pointed ovipositor for the females (Espinosa and Hodges, 2009). The two forewings are pointed at the tip and are approximately 3 mm in length and wings at rest, are held tent-like above the body. The adult female lays pale yellow to orange cylindrical egg measuring 0.28 mm in length and 0.13 mm in width on margins actively growing foliage. The eggs will hatch between 5 to 17 days and there are five nymphal stages. It requires 17 to 45 days to reach adulthood depending on the temperature. The nymphs emerge from small cup-like pit galls to congregate, feed, and mature on the underside of the leaves. Adults can live for 17 to 50 days and females are capable of laying up to 2000 eggs during their lifetime (Espinosa and Hodges, 2009).

The African citrus psyllid is extremely temperature sensitive and will not develop at temperatures exceeding 25 °C (77 °F). They prefer cool and humid conditions, whereas the Asian citrus psyllid prefer lower elevations and warmer areas (`http://www.idtools.org/id/citrus/pests/factsheet.php?name=African%20citrus%20psyllid`).

3.2.3. History and distribution of African citrus psyllid

African citrus psyllid is indigenous to Africa and found in many countries on this world (Van Den Berg and Fletcher, 1988) becoming the only other psyllid worldwide that is an economic pest of citrus (Robert, 2008). It is native to Africa and it has spread to islands of the coast of Africa and to Saudi Arabia and Yemen (Van Den Berg and Fletcher, 1988). It was originally described as a species in 1918 from samples collected from Citrus limon (L.) in Eritrea and the species currently is present mostly throughout the Afrotropic ecozone, including Sub- Saharan Africa (EPPO, 2005; CABI, 2015). *T. erytreae* occurred mostly in the highland areas of Amhara (districts of Gondar and Gojjam) between 1867 and 2460 m asl. It was found on citrus plants and other host plants such as Casimiroa edulis (white sapote) and Clausena anisata (EPPO, 2020).

African citrus pssylid was observed long ago to be feeding on the prevalent C. anisata trees in the highlands of Cameroon and Ethiopia (Aubert et al., 1988) and currently it is invading the white sapote tree to cause production threat in the different parts of Ethiopia such as East Harerge. The pest has severely distorted the leaves of white sapote tree, which stunted and galled, and appeared dusted with faecal pellets. Young leaves are turned yellow when they are found severely damaged and it is one of the major problems of White sapote producing farmers in the area because the infestations were so severe and sometimes caused complete devastation of the plants (Tesfaye and Mulatu, 2019). However, there are no detail data and studies conducted concerning this pest in other parts of Ethiopia, but it is feared that the pest can further distribute to other places and potential host plants and cause economic loss. As the production of the white sapote fruit is not well known and limited to home garden cultivation, the pest can further extend its host plant to other economic crops.

3.2.4. Host plant and damage of African citrus psyllid

The host range of African citrus psyllid is mainly restricted to members of the Rutaceae family. The pest has been found on Clausena anisata, Vespris undulata, Citrus, lemons (C. limon) and limes (C. aurantiifolia) and Lemons appear to be their preferred host (Espinosa and Hodges, 2009). Martin et al. (nd) mentioned the various citrus and non on citrus hosts of African citrus psyllid. Although white sapote is not the target host, African citrus psylla has been attacked the tree as one of its host (Fernandes and Franquinho Aguiar, 2001) and (Tesfaye and Mulatu, 2019) also discovered that the insect was heavily infested the Casimiroa edulis trees in parts of Eastern Ethiopia. As the insect nymphs feed, they cause the formation of distinctive cup-shaped or pit-like galls in the leaves, which are diagnostic for the presence of the insect, particularly in the lower leaf surface of immature leaves.

Because of its negligible direct damage to adult trees, *T. erytreae* was considered as a secondary pest of citrus in its native regions for a long time (Catling, 1973; Van Den Berg and Fletcher, 1988). When heavily infested, the leaves can become chlorotic and slightly curled, but could normally perform their vital functions without dropping (Van der Mewre, 1923). However, in the absence of insecticide application, *T. erytreae* could be able to cause strong deformations on leaves resulting in 90 % of death in young plants in nursery (Tamesse and Messi, 2002). Moreover, additional indirect damage can occur due to the abundant honeydew excreted by the nymphs. These soft, white and sticky granule substances give a dusty appearance to the plants in severe infestations; facilitate the development of fungi; and attract some ants that collect the honeydew, but disrupt the protective actions of potential natural enemies (Van den Berg et al., 1991).

African citrus psyllid is the sap-sucking insect which can transmit the lethal citrus disease known as huanglongbing or citrus greening. Although the insect is a minor pest itself, the citrus greening is a serious threat to citrus-producing areas in the world (Tim et al., nd). It is the principal vector of the causal agent of the African form of citrus greening disease, Liberibacter africanum, which is a very destructive disease of citrus plants. The insect does this under natural conditions in Africa and the Middle East, and has been shown experimentally to transmit the Asian form citrus greening disease, Liberibacter asiaticum, also which is more severe and more destructive, but the Aciatic citrus psyllid. D. citri is act as a principal vector. Asian form of the citrus greening bacterium occurs at higher temperatures (30–35°C), commonly found at lower elevations whereas African form of the bacterium occurs at lower temperature (27°C), which is normally found at higher elevations (Robert, 2008). Trees severely affected by citrus greening are seriously stunted and produce poor fruit yields which are mostly greened and useless as they fail to ripen and cannot used for processing as they impart an unpleasant flavor **(Oberholzer et. al., 1965)**.

3.2.5. Management of African citrus psyllid

Insecticides such as dimethoate can be used against *T. erytreae* (CABI, nd). In their review on bibliography of ACP up to 1987, (van Den Berg and Fletcher ,1988) presented some studies which reported about the natural enemies of the pest, among other studies conducted regarding the this insect pest. The cited works of Annecke and Cilliers in 1963, McDaniel and Moran in 1972, Etienne and Aubert in 1980 and Van den Berg et al. in 1987 shows that African citrus psyllid has long history of attention by the scientists even for its biological control options. Moreover, the work of (Catling, 1970; Prinsloo, 1981; Tamesse et al., 2002) shows some of the studies on African citrus psyllid regarding the natural enemies.

In Reunion, *T. erytreae* has been successfully controlled by the introduction of a parasite, Tamarixia dryi, from South Africa. *T. erytreae* enters orchards from indigenous hosts in the surrounding vegetation (Van den Berg et al., 1991), so it is recommended that these hosts are removed. Phytosanitary Measures can be another options in establishing orchards. Because of the difficulty of ensuring freedom from eggs or nymphs, importation of plants for planting and cut branches of plants from countries where Liberibacter africanum and its vector occur should be prohibited. It is possible to fumigate citrus budwood material against *T. erytreae* (CABI). Under natural conditions, (Tamesse, 2009) discovered 17 different species of Hymenoptera parasitoids that laid their eggs on nymphs of *T. erytreae* belonging Aphelinidae, Ceraphronidae, Encyrtidae, Eulophidae, and Figitidae families and established an identification key for some of the parasitoids.

3.3. White mango scale (*Aulacaspis tubercularis* Newstead (Hemiptera: Diaspididae)) on Mango (*Mangifera indica*) (Sapindales: Anacardiaceae))

3.3.1. Mango and its importance in Ethiopia

Improved fruit production has been one of the focus areas of improving horticulture sector in Ethiopia. Production area of fruit crops is estimated at 61,972 ha in which mango ranks third next to banana and avocado and 2nd after banana in production (CSA, 2012). Mango is one of the most important income-generating fruit crop in the country especially in the rural communities of the western and southwestern part, where it was culturally cultivated for long period. It plays a significant role in the country's economy through feeding the local community, maintaining ecological balance and providing foreign exchange earnings (Duressa, 2018).

Previously the only major economically important insect pest of mango in Ethiopia have been the Tephritid fruit flies (Ferdu et al., 2009)(Tsedeke, 1987; Ferdu et al., 2009), an enormous threat to fruit production throughout the world (Mohamed, 2003). Due to global agriculture and trade coupled with poor quarantine organization, introduction of new disease and insect pests to Ethiopia has become a common phenomenon (Plant Protection Society of Ethiopia (PPSE), 2013). The plant is currently under low production mainly due to the insect white mango scale (*A. tubercularis*). This insect pest is an important biotic factor that causes damage to the fruits resulting in serious economic losses and making the fruits less qualified.

3.3.2. Biology of A. tubercularis

White mango scale are the insects in Diaspididae family of the order Hemiptera. Adult female of *A. tubercularis* lays 80-200 eggs depending on temperature. After hatching crawlers move to feeding sites and settle within 24 hours. Female crawlers settle randomly while the male crawlers settle in groups closing to the females. Up to 80% of crawlers become males (Abo-Shanab, 2012). Female nymphs of Diaspididae family go through two instars before reaching the adult stage whereas the males go through four instars by adding pupa and prepupa (Borror et al., 1989). The females of A. tubercularis are white circular, thin and flat; males are smaller with white cover and walkers (the first nymphal stage) are seen as bright brick red (Hodges and Hamon, 2006). The complete lifecycle of A. tubercularis requires 35-40 days in summer and 70-85 days in winter (Abo-Shanab, 2012), but according to (Arias et al., 2004), the life cycle of A. tubercularis is 52 and 36 respectively for females and males.

The population developmental pattern showed three different stages: a low density period from the end of the rainy season (September to December), a second stage of gradual population growth from March to the beginning of the rainy season (July), and the last stage of drastic fall in population during the rainy season (July-August) (Urias-Lopez et al., 2010). Similarly, ecological studies by (Nabil et al., 2012) revealed that the total number of alive stages had one peak of activity yearly in both top and bottom levels of the trees. Moreover, (Radwan, 2003) reported that *A. tubercularis* had three generations on mango trees. In their study the total effects of abiotic factors (Temperature, RH and Light intensity) on the total numbers of alive stages of the pest were 63.19 and 40.20 % in the top level and 77.66 and 39.44 % in the bottom one, successively for two study years.

3.3.3. History and distribution of A. tubercularis

Aulacaspis tubercularis has been spread by the transport of infested plant material and is now widespread in many mango growing countries. It presents as a significant pest problems on mangoes in South Africa, Australia, East and West Africa, North and South America and the Caribbean Islands (Abo-Shanab, 2012). *Aulacaspis tubercularis* was recorded in Ethiopia in August 2010 for the first time, in private mango farm found at western part of the country (Mohammed et al., 2012; Temesgen, 2014). It was intercepted from mango seedlings collected from elsewhere in June 2013 at Melkassa Agriculture Research Center (MARC). Even if those seedlings were destroyed safely to prevent orchard infestation, the insect was appeared infesting the mango plants in the orchard at the center and nearby areas in June 2014 where there was up to 100% infestation of trees in some orchards. In the same year the pest was also intercepted in Tigray region in Northern Ethiopia from the seedlings purchased for plantation purpose from Arbaminch, the southern Ethiopia (Gashawbeza et al., 2015). The pest has increased its incidence at an alarming rate in the last few years and currently found in every mango growing regions of the country.

3.3.4. Host plant and damage of A. tubercularis

Aulacaspis tubercularis was found on other plants of several families such as Arecaceae (Cocos nucifera) and Rutaceae (Citrus sp.) (Hodges and Hamon, 2006). The white mango scale injures its host plant by feeding on the plant sap through leaves, branches and fruits and cause defoliation, drying up of young twigs and poor blossoming. Furthermore, the infestation and feeding on the fruit is likely to affect the commercial value as it causes noticeable pink blemishes around the feeding sites of the scales. The heavilyvily infested premature fruits may drop and the mature fruits become small wa limited level of juice.of juice. Although the white mango scale mainly cause cosmetic damage to the fruit, the infestation can result in serious economic losses because of the infested fruits are rendered unfit for export (Daneel and Dreyer, 1997). Although the mango scale does not cause internal fruit damage, its cosmetic effect on the fruit skin results in a significant decrease in the ratio of exportable fruit and substantial financial losses for the mango grower. The scale insects can be nibbed off the fruit quite easily, but the marks which are left are unsightly and unacceptable to the foreign market (Labuschagne et al., 1995).

3.3.5. Management of A. tubercularis

Diaspididae, also called armored scales, are all notorious tramp species, primarily due to their small size and the attendant difficulty in finding them during inspections. They also manufacture the protective cover which substantially protects them from topical insecticides, and the fact that they feed directly from plant cells as opposed to xylem or phloem reduces their exposure to systemic insecticides, so they are very hard to control once established **(Ian, 2013)**. Post-harvest pruning is considered as effective cultural control and it is useful for removing the infested tip of the plant and it also help for canopy penetration of the tree to facilitate chemical spray. Numbers of biological control agents have been used for white mango scale insect control. Predatory beetles like *Cybocephalus binotatus* and parasitoids like *Aphytis chionaspis* were found prominent agents in South Africa (Daneel and Dreyer, 1997).

The indigenous parasite *Encarsia citrina* (Craw) was recorded with percentage of parasitism exceeding 80% in South Africa and the predatory thrips, *Aleurodothrips fasciapennis* (Franklin), was also recorded while preying on mango scale while two predatory beetles Rhyzobius lophanthae (Blaisdell) (Coleoptera: Coccinellidae) and *Chilocorus nigritus* (Fabricuis) (Coleoptera: Coccinellidae) have often been noticed feeding on *A. tubercularis* (Labuschagne et al., 1995).

The role of white mango scale insect natural enemies in regulating its abundance was discussed by some authors as mentioned in (Abo-Shanab, 2012) the author also recorded parasitoids (*Aphytis mytilaspidis* (Le Baron) and *Encarsia citrine*, and predators (*Chilocorus bipustulatus* (L.) and *Scymnus syriacus* Marseul (Coleoptera: Coccinellidae). *Aphytis* sp. and *Encarsia* sp. (Aphelinidae), *Habrolepis* *diaspidi* (Risbec) (Encyrtidae) were recorded as parasitoids of *A. tubercularis. Cybocephalus micans* Reitter (Order: Nitidulidae) was recorded as predator of A. tubercularis (Nabil et. al., 2012). *Encarsia* sp. (Hymenoptera: Aphelinidae) was recorded parasitizing A. *tubercularis* on mangoes in South Africa, where parasitism of female scales averaged 17.7% (Schoeman, 1987).

Chemical control of scales with some traditional synthetic insecticides is effective (Tahakur and Hameed, 1981). For A. *tubercularis*, (Arias et al., 2004) obtained good control of scales with commercial insecticides Cochibiol, Banaoil and agricultural oil; Also, (Le Lagadec et al., 2006) also obtained promising results with the neo-nicotenoide insecticide thiamethoxam. Different pesticides have been also used mainly mineral oils (super masrona®, CAPL2® and Diver®) (Abo-Shanab, 2005). Two successive field experiments for eight weeks during early spring (2009 – 2010) aimed to test some summer/light mineral oils, (super masrona®, CAPL2® and Diver®) against A. *tubercularis* on mango trees. The tested mineral oils were effective by the following descending order: Diver > CAPL2® > super masrona® without significant differences between diver and CAPL2 and significant differences with super masrona, with the same effective trend and same statistical means, during the two seasonal experiments (Abo-Shanab, 2012). Activity of buprofezin lambda-cyhalothrin and malathion in controlling white mango scale was tested and use of two sprays at spring and summer enhanced the efficiency of each insecticide in controlling insect in mango orchard (Hamdy et. al., . More recently in developed continents like Australia, a softer but powerful and systemic (Movento® 240 SC) have been used for scale pest management in mangoes.

It is especially important to monitor insect pests before and during flowering for infestation and damage on flowers and new flushes. Integrated Pest Management (IPM) in mango has been developed as an effective and environmentally sensitive approach to insect management that relies on a combination of physical, biological, host-plant resistance and cultural practices. Spray programs are also directed towards reducing the population levels before flowering and fruit development (Muhammad, 2015).

3.4. Red spider mite (*Tetranychus urticae* Koch (Acari: Tetranychidae)) on potato (Solanum tuberosum)

3.4.1. Potato and its importance in Ethiopia

Potato is an important food security and cash crop for farmers in many parts of the country and its low production can bring an impact on national food security. There is a potential domestic market and farmers in Eastern part of the country have even access to export market mainly to Djibouti and Somalia (Bezabih and Hadera, 2007). However, the production of the crop is inhibited by many biotic and abiotic factors among which low yielding cultivars, insect pests and plant diseases are limiting biotic factors of its productivity (Muluken et al., 2016).

The major insect pests of potato in Ethiopia were cutworms (*Agrotis* and *Exigua* spp.), metallic leaf beetle (*Lagria vilosa*), red ants (*Dorylus sp.*), potato aphid (*Macrosiphum euphorbiae*), green peach aphid (*Myzus persicae*), potato epilachna (*Epilachna hirta*), potato tuber moth (*Phthorimaea operculella*) and white grub (Braham, 2014; Bayeh and Tadesse, 1992; Ferdu et al., 2009; Tekalign et al., 2015). The potato tuber moth gained more attention than all the other potato insect pests (Ferdu et. al, 2009). Heavy infestation of potato fields was reported by local potato farmers in Haramaya district in 2014 and the pest was later identified as red spider mite (*Tetranychus urticae Koch*) (Muluken et al., 2016), another arthropod group than hexapoda. The pest was later abled to expand its geographical distribution to other areas and it is currently major pest threat of potato growing areas in eastern Ethiopia (Muluken et al., 2016).

3.4.2. Biology and host plants of T. urticae

The red spider mite, also known as two spotted spider mite (TSSM) is a member of Arachnida (non-insect arthropod) in Tetranychidae family of the order Acari. It develops through five growth phases: egg, larvae, protonymph, deuto-nymph and adult. The larva has the size of the egg and only has six legs so that it can be easily distinguished from the other stages. The protonymph and deutonymph resemble the adult and adults are approximately 0.5 mm long with range of colors from light green to dark red, usually with two dark spots on the dorsal surface of the abdomen. Adults overwinter under vegetative cover and the mated females begin feeding and laying eggs when temperatures increases. Maturity from egg to adult requires at least 5 days, but may approach 1 month depending on the environmental conditions. Dispersal of the red spider mites can occur by either ambulatory or aerial means, but the vast majority of dispersal takes place aerially due to their small size and less amount of time it would take for a spider mite to travel from one plant to another (Oscar and Erin, 2008).

The TSSM is an abundant species which present worldwide on a wide variety of plants (Helle and Sabelis, 1985) and it has more than 1200 species of host plants of which more than 150 are economically important (Zhang, 2003). Strawberries are also found susceptible to TSSM and the pest occurs year-round in the greenhouse, but its presence in the field required warm temperatures **(Oscar and Erin, 2008)**. This pest was found feeding on rose plants in flower farms in Ethiopia (**Elings et. al., 2011**).

The development and incidence of TSSM were depended upon the dominating environmental conditions such as temperature, relative humidity and rainfall (Woiwod, 1997). In fact, the timing of pest attacks can vary greatly from region to region and from year to year (Collier and Finch, 2001). The study similarly indicated that the decreasing in rainfall intensity and relative humidity and increasing of temperature have contributed to increasing level of incidence and severity of TSSM on potato crops (Gebissa et al., 2019). Earlier studies also suggest the increase in temperature favors the occurrence and damage status of TSSM. High temperature with low relative humidity found to exaggerate the feeding and reproduction capacity of the TSSM (Pakyari and Enkegaard, 2012). In addition, the incubation period of *T. urticae* increased with decreasing temperature and total time taken for completing the life cycle decreased with increasing temperature **(Paramjit et. al., 2017)**.

3.4.3. Importance and damage of T. urticae

The pest prefers to feed on the underneath of the leaves (Reddall et al., 2004) and it uses stylets to pierce plant cells and digest the cellular contents (Riley, 1989). The chloroplast within the plant cells is removed and continued feeding can cause a stippled bleached effect and later, the leaves turn yellow, grey or bronze (Riley, 1989). Large population of the spider mite can destroy whole plants resulting in complete yield loss (Stavrinides and Hadjistylli, 2009). As it was observed in the infested potato fields in Ethiopia, the adults, nymphs and larvae of TSSM feed mostly on green parts of the crop leading to its complete destruction and total yield loss under heavy infestation. Despite the potato, the red spider mite was also infested other crops like tomato and cucumber and surprisingly found inhabiting khat (Chata edulis) and maize (Muluken et al., 2016), thereby indicating that it would be a threat to other cultivated crops sooner or later. Non crop plants like Datura stramonium and Solanum elaeagnifolium from Solanaceous were found infested during the study of (Muluken et al., 2016) and plant species Melia azediarach, known for its insecticidal properties was also observed heavily infested (Carpinella et al., 2002) by the red spider mite. The pest is a major pest of rose flowers in commercial farms (Belder et al., 2009).

In fact, T. urticae was earlier reported on pigeon pea (Tsedeke, 1987) and tomato (Gashawbeza et. al., 2009) in Ethiopia. The pest red spider mite is, currently a serious threat to potato production in eastern part of the country (Muluken et al., 2016) and there is no available data and study reports in other parts of the country. It is possible to presume the pest could expand its geographical range to other parts of Ethiopia based on lack of unawareness and transportation of materials within the country, its wide host nature and increase in production and market demand of horticultural crops throughout the country, which might provide the pest with whole year access to its host plants.

3.4.4. Management of T. urticae

Farmers in the area where the pest found to heavily infest potato reported using different cultural control methods and some of them also applied chemical insecticide and fungicides (Gebissa et al., 2019). Roughing of infested plants, irrigating weekly and early planting was the cultural management strategies and chemicals like Profit, Mitac and Dimethoate were also used by farmers to minimize the yield losses by the pest TSSM. Insecticide application was highest in some districts studied and some farmers were also obviously implemented more than one management strategy to reduce the infestation (Gebissa et al., 2019).

The two-spotted spider mite a major pest of both ornamental and vegetable plants, is controlled by releases of the phytoseiid mite Phytoseiulus persimilis. Much of the information developed for releasing natural enemies in European glasshouses can be adapted to control glasshouse pests elsewhere because these pests are widely distributed **(Marjorie, 2008)**. Neoseiulus californicus, as well as other predatory mites (e.g., N. fallacis, Phytoseiulus persimilis and Mesoseiulus longipes) is commercially produced and used to control the two-spotted spider mite, T. urticae in North American and European greenhouse horticulture (Norma et al., 2008).

4. Conclusion and Future Research Directions

The agricultural sector in Ethiopia, employing most of the country's population, remains a key source of growth. The country is endowed with great variety of climate and soil types that can grow diverse horticultural crops for home consumption and foreign markets so they used as income generation through creating employment opportunities also. Beside these all, the challenges of combating the crop pests especially the invasive ones is among the major constraints seriously affecting the sector's sustaining and accelerating production and productivity.

In the last decade only the insect pests are threatening the productivity of some horticultural crops which are among the major crops of income sources for local farmers. Although the pests are recognized for their importance, there is no promising management strategy developed for any of the pests yet. On the contrary, potential natural enemies have been recorded, tested for some of them and efficiently utilized against some the pests around the world which can be used as biocontrol agent. Similar trends are needed to identify available indigenous natural enemies in the country so that conservative and augmentative biological control can be exploited. Moreover, coordinated works are required from every stakeholders in order to keep the pests under regulation and control further distribution. Collaborative researches have to be done by giving due attention to such devastating pests especially focusing on IPM strategies.

Conflict of Interest

The author declares that there is no conflict of interest.

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