

Addis Ababa University, School of Graduate Studies



Bionomics and Management of White Mango Scale, *Aulacaspis tubercularis* Newstead (Homoptera: Diaspididae) on Mango in Western Ethiopia, and Central and Eastern Kenya

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This is to certify that the thesis prepared by Ofgaa Djirata, entitled: Bionomics and Management of White Mango Scale, *Aulacaspis tubercularis* Newstead (Homoptera: Diaspididae) in Western Ethiopia, and Central and Eastern Kenya and submitted in fulfilment of the requirements for the Degree of Doctor of Philosophy in Biology (Insect Sciences) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Dedication

To my father, Mr. Djirata Dako (1893-2001), and my late sister in-law,
Mrs. Tersit Hailegeorgis (1960- 2008)

Abbreviations

AMAGRO	Association of Mango Growers
ANOVA	Analysis of Variance
EARO	Ethiopian Agricultural Research Organization
FAO	Food and Agriculture Organization of the United Nations
GLM	General Linear Model
GPS	Global Positioning System
HCDA	Horticultural Crops Development Authority
KALRO	Kenyan Agricultural and Livestock Research Organization
LBB	Ladybird beetle
LSD	Least Significant Difference
LTD	Limited
PLC	Public Limited Company
SAS	Statistical Analysis System
SD	Standard Deviation
SE	Standard Error
SPSS	Statistical Package for the Social Sciences
UNCTAD	United Nations Conference on Trade and Development
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
WMS	White Mango Scale

**Bionomics and Management of White Mango Scale, *Aulacaspis tubercularis*
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Abstract

Mango (*Mangifera indica* L.) is the third most important fruit crop in the tropics following citrus and banana. It is consumed as a fresh fruit and different forms of preparations for its contents of sugar, vitamins, minerals and protein, among others. Mango is produced in Ethiopia and Kenya for domestic consumption and export market. Mango production in these two countries is currently constrained by infestation of white mango scale, *Aulacaspis tubercularis* Newstead (Homoptera: Diaspididae). In Ethiopia, white mango scale was recorded for the first time in 2010, from mango orchard located at Loko Village in East Wollega Administrative Zone of western Ethiopia. It constrained mango production in the region and released panic among mango farmers. Occurrence of white mango scale in Kenya was much earlier. These studies were designed and conducted to know the distribution, population dynamics, and host range of white mango scale for designing management options of the pest. The studies were conducted in western Ethiopia, and some mango growing counties in central and eastern Kenya, from May 2013 to July 2016. Randomized Complete Block Design was used for sample collection from the total of five study orchards in Ethiopia and Kenya to determine population dynamics and, screen insecticide in Ethiopia. Purposive sampling method was employed for white mango scale survey. It was known from the results that, in western Ethiopia, white mango scale showed population peaks in April at Arjo and in May at Bako orchards, with marked decline with decreased precipitation. Abundances of eggs, crawlers and sessile stage white mango scale showed significant differences among the study months ($P < 0.05$). Abundance of sessile white mango scale was significantly higher at Bako orchard than Arjo ($P < 0.05$). In the entire study orchards in both Ethiopia and Kenya, white mango scale population was significantly more abundant on upper mango leaf surface than lower ($P < 0.05$). At Bako orchard population of male white mango scale was found to be significantly higher than that of the female ($P < 0.05$). In the current study, larvae of *Chilocorus* sp. (Coleoptera: Coccinellidae) was recorded preying on live white mango scale, a new association reported for the first time with this study, of a native natural enemy with the exotic white mango scale in Ethiopia. This study revealed the presence of statistically significant ($P < 0.05$) positive correlation between populations of white mango scale and the predatory larvae in both study orchards in western Ethiopia. In the Kenyan study orchards, population peaks of white mango scale were found to be in February and April, with general trend of decline towards the colder dry months. The variation among the study months were statistically significant at both Kimani and Samuru ($P < 0.05$) whereas that at Kenyatta

University mangos showed no significant difference ($P>0.05$). Sessile stage white mango scale population was found to be significantly more abundant at Samuru orchard than Kimani ($P<0.05$). Some mango varieties were found to be more susceptible to white mango scale infestation than others with significant difference ($P<0.05$). White mango scale distribution was found to have covered 189km east-to-west and over 141km north-to-south air distances, with more of high and very high severity status of infestations in west Ethiopia. In central and eastern Kenya, white mango scale was recorded from all of mango farms visited except only four with level of infestation being mild in most cases. White mango scale distribution was uneven within each county in Kenya and each administrative Zone in Ethiopia. Implementation of chemical and cultural control methods could help some mango farmers in Kenya to manage white mango scale infestation. The result of this study showed that white mango scale had no alternative host plant apart from mango tree, in western Ethiopia. Performance of Folimat 500 SL in reducing number of the insect pest on mango tree was significantly higher ($P<0.05$) than Closer 240 and D-C-Tron plus. The current investigations concluded that temperature and rainfall were the main factors that determine population dynamics of white mango scale. *Chilocorus* sp. was newly associated with white mango scale but couldn't control the pest yet. White mango scale infestation on mango can be mitigated by the use of indigenous knowledge of pest management combined with insecticide application.

Key words: Population dynamics, Distribution, Orchard, Infestation, *Mangifera indica*.

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Chapter 1

General Introduction

Mango (*Mangifera indica* L) is a fruit crop known to have originated in tropical Asia and distributed to other tropical and sub tropical areas of the world, following human distribution (Dirou 2004; Crane *et al.*, 2013; Ubwa *et al.*, 2014). Following citrus and banana, mango is the third most important fruit crop in the tropics (Louw *et al.*, 2008). It is preferred for its pleasant aroma and taste, and high nutritional value. Pertaining to its global demand, mango could play significant role in foreign currency generation, and accordingly, its production has been on a rise from time to time (UNCTAD, 2016).

Ethiopia and Kenya are among mango producing countries in Africa. Mangos in Ethiopia and Kenya were reported to have been infested by various insect pests, including white mango scale (<http://www.jkuates.co.ke>; Findlay 2003; Seid Hussien and Zeru Yimer, 2013; Alemayehu Chala *et al.*, 2014; Ofgaa Djirata and Emanu Getu, 2015).

White mango scale (WMS) is a tiny armoured scale which feeds on plant through sap sucking. It poses severe damage to mango plantation. Yellowing of leaves, dieback and total death of young mango trees are some of the damages caused by this insect pest (Abo-Shanab, 2012). Mango fruits infested by white mango scale ultimately develop pink blemish, and as a result acceptability of the fruit is highly affected (USDA, 2006; El-Metwally *et al.*, 2011). White mango scale is reported to have infested host plants other than mango (Erichsen and Schoeman, 1992; Malumphy, 2014).

Infestation of white mango scale, as a new insect pest on mango, was reported in 2010 from an orchard owned by Green Focus Ethiopia LTD located at Loko Village, Gida

Ayana District in East Wollega Administrative Zone of Oromia National Regional State, western Ethiopia (Temesgen, 2014). The insect pest was identified in April 2011 at California Department of Agriculture, as White Mango Scale, *Aulacaspis tubercularis* Newstead (Hemiptera: Diaspididae) (Mohammed Dawd *et al.*, 2012). Green Focus Ethiopia LTD, and another company which is the current owner of Loko mango orchard, Raj Agro PLC, were both Asian companies and used to import seedlings of improved mango varieties from Asia (Ofgaa personal communication). Therefore, the insect could most likely be introduced to Ethiopia accidentally from Asia, with mango seedlings imported by Green Focus Ethiopia LTD.

White mango scale infestation on mango in Kenya had been reported much earlier than its report from Ethiopia. Findlay (2003) underlined the presence of white mango scale infestation on mango in Kenya and warned that it could cause damage to the crop. Moreover, Germain *et al.* (2008) mentioned Kenya among the list of countries from which white mango scale infestation on mango was recorded, even though the level of its damage on the crop in this country was not evaluated at that time.

Knowledge on bionomics of white mango scale (comprehensive study of the insect's interaction with components in its environment) is vital for planning and implementing effective management practice of the insect pest. However, there were no or only few studies conducted on population dynamics, distribution, host range, and relevant management practices, in both countries. These studies were, accordingly, initiated and conducted with the following objectives.

1.1 Objectives

1.1.1 General objective

To know the distribution, abundance and host range of white mango scale and assess efficacy of insecticides to develop effective management of the insect pest.

1.1.2 Specific objectives

To understand the population dynamics of white mango scale and its natural enemies

To investigate the distribution of white mango scale

To assess host range of white mango scale

To screen insecticides for efficacy against white mango scale

Chapter 2

Literature Review

2.1 Mango, its origin and distribution

Mango (*Mangifera indica* L.) is classified under the family Anacardiaceae, and genus *Mangifera*. Sawangchote *et al.* (2009) underlined that the genus *Mangifera* consists of 69 species in the tropical Asia. *M. caesia*, *M. foetida*, *M. odorata* and *M. sylvatica* are among some of edible fruits found under this genus, of which *M. indica* L. is the only species grown commercially on large scale (Ramcharan, 1997; Nagina, 2015).

Existing literatures agreed that mango originated in tropical Asia (Ramcharan, 1997; Naturland, 2001; Dirou 2004; Crane *et al.*, 2013; Okoth *et al.*, 2013; Ubwa *et al.*, 2014). It is believed that mango cultivation had history of over 4000 years in and around India and Burma. Moreover, Mukherjee (1972) and Sawangchote *et al.* (2009) precisely put from detailed fossil studies that the origin of the genus *Mangifera* was somewhere in Malaya or in Thailand-Laos-Cambodia-Vietnam areas from where the spread and maximum diversification of various species had taken place in India-Barma-Thailand, Indonesia-Borneo and the Philippines areas.

The current distribution of mango covers all tropical and subtropical lowland areas throughout the world (Bhushan, 2013). Accordingly, more than 80 countries are growing mango for commercial purposes. Such wide distribution of mango in tropical and subtropical areas may be related to its tolerance to a wide range of climatic conditions and its conjunction with the history of spread of human being. Mango is successfully cultivated under conditions which vary from very hot-very humid to cool and dry or arid areas; its mean annual rainfall is between 400mm and 3600mm (Bally,

2006). It is indicated that mangos grow well at altitudes ranging from sea level to 1200 m.a.s.l with evident decrease in production at further higher altitudes. Accordingly, long dry season i.e., a dry period of over three months followed by sufficient rainfall is known to be ideal climatic condition for mango production.

2.2 Economic importance of mango

The driving force behind the wide distribution of mango across the world in tropic and sub-tropic countries may be associated with its multifaceted importance. Mango is the third most important fruit crop in the tropics after citrus and banana (Louw *et al.*, 2008). It is nick-named “the king of fruits”. Mango is widely consumed as a fresh fruit and various forms of beverages. Mango is known for its high contents of sugar, protein, fats, salts and most of the vitamin types (Griesbach, 2003; Nabil *et al.*, 2012). It is used as animal feed, poultry diets, and moreover, plays vital role in Ethnopharmacology and various chemical industries in different parts of the world (Wauthoz *et al.*, 2007; Kayode and Sani, 2008; Masibo and He, 2008; Nwinuka *et al.*, 2008). Shah *et al.* (2010) indicated that mango possesses antidiabetic, anti-oxidant, anti-parasitic, cardiogenic, hypotensive, anti-inflammatory and antispasmodic properties.

Mango is considered as an important element in certain sociological aspects in some parts of Ethiopia. In Benishangul-Gumuz Regional State, in particular, and other parts of western Ethiopia, in general, mango tree is used as a shade for livestock and conference hall for local people, during hot weather conditions (Plate 2.1).

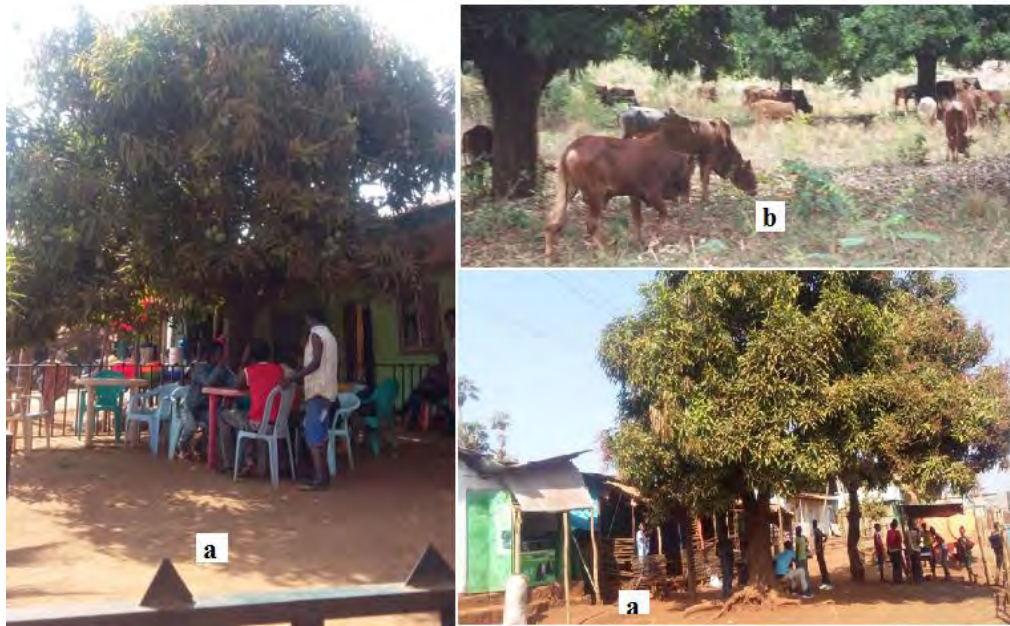


Plate 2. 1 People under mango tree shade during hot hours in a village of Arjo, around Didessa Valley (a) & cattle grazing under mango shade near Bako town (b)

United Nations Conference on Trade and Development (UNCTAD, 2016) reported that global production of mango had doubled within thirty years to around 35 million tonnes (Mt) by the year 2009 and its export-import business had become considerable source of foreign currency generation for the main producers. Asia is the largest mango producing continent (77%) followed by the Americas and Africa, with 13% and 10% of global production, respectively. The major import markets for these producers are the Middle East, Europe and United States.

2.3 Overview of mango production in Ethiopia and Kenya

Introduction of mango to east Africa dated back to 10th century, when the Persian traders who used to visit the region for business purposes had brought the seed (<http://www.vanwhole-produce.com/product/mango/>). The fact that mango tree was reported from Somalia as early as 1331 (Griesbach, 2003) indicated that it had already been established in east Africa prior to that time.

2.3.1 Ethiopia

Ethiopia has diverse agro-ecological zones and substantial areas to support various fruits in general, and mango plantation in particular (Yilma Tewodros, 2009). More than 47, 000 hectares of land were reported to have been under fruit crop cultivation in Ethiopia, of which about 60.56% was occupied by banana followed by mangos with about 12.61% (Central Statistical Agency, 2008). According to same report, a total of 716447 private farmers holding 6051 hectares of cultivated mango land could produce 441582 quintals of mango in 2008/2009 production season, in Ethiopia. The yield was said to have been about 73 quintals per hectare.

Mango is grown in many parts of Ethiopia, of which large production comes mainly from the Rift Valley, western and south western areas (Takele Honja, 2014). Mango is produced in Ethiopia at small scale level, primarily for family consumption and local markets, whereas very few large farms produce mango for local and export markets (Alemayehu Chala *et al.*, 2014). Upper Awash Agro Industry Enterprise and Raj Agro PLC are among modern farms producing mango fruit at a relatively larger scale. Very limited numbers of companies are producing fruit juices in Ethiopia, of which a mango juice producing company is found in Sebeta, 24 km southwest of Addis Ababa (Wiersinga and Jager, 2009). Ethiopia exports fresh mango to Djibouti, Saudi Arabia, Yemen, Sudan and Emirates (Yilma Tewodros, 2009). However, the export share of mango from Ethiopia was reported to have been very small pertaining to low productivity and low quality (Alemayehu Chala *et al.*, 2014). The mangos commonly grown in Ethiopia are the local varieties. These are known for their fibrous feature which limits their processing and international market acceptance (Bezabih Emanu, 2010; Yigzaw Dessalegn *et al.*, 2014). Likewise, Wiersinga and Jager (2009) stated that with small scale and scattered production of indigenous mango varieties which are unfit

for further processing, Ethiopia can hardly compete for international mango export market.

The practice of mango production in Ethiopia is generally unprofessional (Yilma Tewodros, 2009; Seid Hussen and Zeru Yimer, 2013). Absence of patterns and recommended spacing, growing mangos with bushy and weak branches, practice of harvesting the fruit after peak maturity and consequent short shelf life, none or very rare introduction of improved varieties are some of poor management practices of mango. Furthermore, mango production in Ethiopia was reported to have been constrained by various pests and diseases, and yet management practices such as pruning and application of insecticides are not put in to effect (Tewodros Bezu *et al.*, 2014). However, based on recommendations made by Ethiopian Agricultural Research Organization (EARO, 2004), new mango varieties such as Tommy Atkins, Apple mango, Kent and Keitt have been introduced and were under production (Kahsay Berhe *et al.* www.eap.gov.et; Bac, 2010).

2.3.2 Kenya

Pertaining to its enabling agro ecological climate, Kenya is known to be one of the leading mango producers in East Africa; where its production is both at large and small scale for export, processing into juice and fruit concentrates, and for domestic consumptions (Boersma, 2006; HCDA, 2008). It is stated that Kenya could take the advantage of being situated on both of North and South hemispheres, and as a result enjoys two seasons of mango production (AMAGRO, 2011). Accordingly, average mango produced for the years 2005-2007 was 16,520 hectares of land cover and 295,802 metric tonnes of fruit harvest (HCDA, 2008). In order of importance, mango is the third major fruit grown in Kenya, following banana and pineapple (Kenya Bureau of Standards, 2014). The main mango producing regions being in the eastern, central and

coast areas, most of the counties in Kenya produce the crop (<http://www.jkuates.co.ke>).

In Kenya, both indigenous and exotic mango varieties are grown. It was reported that 50 mango cultivars were grown in Kenya (Kehlenbeck *et al.* www.worldagroforestry.org) of which Griesbach (2003) described 31 cultivars in detail. Okoth *et al.* (2013) also stated the presence of several exotic and indigenous mango varieties in the nation. The exotic varieties are known to be of higher quality compared to the local, and their production usually targets export market.

There seems no common understanding in describing the exact origin of a given mango variety in Kenya i.e., between exotic and indigenous ones. Msabeni *et al.* (2010) added Apple mango in the list of exotic varieties, while other sources considered it as local variety (Griesbach, 2003; Kehlenbeck *et al.* www.worldagroforestry.org).

Mulinge *et al.* (2015) stated that mango farmers of different localities in Kenya select certain varieties of mango for production, based on some defined priorities and advantages that they can fetch from the harvest. Some of these are market attraction pertaining to fruit colour, taste and fibre content, suitability of soil type to respective varieties, resistance to drought and tolerance to diseases and pests, tree size for ease of insecticide spray, pruning and maintaining of hygiene of mango tree.

Kenya exports mango to various international markets. Mango was listed on the third line among the biggest gains from export market of horticultural crops, following flower and avocado, whose volume to the Middle East market increased in 2012-2014 (Kenya Bureau of Standards, 2014). According to AMAGRO (2011), Kenya exported about 2,500 to 3,000 tons of mango fruit to its second export market, Tanzania, in 2009.

2.4 Some pests and diseases as constraints in mango production

Mango production is constrained by a variety of pests and pathogens. Medina and García (2002) depicted that over 492 species of insects, 17 species of mites and 26 species of nematodes were reported to have been damaging mango trees. Moreover, pathogenic fungi and bacteria cause diseases to mango plantation (USDA, 2006).

Mango productions in Ethiopia and Kenya are impeded by various pests and diseases (<http://www.jkuates.co.ke>; Findlay 2003; Griesbach 2003; Biovision, 2011; Alemayehu Chala *et al.*, 2014; Tewodros Bezu *et al.*, 2014). Mango pests include insects such as fruit fly complex, mango seed weevil, thrips, mealy bugs and scale insects, and non insect pests such as mites, among others. Powdery mildew and anthracnose are among disease causing pathogens that severely affect mango production in both countries. The threats were reported to have caused damages ranging from significant vegetative damage to total mango yield losses (<http://www.jkuates.co.ke>; Seid Hussen and Zeru Yimer, 2013; Alemayehu Chala *et al.*, 2014). Different species of fruit flies resulted in more than 50% yield loss to mango in Kenya. Besides its impact on local consumption of mango fruit, mango seed weevil, *Sternochetus mangiferae* (F), hindered the development of a fresh fruit export market, because Kenyan mango importers in the Middle East and other places maintained strict quarantine regulations on mangos infected by the beetle (Griesbach, 2003). In Ethiopia, thrips, fruit flies, termites, and various fungal diseases constrain mango production, in the absence of proper management practices (Tewodros Bezu *et al.*, 2014). Mango anthracnose, caused by *Colletotrichum gloeosporioides* was reported to be 100% prevalent in the humid agroecology of southwest Ethiopia, and found causing severe damage to the fruit crop (Ayantu Tucho *et al.*, 2014). White mango scale is among insect pests inflicting damage to mango in Ethiopia and Kenya.

2.5 Biology of white mango scale

White mango scale of the Order Homoptera, Super family Coccoidea, Family Diaspididae, and Genus *Aulacaspis* is known by its accepted name *Aulacaspis tubercularis* Newstead, 1906 (Varshney *et al.*, 2002). However, there were times when it was known by several different names, namely, *Aulacaspis cinnamomi* Newstead, 1908, *Aulacaspis cinnamomi mangiferae* Sasser, 1912, *Aulacaspis mangiferae* MacGillivray, 1921, *Aulacaspis sennamomi* Kuwana, 1926, *Aulacaspis tubercularis* Sanders, 1909, *Diaspis cinnamomi* Hall, 1928, *Diaspis cinnamomi mangiferae* Newstead, 1911, among others (<http://scalenet.info/catalogue/Aulacaspis%20tubercularis/>; Halteren, 1970).

White mango scale secretes waxy protective covering under which it lives and feeds. The coat is attached to the plant surface, while the insect is free within the cover. The waxy cover is tough; thus, white mango scale is known as armoured or hard scale insect. Sizes of scale insects range from 1.5 mm to 25 mm in length, and they also vary in shape and colour (Varshney *et al.*, 2002; Moharum, 2012).

White mango scale shows sexual dimorphism. Adult female is larger in size than the male; with thin and nearly circular body shape and white armour that possesses dark and oval terminal exuviae (Abo-Shanab, 2012 cited from Borchsenius, 1966). The naked adult female's body is wrinkled, with quadrate and enlarged prosoma. Takagi (2010) describes the body of fully-grown adult female *rosae* type, as its prosoma (the fused head, prothorax and mesothorax) is swollen and wider than the postsoma (the fused metathorax and abdomen).

Adult female has neither wing nor appendage for locomotion. It glues itself to the plant

part by the use of its armour and remains sucking sap from the plant tissues. Like most species of armoured scale insects, adult male white mango scale is smaller in size than the female; its body is elongated and nearly rectangular in shape with three raised parallel dorsal ridges on its cover (Tagaki, 2010; Ben-Dov, 2012). Unlike the female, male mango scale possesses one pair of wings. They occur in groups gathering around the female, while the female usually occurs singly.

The reproductive biology of scale insects in general exhibits marked diversity. A variety of sexual and asexual modes of reproductions are present in scale insects (Ross *et al.*, 2012). Hermaphroditism is among the sexual modes of reproduction in this group of insects. Adult female of some scale insects may lay eggs or give birth directly to live first instars (Gyeltshen and Hodges, 2006). In the course of development, female scale insects undergo incomplete metamorphosis with a total of three to four instars; whereas the male passes through five instars exhibiting a metamorphosis which resembles the complete one. However, it is evident that members of the order Homoptera normally undergo incomplete metamorphosis.

The life cycle of white mango scale begins when the female lays fertilized eggs under its cover, which may be about 80-200 depending on variations in temperature (Sayed, 2012). After an incubation period of 7- 8 days the first instars hatch, and move out of their mother's cover (Halteren, 1970). Moharum (2012) described the external morphology of first instar white mango scale. Accordingly, the newly hatched nymph is small in size, elongate-oval and totally bare of wax secretion. It has well developed functional legs, antennae and eyes. Claws and tarsus on the legs have setae. The presence of such structures may help the nymph to attach itself to body of other animals to disperse phoretically. It was reported that crawlers of armoured scale insects could

remain attached to flying insects for certain periods of time, which may be an indication that phoresy might help them disperse (Magsig-Castillo *et al.*, 2010).

In scale insects first instars of both sexes usually look alike, but sexual dimorphism becomes evident as of second instar (Gyeltshen and Hodges, 2006). The crawlers move about until they get suitable feeding site on the plant where they settle and continue moulting. Following its settlement, cottony filamentous wax exudes from body of the first instar nymph, and covers it externally, completely. White mango scale is enclosed within this tough coat, where it remains feeding and moulting until fully develops.

The male crawlers settle in groups, while the females settle randomly (Louw *et al.*, 2008). The wax develops into tricarinate puparia in the male. The male passes through two pupa-like stages after which the winged adult emerges out. But, the settled female nymph moults first in to pre-ovipositional immature and then into ovipositional adult, and remains the rest of its life attached to the host plant. The overall generation time (from egg to egg) is reported to be 35-40 and 23-28 days in the female and male white mango scales, respectively, indicating relatively longer period in the female (Halteren, 1970). In bi-parental species of scale insects, like white mango scale, the male insect does not have functional mouth part to feed and hence lives for only few hours after begins flying, while the female normally feeds and lives longer (Beardsley and Gonzales, 1975; Bautista-Rosales *et al.*, 2013). Infestation of a new feeding site on the same or another host plant to establish a new population is the responsibility of crawlers. Though the male is capable of moving, it is unable to establish a new population.

Population of white mango scale shows overlap of generation. One of the main explanations for such overlapping is long ovipositional period which allows the female offspring to reach reproduction, while the first adult female is still laying eggs (Labuschagne *et al.*, 1995).

2.6 White mango scale infestation on mango

Various reports indicate that white mango scale is distributed throughout the world wherever mango is grown (USDA, 2007, El-Metwally *et al.*, 2011, Ha *et al.*, 2015). These include northern part of South America, the Caribbean, the east and west coasts of Africa, Asia, and Italy, among others. In Africa alone, the pest is reported to have infested mango in about 21 countries (Abo-Shanab, 2012 cited from Borchsenius, 1966). These include Ghana, Kenya, Madagascar, Mauritius, Tanzania, Uganda, Zimbabwe, and Zanzibar, among others (Hodges and Harmon, 2016). The year of first report of infestation of white mango scale on its host markedly varied among African countries. White mango scale was first recorded on one cultivar of mango in South Africa in 1947 (Waafa *et al.*, 2014), but it was reported to have been recorded infesting mangos in Ethiopia in 2010 (Mohammed Dawd *et al.*, 2012). In Benin, white mango scale was recorded from mango during 2005-2007 (Germain *et al.*, 2010).

This pest is currently posing severe threat to mango plantations in various mango growing countries. (Labuschagne *et al.*, 1995; Pena *et al.*, 1998; Nabil *et al.*, 2012; Tesfaye Hailu *et al.*, 2014; Ofgaa Djirata and Emanu Getu, 2015). As a sucking insect white mango scale inserts its stylets and feeds on sap from fruit, leaf, twigs and other young parts of mango plant. Juárez-Hernández *et al.* (2014) described high level of nutrient exploring potential of white mango scale by stating that it can pierce cell walls, even the lignified secondary walls of xylem by the use of its stylet bundles, resulting in severe damage to the crop. They described that the stylet bundles of the female insect is about 3 millimetres, which may be 3x the length of the insect body.

Pertaining to feeding habit of the pest, the damage caused to mango plantation includes yellowing of leaves, development of conspicuous pink blemish on mature and ripe fruit

and dieback (El-Metwally *et al.* 2011; Abo-Shanab 2012). Infestation in young trees may lead to excessive fall off leaves, retarded growth and death of the whole plant (Nabil *et al.*, 2012). The discolouration and consequent appearance of conspicuous pink blemishes on ripe mango fruit results in resistance from fruit market, including export potential, and eventually leads to marked economic loss (USDA, 2006, Ofgaa *et al.*,2016). In line with this, United States entered white mango scale in the list of pests that were of quarantine significance and underlined that further analysis should be put in to effect when mango and fresh longan fruits are imported in to the nation from India and Taiwan, respectively (USDA, 2006; USDA, 2007).

It is reported that damage by the pest is not limited to mango plantation. According to Malumphy (2014) white mango scale is a polyphagous pest which feeds on plants belonging to 18 families, even though it is a serious pest of mangos. Borchsenius (1966) cited in Abo-Shanab (2012) stated that the pest has been recorded mainly from four plant families such as Palmae, Lauraceae, Rutaceae, and Anacardiaceae particularly from mangos and cinnamon. Erichsen and Schoeman (1992) reported that white mango scale was found feeding on avocado in South Africa.

2.7 Management practices of white mango scale

Like other phytophagous insects, white mango scale needs its host for food, oviposition site, and shelter. In the process of exploiting the host plant for the aforementioned purposes, it poses deleterious threats to the host plant which interferes with mango growers' interest and as a result the issue of management of the pest comes in.

2.7.1 Cultural control

Cultural pest control is a practice of manipulation of a garden's planting, growing and cultivation with the purpose of reducing pest number and its damage to the crop under

consideration (Waskom, 1995). It is believed to be a better alternative to pesticide application from conservation of non target insects, environmental and other health concerns points of view. In relevance to control of scale insects, cultural control includes practices such as pruning, smoking and area clearing, application of soaps and homemade oils, use of humus as supportive plant nutrient, among others (Buss and Turner, 2006; Johnson 2008; Tesfaye Hailu *et al.*, 2014). In eastern Kenya, some mango growers could reduce white mango scale infestation on mango through regular and cyclic pruning (Ofgaa Djirata *et al.*, 2016).

Bautista-Rosales *et al.* (2013) revealed that mango tree pruning significantly decreased the number of female white mango scale in Mexico. On the other hand, they showed that the use of humus in organically managed mango plantation encouraged the female pest to become abundant. It was implicated that increasing nutritional quality of plants favours reproduction and dispersal of phytophagous insect species.

Temesgen Fita (2014) states that farmers in Ethiopia used pruning, smoking and area clearing as cultural management practices to control white mango scale. However, there is no information regarding the level of their efficacy in these instances.

2.7.2 Biological Control

Biological control is the utilization of natural enemies to reduce the damage caused by noxious organisms (pests) to tolerable level. The most known natural enemies used as bio-control agents in frequency of their use include parasitoids (parasitic wasps and flies) predators (some insects, spiders and predatory mites) and pathogens (fungi, protozoa, bacteria and virus) (Mills and Daane, 2005). Buss and Turner (2006) stated that predator such as ladybird beetles and green lacewings, and tiny parasitic wasps may be used to suppress scale insect population.

There are many natural enemies of white mango scale. Nabil *et al.* (2012) recorded *Aphytis* sp. and *Encarsia* sp. (Aphelinidae), *Habrolepis diaspidi* (Risbec) (Encyrtidae) as parasitoids and *Cybocephalus micans* Reitter as predator of white mango scale in Egypt. Similarly, Abo-Shanab (2012) recorded little numbers of natural enemies which included parasitoids such as *Aphytis mytilaspidis* (Le Baron) and *Encarsia citrina* (Craw), and a predatory beetle, *Scymnus syriacus* Marseul in the same country. The predatory thrips, *Aleurodothrips fasciapennis* (Franklin) and parasitoid *Encarsia citrina* (Craw) were also recorded as natural enemies of white mango scale in South Africa (Labuschagne *et al.*, 1995). However, the report indicated that the indigenous parasite *Encarsia citrina* (Craw) couldn't control the pest, despite record of over 80% parasitism. On the other hand, the ectoparasitoid *Aphytis chionaspis* Ren (Hymenoptera: Aphelinidae) which was introduced from Thailand was known to have been established and made valuable control in South Africa (Daneel and Joubert, 2009).

Considerable studies reported that various species of *Chilocorus* preyed on armoured scale insects (Mendel *et al.*, 1985; Erkiling and Uygun, 1995; Lambdin, 1995). *Chilocorus bipustulatus* (L.), for example, caused mortality among adult females of *Parlatoria blanchardi* (Homoptera: Diaspididae) and significantly lowered its infestation on date palms in Northern Niger of West Africa (Stansly, 1984). Moreover, *Chilocorus bipustulatus* (L.) and *Chilocorus nigritus* (Fabricius) were found feeding specifically on white mango scale in Egypt and South Africa, respectively (Labuschagne *et al.*, 1995; Abo-Shanab, 2012). Product of *Chilocorus nigritus* is also being used as biological control agent against armoured scales (Entocre, 2015).

2.7.3 Chemical control

Insecticides of various types are used to control insect pests in agriculture. Pesticides

are chemicals or mixture of different chemicals used for the purpose of killing, repelling, mitigating or reducing pest damages (Pal and Gupta, 1994). FAO (1989) defines pesticide as any substance or mixture of substances intended for prevention, destroying or controlling of any pest. Likewise, insecticides are used in agriculture to prevent, inhibit or kill insects. The use of insecticides may give faster solution temporarily. However, it is obvious that the use of toxic insecticides in pest control bears adverse effects on the ecosystem in general, and affects non target species including natural enemies of the pest under consideration, in particular.

Many experiments have been conducted to test some chemicals which were thought to have been effective in suppressing white mango scale. Abo-Shanab (2012) describes that a series of field test of three mineral oils against white mango scale showed effectiveness by the following descending order of efficacy : Diver® > CAPL2® > super masrona®, the first two being statistically not different from each other. USAID Kenya Business Development Services Program recommended Deltametrine and pyrethrin to be used for the control of white mango scale in Kenya (Findlay, 2003).

There has been very limited report of experiments performed regarding insecticide screening against white mango scale in Ethiopia. This may be because introduction of white mango scale to Ethiopia has been less than a decade. Gashawbeza Ayalew *et al.* (2015) tested Movento and Methidathion, and reported they had equal efficacy in reducing white mango scale infestation on mango in Central Rift Valley of central Ethiopia.

In general, pertaining to its waxy covering, the commonly used contact insecticides can't penetrate into the body of white mango scale from its cuticle (Buss and Turner, 2006). Therefore systemic insecticides and horticultural oils that may suffocate the pest are the most used formulations for the control of white mango scale.

Chapter 3

Population Dynamics of White Mango Scale

3.1 Introduction

White mango scale is reportedly posing damage to mango production in many tropical and sub tropical countries in general, and in Ethiopia and Kenya in particular (<http://www.jkuates.co.ke>; Findlay 2003; Seid Hussen and Zeru Yimer, 2013; Alemayehu Chala *et al.*, 2014; Ofgaa Djirata and Emanu Getu, 2015). Even though the presence of white mango scale in Kenya was reported many years back, complaint regarding severity of its damage on mango production has been reported more frequently from Ethiopia, where its introduction has been less than a decade (Mohammed Dawd *et al.*, 2012; Temesgen Fita, 2014). It spread to various areas known for their mango production in western Ethiopia and caused devastating impact on the product.

Reproduction and growth of insect population depend on biotic and abiotic factors within the environment. There had been few or no study on ecological aspects of white mango scale such as composition of its developmental stages, population fluctuation and peak periods in both Ethiopia and Kenya, the aspects which are very essential in designing management strategy of the pest in question. White mango scale being a newly introduced mango pest to Ethiopia, its population fluctuations and the contributing factors have not been studied. Hence, this study was initiated with the following objectives.

To investigate the factors that influence population dynamics of white mango scale

To investigate natural enemy of white mango scale and its population dynamics

3.2 Material and methods

3.2.1 Description of the study area

This study was conducted in western Ethiopia and, central and eastern Kenya (Figure 3.1-3.2).

Ethiopia

Two sites (orchards) within two neighbouring administrative zones of Oromia, western Ethiopia were used for data collection. They were Bako and Arjo Orchards.

Both Bako and Arjo areas received unimodal rainfall (Ethiomet, 2016).

Bako mango orchard ($09^{\circ} 07'N$ and $037^{\circ} 03'E$) was located in West Shoa Administrative Zone, Bako Tibe District, adjacent to Bako town at a distance of 250km west of Addis Ababa. Bako received mean annual rainfall of 1219 mm. This orchard had a total farm area of 10 hectares stretched over a gentle slope, its altitude ranging from 1622 to 1661m.a.s.l. The farm was under a joint administration of two government schools, Bako Preparatory and Bako Secondary Schools. Almost all of the mangos in this orchard belonged to indigenous variety. They were planted 35 years ago. There have been no management practices such as pruning and application of insecticide for pest control prior to this study. The mango trees were 12 metres tall, and spaced at 10 metres distance from each other, on average. However canopies of most of the neighbouring mango trees touched each other.

Arjo orchard ($09^{\circ} 03'N$ and $036^{\circ} 17'E$) was found in East Wollega Administrative Zone, Diga District, adjacent to Gudetu Arjo town at a distance of 370km west of Addis Ababa. Arjo received a mean annual rainfall of 1649mm. The altitude of the orchard

site was between 1326 and 1379 m.a.s.l. The farm was under private ownership of a local farmer. All of the mangos at Arjo orchard were indigenous variety. They were planted about 25 years back. Total field area of Arjo mango orchard was 18 hectares. Mango trees in this orchard were 10 metres tall on average. They were spaced at an average distance of 9 metres from each other. There has been no pruning, and hence branches of the mango trees were bushy. There has been no application of pesticide for the purpose of pest control so far. Sorghum and maize were intercropped with mango, on about a quarter of the total mango field on the lower side.

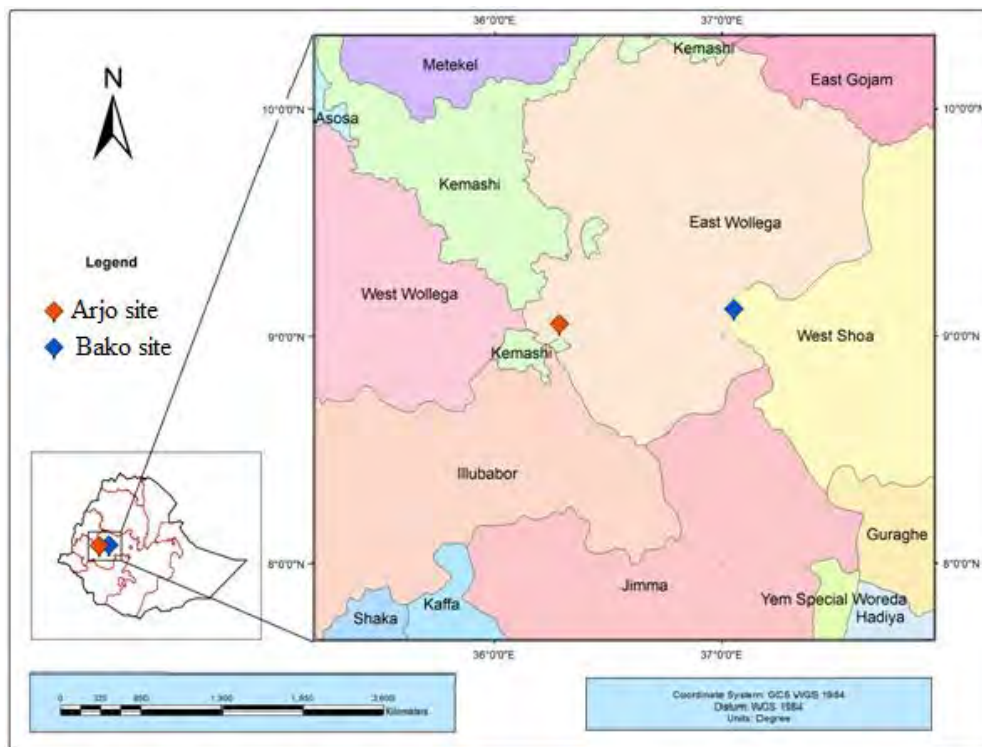


Figure 3. 1 Study sites of population dynamics in western Ethiopia

Kenya

Study on population dynamics of white mango scale was conducted in three counties of Kenya, Machakos from eastern, Murang'a and Nairobi City County from central Kenya. Kimani in Machakos ($01^{\circ} 10'S$ and $037^{\circ} 30'E$), Samuru in Murang'a ($00^{\circ} 59'S$ and $037^{\circ} 05'E$) and Kenyatta University yards in Nairobi City County ($01^{\circ} 11'S$

and 036° 56'E) were the three orchards addressed in this study. These counties were known to receive bimodal pattern of rainfall.

Kimani mango farm was located at about 100km from Nairobi closer to Matuu town. The total area of the farm was one hectare. It was nearly levelled plot with elevation of 1276 m.a.s.l. The soil was characterized by its sandy texture. Kimani received annual rainfall of 582 mm in the year 2015. Its average monthly maximum and minimum temperatures were 29°C and 16°C, respectively. Kimani mango farm belonged to a local farmer. Apple, Ngoe, Tommy Atkins and Kent were found mixed in nearly equal proportions, except that Apple had relatively higher number of trees. The farm was well managed through weeding, pruning, and other agronomic practices. Pesticides were frequently applied for arthropod pest control in Kimani mango farm.

Samuru mango farm belonged to Kenyan Agricultural and Livestock Research Organization (KALRO). Total area of the farm was 3.8 hectares. The farm was located at top of a small plateau with elevation of 1527 m.a.s.l. Samuru soil has sandy clay loam texture. In the year 2015, Samuru received an annual rainfall of 920mm. Its average monthly maximum and minimum temperatures were 27°C and 14°C, respectively. There were about 20 mango varieties in the farm, of which Apple, Kent, Tommy Atkins and Vandyke had sufficient numbers of mango trees for this study and hence selected. The mango farm was not weeded, not pruned, and there was no application of pesticide for one year prior to the beginning of this study (Ofgaa personal communication).

Mangos in Kenyatta University yards were located in the university main campus as homestead plantation within blocks of staff residences. The plot of land holding all the blocks was bounded by streets named for African countries in all cardinal directions.

Average area of the blocks was 1.5 hectares with average number of 29 mango trees. Kenyatta University study site exhibited sandy loam soil texture. The blocks laid on a very gentle slope ranging from 1538 to 1553 m.a.s.l. The site received an annual rainfall of 1330mm in 2015 with its average monthly maximum and minimum temperatures of 27°C and 15°C, respectively. Almost all of the mango trees in Kenyatta University yards were of local variety.

Weather data on rainfall, maximum and minimum temperatures of all the three sites were obtained from Kenya Meteorological Department (Kenya Meteorological Services, 2015).

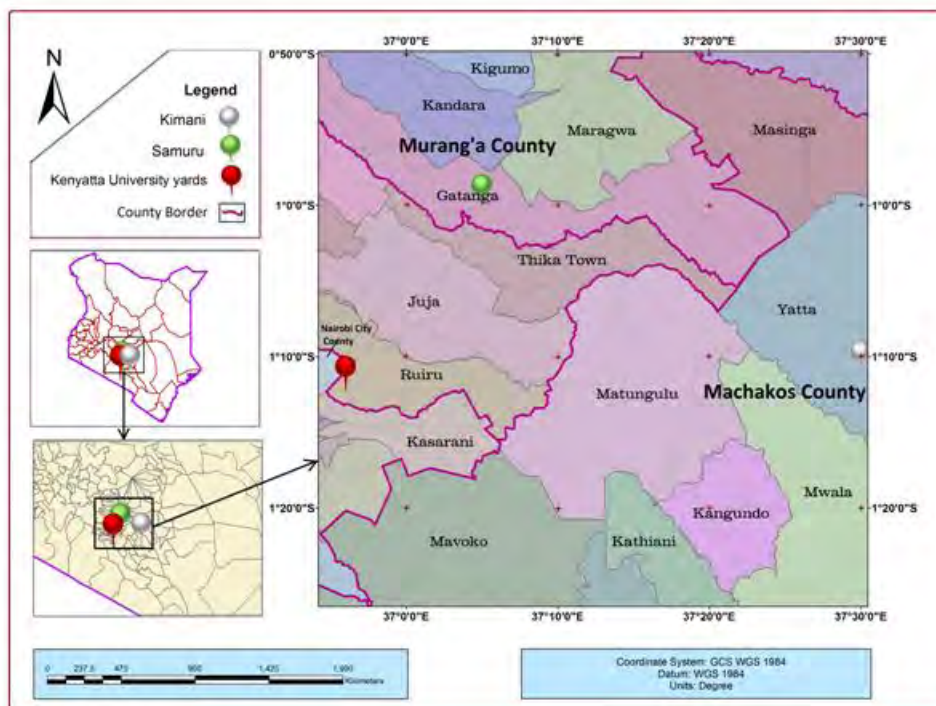


Figure 3. 2 Study sites of population dynamics in central and eastern Kenya

3.2.2 Study design and sampling procedure in Ethiopia

Arjo and Bako sites

Weather data of about 30 years (1983 to 2013) on rainfall, maximum and minimum temperatures were obtained from Ethiopian National Meteorology Agency. Stations encompassing the current study area in Ethiopia didn't have relative humidity and

hence only mean rainfall and temperature data were used in this study.

In each orchard, five blocks were specified, one at each of the four corners and the centre, hence Randomized Complete Block Design (RCBD) was used for the experiment. From upper, middle and lower canopies of a mango tree within every block, a total of ten leaves were plucked. The sampling started from the trees at each corner in the blocks and continued toward the centre, and that started from central block continued in the four cardinal directions on successive trees, once within a month for 12 consecutive months. The leaves collected from each tree were placed in a separate cloth bag, labelled, kept in a plastic bag and taken to Addis Ababa University, Science Faculty, Insects and Vector Research Laboratory. The leaves were observed under stereomicroscope and numbers of white mango scales and predatory larvae were recorded. On which developmental stages of white mango scales did the predatory larvae prey and their preying behaviour were observed and recorded. In this study, the first instar was recorded as *crawler* whereas; all the remaining developmental stages and the adult were collectively considered as *sessile* stage. Male and female sessile stage mango scales were identified and recorded. Dissecting needle was used to open up the armour of the female for ease of counting the eggs underneath. During each sampling time, ten leaves infested by white mango scale were plucked and placed in insect rearing cages, kept in the orchards, and checked every five days for emergence of natural enemies. Before placement, the leaves were physically checked using a hand lens to remove other insects, leaving white mango scales. Natural enemies observed preying on white mango scale were photographed and videotaped by the use of camera fixed on eyepiece of stereomicroscope. These documents were used as a support in identifying the predator with available taxonomic keys (Pope, 2012; Chowdhury *et al.*, 2015).

3.2.3 Study design and sampling procedure in Kenya

Samuru and Kimani farms

Four transect lines, one at either side of centre of the field, and one 10 metres toward interior from edge of each periphery, were formed across the length of the fields from end to end. On both sides closer to the lines, 24 mango trees of each selected variety were tagged with permanent marker on piece of polyethylene, prior to sampling. Each treatment was replicated four times.

Kenyatta University mangos

A mango tree at the western boarder of every block and five additional trees in respective frontlines toward east were tagged jumping every two mango trees in between.

From each of the sample mango tree of the orchards in Kenya, a total of ten leaves were plucked from upper, middle and lower canopies, once within a month for six successive months. The leaves from each tree were placed in separate cloth bag, labelled, kept in a plastic bag and taken to Kenyatta University, Science Zone Laboratories Complex- Agricultural Sciences Laboratory. The leaves were observed under stereomicroscope and numbers of white mango scales recorded. Dissecting needle was used to uncover the female white mango scale off its armour to count the eggs. During each sampling time, ten leaves infested by white mango scale were plucked and placed in insect rearing cages, kept in the orchards, and checked every three days for emergence of natural enemies. Before placement, the leaves were physically checked using a hand lens to have removed other insects leaving white mango scales.

Data analysis

Microsoft Excel was used to summarize data on population fluctuation of white mango scale and the natural enemy observed. Data on white mango scale count was analysed

using Proc ANOVA of SAS software V9. Significant means were separated by Fisher's Least Significant Difference (LSD) at 5% error level. Proc correlation of SAS software was applied to identify association between white mango scale and the natural enemy identified. Significance levels of correlation coefficient values of the variables were determined with alpha level of 5%. Square root transformation was used to normalize data obtained from count of the natural enemy and white mango scales where applicable.

3.3 Results

3.3.1 Population fluctuations of white mango scale in Ethiopia

Population fluctuations of egg, crawler and sessile mango scales followed more or less similar patterns across the months of the study year. Sessile mango scale persisted throughout the year at Arjo orchard, and in most of the months of the year at Bako (Figures 3.3-3.4). Marked population fluctuations were observed, with general trend of decline with decreased precipitation. Population peaks were recorded in April and May, in Arjo and Bako respectively. In Arjo, the maximum average number of sessile white mango scale recorded per leaf was 59, which was in April, but only one was recorded in November. In Bako orchard, maximum average number of sessile white mango scale per leaf was recorded in May, which was 102, whereas it was one per leaf in each of the months from September to November.

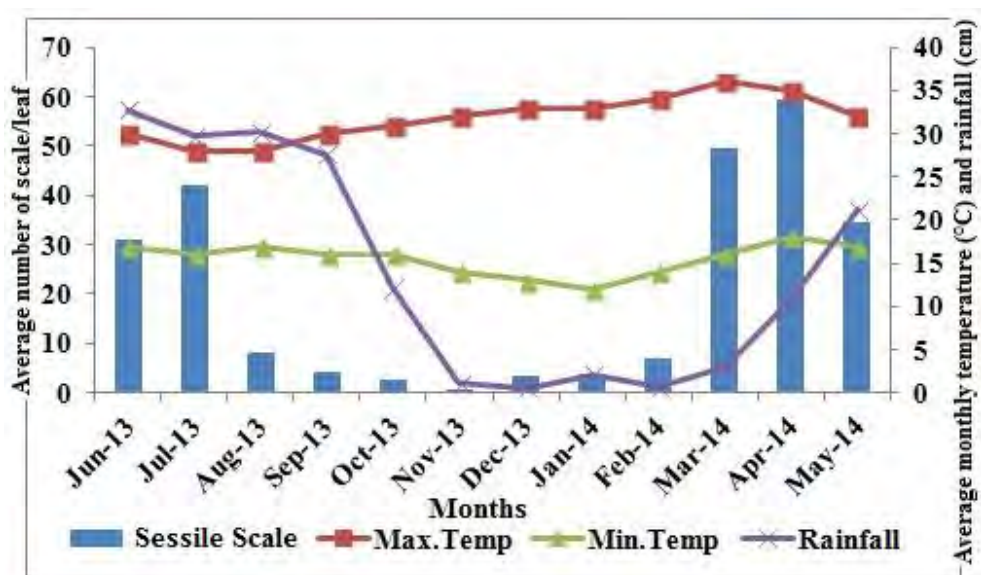


Figure 3. 3 Population fluctuation of sessile white mango scale in mango orchard at Arjo

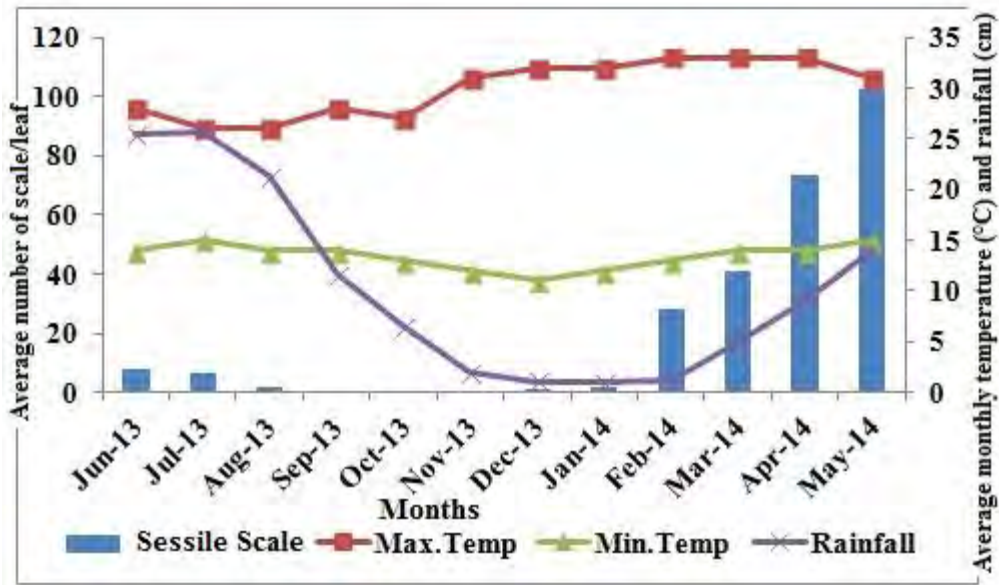


Figure 3. 4 Population fluctuations of sessile stage white mango scale in mango orchard at Bako

Data from Arjo orchard depicted that the male white mango scale had its population peaks in March, April, and July with slight differences of density among the months. Average numbers of the male scale per leaf were 37, 33 and 32 in March, April and July, respectively. No male white mango scale was recorded in October at Arjo orchard. In this orchard, population peak of female white mango scale was recorded in April, at which the average number per leaf was 27. The female scale persisted better than the male during the months of low precipitation (Figure3.5).

In Bako orchard, populations of both sexes rose at the beginning of rainy season from March and reached their peaks in May. The average numbers of male and female white mango scales in May were 72 and 31 per leaf, respectively. From September to November male white mango scale was not registered in Bako orchard. Similarly, densities of the female scale were minimal from September to January, with an average of one scale per leaf. These months were characterized with declining precipitation in Bako site (Figure 3.6). In general, months from September to January were

characterized by inconsequential record of scale population in Bako.

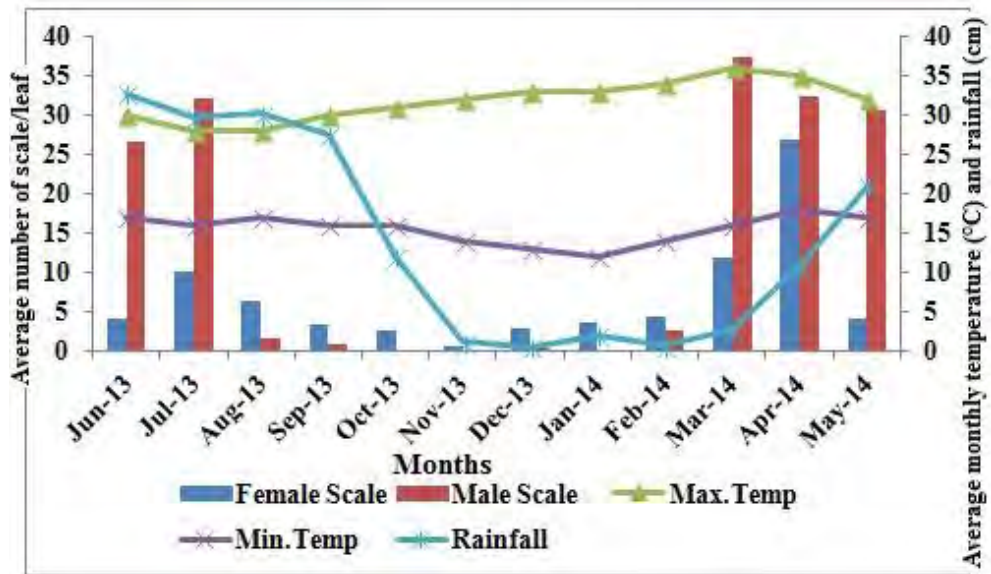


Figure3. 5 Population fluctuations of male and female white mango scale in mango orchard at Arjo

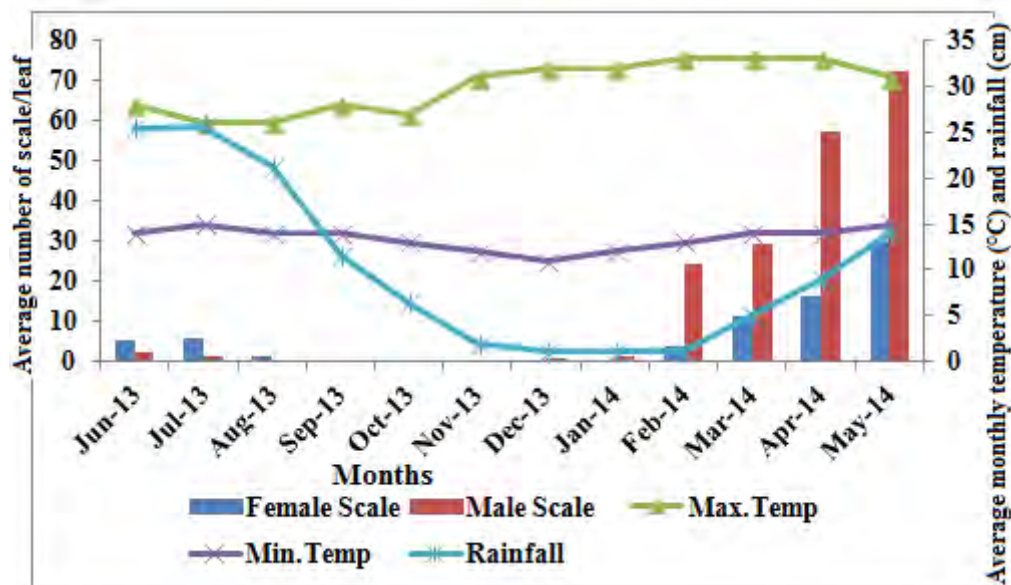


Figure 3. 6 Population fluctuations of sessile white mango scale male and female in mango orchard at Bako

Populations of egg and crawler began to have risen with the beginning of rain from around March and persisted relatively better during the rainy months in Arjo, but they were more noticeable from February to May, in Bako (Figures 3.7- 3.8).

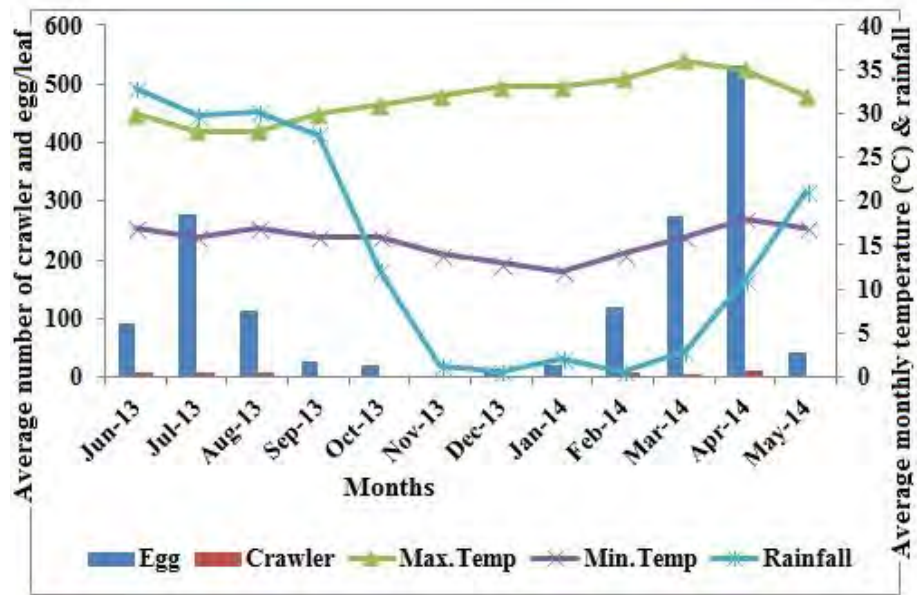


Figure 3. 7 Population fluctuations of white mango scale crawler and egg in mango orchard at Arjo

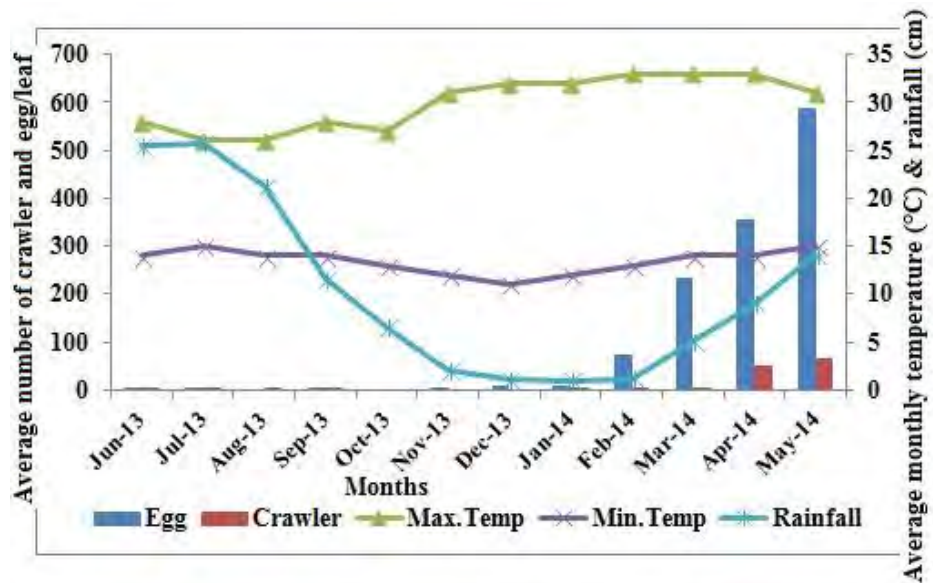


Figure 3. 8 Population fluctuations of white mango scale crawler and egg in mango orchard at Bako

Predator

A total of 116 larvae of the ladybird beetle *Chilocorus* sp. (Coleoptera: Coccinellidae) (78 from Arjo and 38 from Bako) were collected from mango leaves infested with white

mango scale in the two sampling sites (Plate 3.1). They were found feeding on both male and female white mango scales. When feeding, the larvae easily destructed coat of the male mango scale and reached it, whereas they forcefully pushed their heads inward and partly opened up cover of the female, captured and chewed it. In all instances of observations the presence of the larvae was associated with colony of white mango scales. Adult stage was not obtained directly from leaves collected and investigated in laboratory. However, a total of 11 adult beetles (7 from Bako and 4 from Arjo sites) emerged in March, April, June and July from the leaves kept in rearing cages, 15 to 23 days after the leaves were kept in the cages.



Plate 3. 1 Larvae of ladybird beetle at different stages of development

In both sites, there was statistically significant ($p < .05$) positive correlation between the populations of white mango scale and the predatory larva, as depicted by the table below (Table 3.1; Appendices 3.1 and 3.2). Moreover, there was no significant difference in the recorded number of the predatory larva population between Arjo and Bako sites ($P > 0.05$) (Table 3.2).

Table 3. 1 Correlations of *Chilocorus* sp. larva population with male, female and sum of male and female white mango scale populations in Arjo and Bako orchards

Pearson's Correlation Coefficient (r) and p(r)				
		Female	Male	Sum male_female WMS
Arjo	r	0.64	0.74	0.77
	p(r)	0.024	0.006	0.003
Bako	r	0.93	0.90	0.94
	p(r)	<.0001	<.0001	<.0001

Table 3. 2 Mean numbers of *Chilocorus* sp. larvae in Arjo and Bako

Study sites	Mean± SE	p
Arjo	5.34±0.15a	0.13
Bako	2.16±0.14a	

Means followed by the same letter within a column are not significantly different from each other at 5% level, (T-test).

Chilocorus sp. larva showed population peaks in April and May in Arjo and Bako respectively (Figure 3.9). In Arjo, there was stable population in June and July, with continuous decrease from August to October. In Bako, *Chilocorus* sp. larva was not recorded from September to January and, in March and June. In Arjo, too, the predatory larva was not recorded from November to January, the months observed to have experienced relatively low precipitation, in both study orchards.

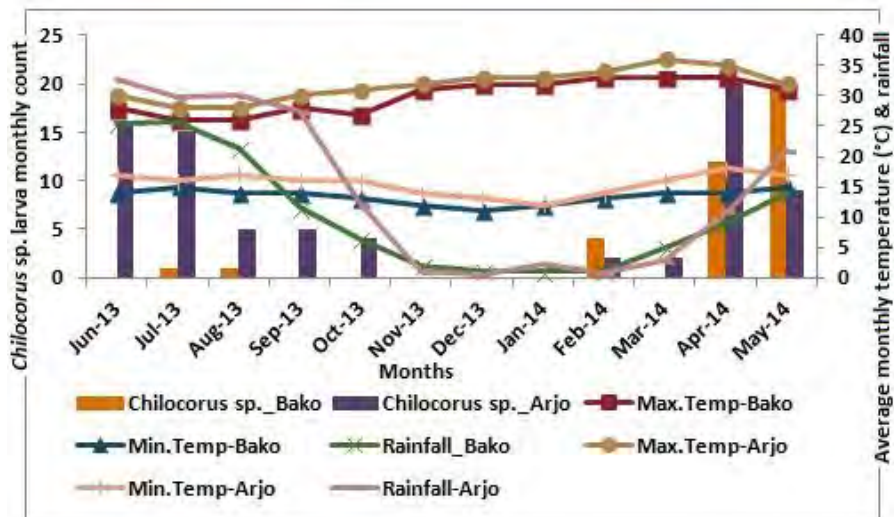


Figure 3. 9 Population fluctuations of *Chilocorus* sp. larva on mango trees at Arjo and Bako orchards

3.3.2 Population abundance of white mango scale in Ethiopia

Abundant infestation of white mango scale on mango leaves was observed in the study area. The infestation was so severe that some of the infested mango leaves were almost completely covered by the insect. Heavily infested leaves turned brownish and wilted (Plate 3.2).

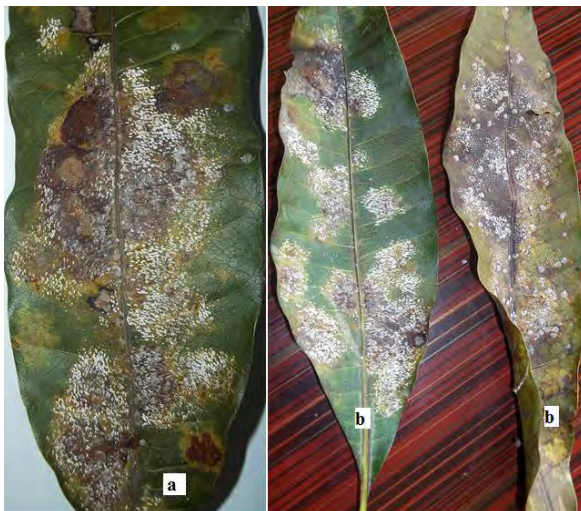


Plate 3. 2 Colour change and wilting of mango leaves caused by white mango scale infestation at Arjo (a) and Bako (b)

When the scale insects were removed from infested leaves, the vacated spots were

observed to have been turned yellowish, with damaged tissues in some areas (Plate 3.3).

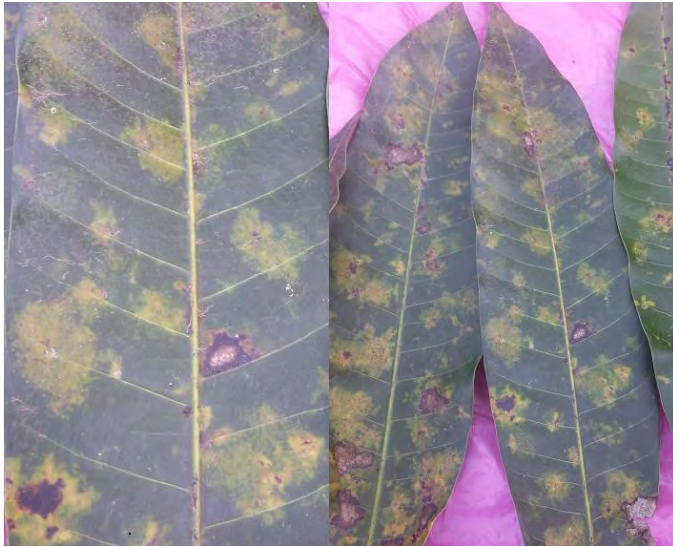


Plate 3. 3 Mango leaves lost their green colours on and surrounding the spots of white mango scale infestations

On the other hand, during the months from September to January yellow blemishes (spots) corresponding to those mentioned above, were more evident on leaf surfaces. Traces of male white mango scale cover were found attached on such spots in some instances. Plate 3.4 shows leaf pictures taken in November 2013 from Bako orchard, while the leaves were intact on mother trees.



Plate 3. 4 Mango leaves with yellow scars analogous to spots infested by white mango scale

Abundance of sessile mango scale in Ethiopia

Population of sessile white mango scale was found to be significantly abundant ($p < 0.05$) at Bako (24.87 ± 0.36 (5.09)) orchard than Arjo (18.55 ± 0.37 (4.42)). Pooled data from Arjo and Bako showed significant differences of population sizes between male and female scales ($p < 0.05$), and between upper and lower mango leaf surfaces ($p < 0.0001$) (Table 3.3) (Appendix 3.2). The sex ratio of mango scale in the study area was 2.28 male to 1 female.

Table 3. 3 Mean numbers of sessile scale on upper and lower mango leaf surfaces, and mean numbers of male and female scales (pooled data, Arjo and Bako orchards) (number in parenthesis indicates transformed mean value)

Sex of WMS	Mean±SE	Mango leaf Surface	Mean±SE
Male	28.43± 0.44 (5.42) ^a	Upper	36.79± 0.44 (6.15) ^a
Female	15.66± 0.26 (4.08) ^b	Lower	10.29± 0.24 (3.56) ^b
LSD	0.62	LSD	0.62

Means followed by the same letter within a column are not significantly different at 5% level, (LSD).

Population abundance of sessile stage mango scale was found to be significantly different among the study months in western Ethiopia, as combined data of both sites depicted ($p < 0.0001$). Maximum numbers of white mango scales were recorded in April and May, with mean numbers of 123.93 and 128.33, respectively. Mean numbers of the mango scale were very low during the months from August to January (Table3.4).

Table 3. 4 Mean numbers of sessile mango scale during the months of the study period (pooled data, Arjo and Bako orchards) (number in parenthesis indicates transformed mean value)

Month	Mean \pm SE
June	30.57 \pm 0.67(5.62) ^c
July	22.84 \pm 0.99 (4.88) ^c
August	4.70 \pm 0.44 (2.39) ^d
September	2.81 \pm 0.27 (1.95) ^d
October	1.17 \pm 0.23 (1.47) ^d
November	0.69 \pm 0.09 (1.30) ^d
December	3.37 \pm 0.23 (2.09) ^d
January	2.84 \pm 0.31 (1.96) ^d
February	23.05 \pm 0.72 (4.90) ^c
March	61.76 \pm 1.14 (7.92) ^b
April	123.93 \pm 1.04 (11.18) ^a
May	128.33 \pm 1.05 (11.37) ^a
LSD	1.52

Means followed by the same letter within a column are not significantly different at 5% level, (LSD).

At both Arjo and Bako orchards, the sessile scale abundances varied significantly among months of the study period ($P < .0001$) (Table 3.5)

Table 3. 5 Mean numbers of sessile mango scale in the study months at Arjo and Bako orchards (number in parenthesis indicates transformed mean value)

Month	Mean± SE	
	Arjo	Bako
June	48.32±1.23 (7.02) ^b	16.76± 0.34(4.21) ^e
July	38.20±1.88 (6.26) ^b	11.29±0.55(3.51) ^e
August	6.95±0.84 (2.82) ^c	2.83±0.25(1.96) ^f
September	6.47±0.47(2.73) ^c	0.37±0.15(1.17) ^{gh}
October	2.65±0.44(1.91) ^c	0.07±0.04(1.04) ^h
November	1.22±0.15(1.49) ^c	0.23±0.06(1.11) ^{gh}
December	4.83±0.41(2.42) ^c	2.13±0.20(1.77) ^{gf}
January	2.69±0.59(1.92) ^c	2.99±0.24(2.00) ^f
February	5.38±0.79(2.52) ^c	52.03±0.96(7.28) ^d
March	37.41±2.13(6.20) ^b	92.04±7.23(9.65) ^c
April	100.07±1.59(10.05) ^a	150.31±1.33(12.30) ^b
May	58.36±1.22(7.70) ^{ab}	225.22±1.28(15.04) ^a
LSD	2.83	0.71

Means followed by the same letter(s) within a column are not significantly different at 5% level, (LSD).

Population abundance of male white mango scale was significantly ($p < .0001$) higher than that of female at Bako orchard while the difference was not significant at Arjo orchard ($p > 0.05$) (Appendices 3.3-3.4). Mean numbers of male and female WMS is presented in Table 3.6 below. The differences of WMS populations between upper and lower surfaces of mango leaves at both Arjo and Bako orchards were also found to be statistically significant ($p < .0001$). The scale was densely populated on upper surface

than the lower (Table 3.7).

Table 3. 6 Mean numbers of male and female WMS at Arjo and Bako orchards (number in parenthesis indicates transformed mean value)

Study site	Mean \pm SE		LSD
	Male WMS	Female WMS	
Arjo	22.43 \pm 0.62 (4.84) ^a	15.00 \pm 0.40 (4.00) ^a	1.16
Bako	35.09 \pm 0.61(6.01) ^a	16.34 \pm 0.35(4.16) ^b	0.29

Means followed by the same letter within a row are not significantly different at 5% level, (LSD).

Table 3. 7 Mean numbers of sessile WMS on upper and lower mango leaf surfaces at Arjo and Bako orchards (number in parenthesis indicates transformed mean value)

Study site	Mean \pm SE		LSD
	Upper	Lower	
Arjo	33.70 \pm 0.90(5.89) ^a	7.71 \pm 0.56(2.95) ^b	1.16
Bako	40.02 \pm 0.59 (6.40) ^a	13.19 \pm 0.36(3.77) ^b	0.29

Means followed by the same letter within a row are not significantly different at 5% level, (LSD).

Abundance of egg and crawler in Ethiopia

White mango scale eggs recorded from mango leaves were relatively more abundant in relation to that of the crawler population at the study orchards in western Ethiopia. Up to 2400 and 2159 eggs were recorded per leaf from Bako and Arjo orchards, respectively. Most of the leaves had eggs in many hundreds, even though considerable numbers were with no any egg. To the contrary, the maximum numbers of crawlers recorded per leaf were 300 in Arjo and 445 in Bako mango orchards with very few leaves bearing them in tens while most of the leaves had no crawlers. On the other hand, it was a common incidence to have observed as many eggs as 200 per female

scale in the study area. In May 2014, the maximum numbers of 240 and 233 eggs were recorded per female from Arjo and Bako orchards, respectively. In such cases fecund female's armour appeared dull red when focused from dorsal position, pertaining to colour of the egg mass underneath.

Mango scale eggs and crawlers population abundances followed more or less similar patterns of that of sessile stage in both study sites and over the months of the study period. Statistically significant differences were recorded in populations of scale crawlers between the study orchards, population at Bako (1.90 ± 0.17 (1.69)) being higher than that at Arjo (0.92 ± 0.09 (1.39)) ($p < 0.05$). Pooled data of Arjo and Bako study sites showed significant differences of crawlers among the months of the study period and between upper and lower mango leaf surfaces ($< .0001$) (Tables 3.8-3.9, Appendix 3.5).

Table 3. 8 Mean numbers of monthly crawler population (pooled data, Arjo and Bako orchards) (number in parenthesis indicates transformed mean value)

Month	Mean ± SE
June	1.86±0.23 (1.69) ^b
July	1.04±0.20(1.43) ^{cb}
August	0.64±0.23(1.28) ^{cb}
September	0.05±0.01(1.03) ^c
October	0.02±0.01(1.02) ^c
November	0.00±0.00 (1) ^c
December	0.00±0.00 (1) ^c
January	0.24±0.07(1.11) ^{cb}
February	0.96±0.24 (1.40) ^{cb}
March	0.60±0.15 (1.27) ^{cb}
April	8.64±0.60(3.10) ^a
May	9.02±0.64 (3.17) ^a
LSD	0.64

Means followed by the same letter (s) within a column are not significantly different at 5% level, (LSD).

Table 3. 9 Mean numbers of crawler population on upper and lower mango leaf surfaces (pooled data, Arjo and Bako orchards) (number in parenthesis indicates transformed mean value)

Mango leaf surface	Mean \pm SE
Upper	2.33 \pm 0.17(1.83) ^a
Lower	0.58 \pm 0.08(1.26) ^b
LSD	0.26

Means followed by the same letter within a column are not significantly different at 5% level, (LSD).

Crawler population exhibited significant differences ($p < 0.0001$) of population sizes among the months of the study period in both Arjo and Bako orchards (Table 3.10, Appendices 3.6-3.7). Similarly, population sizes of crawler on upper and lower surfaces of mango leaves were found to be statistically significant in both study sites ($p < 0.05$) (Table 3.11).

Table 3. 10 Mean numbers of monthly crawler populations at Arjo and Bako orchards (number in parenthesis indicates transformed mean value)

Month	Mean± SE	
	Arjo	Bako
June	2.44±0.38(1.85) ^{ab}	1.34±0.28(1.53) ^b
July	2.24±0.37(1.80) ^{abc}	0.12±0.23(1.06) ^b
August	1.42±0.45(1.56) ^{abcd}	0.01±0.00(1.00) ^b
September	0.09±0.27(1.05) ^{cd}	0.01±0.00(1.00) ^b
October	0.34±0.01(1.02) ^d	0.00±0.00(1.00) ^b
November	0.00±0.00(1.00) ^d	0.00±0.00(1.00) ^b
December	0.00±0.00(1.00) ^d	0.00±0.00(1.00) ^b
January	0.03±0.01(0.01) ^d	0.45±0.13(1.21) ^b
February	2.07±0.47(1.75) ^{abcd}	0.09±0.03(1.04) ^b
March	0.88±0.30(1.37) ^{abcd}	0.34±0.06(1.16) ^b
April	3.16±0.50(2.04) ^a	16.39±0.99(4.17) ^a
May	0.44±0.11(1.20) ^{bcd}	25.34±0.94(5.13) ^a
LSD	0.77	0.98

Means followed by the same letter (s) within a common are not significantly different at 5% level (LSD).

Table 3. 11 Mean numbers of crawler population on upper and lower mango leaf surfaces at Arjo and Bako orchards (number in parenthesis indicates transformed mean value)

Study site	Mean \pm SE		LSD
	Upper	Lower	
Arjo	1.84 \pm 0.17 (1.68)a	0.19 \pm 0.04(1.09)b	0.31
Bako	2.87 \pm 0.29(1.97)a	1.02 \pm 0.15(1.42)b	0.40

Means followed by the same letter within a row are not significantly different at 5% level, (LSD).

The two orchards having been compared for their eggs, Arjo was found to be significantly higher ($p < 0.05$) with mean number of 31.54 ± 0.52 (5.70) than Bako whose mean number was 17.60 ± 0.55 (4.31) (LSD = 0.74).

Pooled data of eggs from the two study sites indicated the presence of significant differences ($p < .0001$) among the months of the study period (Table3.12; Appendix 3.8).

They were concentrated more significantly ($p < 0.05$) on upper (48.27 ± 0.67 (7.02)) than the lower leaf surface (7.99 ± 0.25 (3.00)) (LSD = 0.74).

Table 3. 12 Mean numbers of WMS eggs in the months of the study period (pooled data, Arjo and Bako orchards) (number in parenthesis indicates transformed mean value)

Month	Mean ± SE
June	12.43±0.81(3.66) ^{def}
July	27.87±1.49(5.37) ^{dc}
August	13.39±0.89(3.79) ^{de}
September	3.54±0.42(2.13) ^{gef}
October	2.53±0.37(1.88) ^{gf}
November	0.27±0.13(1.13) ^g
December	2.69±0.26(1.92) ^{gf}
January	5.24±0.33(2.50) ^{gef}
February	30.78±0.95(5.64) ^c
March	94.31±1.32(9.76) ^b
April	163.76±1.75(12.84) ^a
May	88.87±1.89(9.48) ^b
LSD	1.81

Means followed by the same letter (s) within a column are not significantly different at 5% level, (LSD).

At each of Arjo and Bako orchards, mean numbers of eggs showed significant differences ($p < .0001$) among the study months, and between the upper and the lower mango leaf surfaces (Tables 3.13-3.14, Appendices 3.9-3.10).

Table 3. 13 Mean numbers of monthly egg populations at Arjo and Bako orchards (number in parenthesis indicates transformed mean value)

Month	Mean± SE	
	Arjo	Bako
June	31.28±1.29(5.68) ^{dc}	1.72±0.44 (1.65) ^e
July	89.24±2.35(9.50) ^b	0.55±0.25 (1.25) ^e
August	42.39± 1.28(6.59) ^c	0.00±0.00 (1.00) ^e
September	9.19±0.70(3.19) ^{fe}	0.15±0.07 (1.07) ^e
October	6.60± 0.63 (2.76) ^{fc}	0.00±0.00 (1.00) ^e
November	0.00±0.00 (1.00) ^f	0.57±0.25 (1.25) ^e
December	2.45± 0.29(1.86) ^f	2.95±0.44 (1.99) ^e
January	7.35±0.52 (2.89) ^{fe}	3.43±0.39 (2.11) ^e
February	41.65±1.40 (6.53) ^c	21.51± 1.28(.74) ^d
March	104.95±1.90 (10.29) ^b	84.23±1.92 (9.23) ^c
April	193.94±2.84 (13.96) ^a	136.15±2.14 (11.71) ^b
May	16.72± 0.64 (4.21) ^{dc}	216.59±2.92 (14.75) ^a
LSD	2.30	2.26

Means followed by the same letter within a column are not significantly different at 5% level, (LSD).

Table 3. 14 Mean numbers of egg population on upper and lower mango leaf surfaces at Arjo and Bako orchards (number in parenthesis indicates transformed mean value)

Study site	Mean \pm SE		LSD
	Upper	Lower	
Arjo	62.55 \pm 0.90(7.97) ^a	10.82 \pm 0.33(3.44) ^b	0.94
Bako	35.80 \pm 0.99(6.10) ^a	5.55 \pm 0.36(2.56) ^b	0.92

Means followed by the same letter within a row are not significantly different at 5% level, (LSD).

3.3.3. Population fluctuations of white mango scale in Kenya

At Kenyatta University mango, sessile stage scales and egg showed population peaks in April (Figure 3.10-3.11). They persisted throughout the study months with marked population fluctuations. On the other hand, crawlers remained at a more or less stable state throughout the six months, with a relatively very low population size.

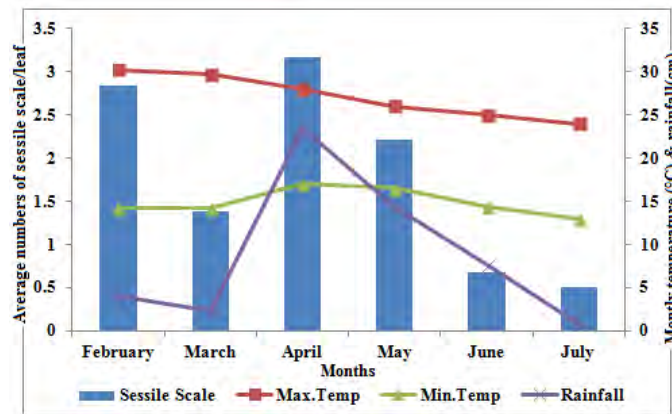


Figure 3. 10 Population fluctuations of sessile white mango scale at Kenyatta University mango

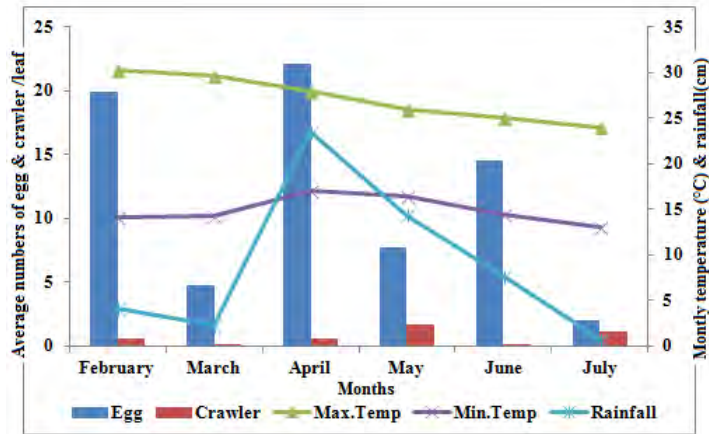


Figure 3. 11 Population fluctuations of white mango scale egg and crawler at Kenyatta University mango

At Kimani orchard, sessile white mango scale was recorded throughout the study months with two peaks of population, i.e., in February and April, that of April being relatively higher (Fig.3.12). Crawlers were recorded only in April and May. Egg was at its peak in April with no record in June and July like crawler (Fig.3.13).

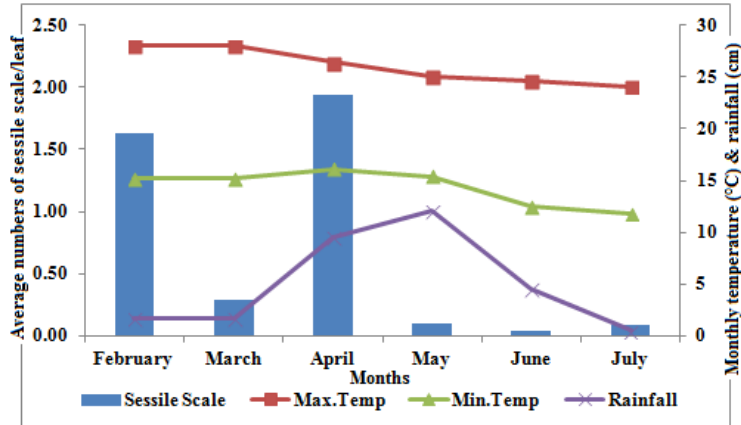


Figure 3. 12 Population fluctuations of sessile white mango scale in mango orchard at Kimani

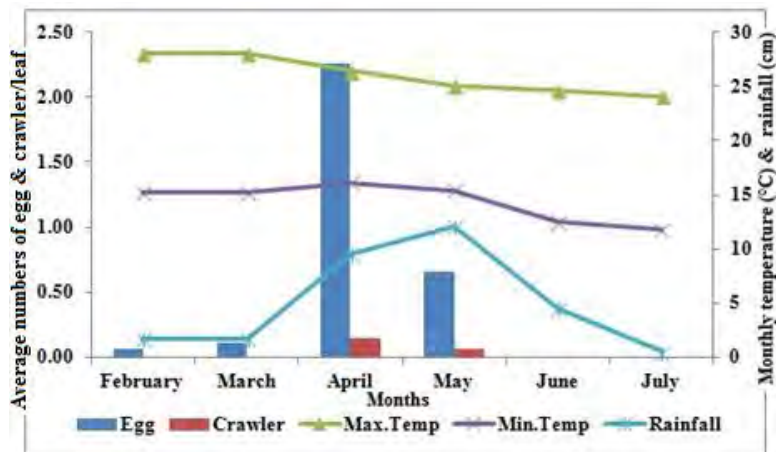


Figure 3. 13 Population fluctuations of white mango scale egg and crawler in mango orchard at Kimani

At Samuru orchard sessile mango scale population was recorded in all of the study months, with noticeable population fluctuation having its peak in February (Fig.3.14). Egg showed considerable population fluctuations with peaks in consecutive months, but population of crawler didn't show much difference in size across the months in which they occurred (Fig.3.15). There was no record of crawler in April and July from Samuru orchard.

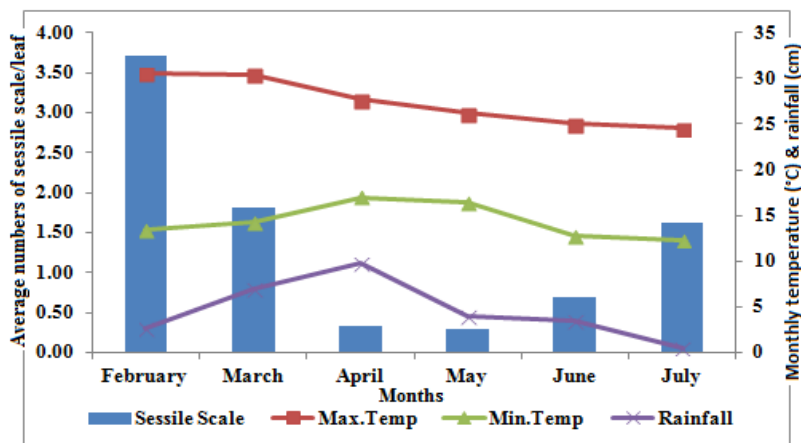


Figure 3. 14 Population fluctuations of sessile white mango scale in mango orchard at Samuru

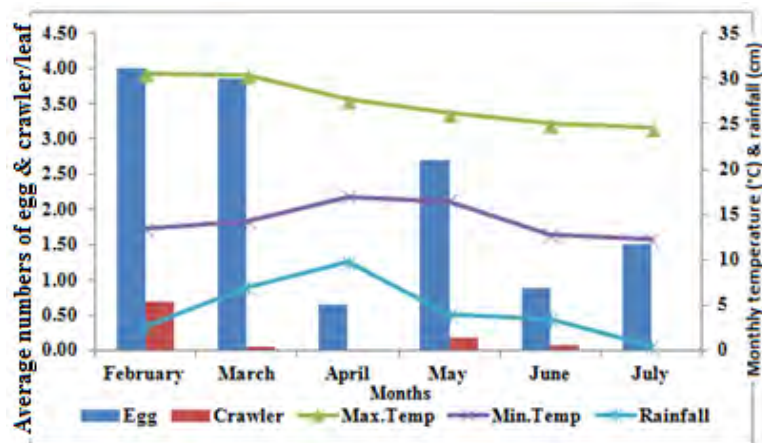


Figure 3. 15 Population fluctuations of white mango scale egg and crawler at Samuru orchard

3.3.4 Population abundance of white mango scale in Kenya

White mango scale infestation was witnessed from various mango cultivars from Kimani, Samuru and Kenyatta University mangos. However, the infestation appeared not to be as severe as in Ethiopia.

Population abundance of sessile, egg and crawler stages mango scale in Kenyatta University mango field

In Kenyatta University mango, WMS sessile stage infestation was found to be significantly more abundant ($p < 0.05$) on the upper leaf surface (3.99 ± 0.24 (2.23)) compared to the lower surface (0.93 ± 0.09 (1.39)). Female scale population (4.08 ± 0.21 (2.25)) was encountered in higher numbers compared to the male (0.88 ± 0.14 (1.37)) with significant difference ($p < 0.05$) in this site. Female to male ratio was 3.5 to 1 at this orchard. There was no significant difference ($p > 0.05$) in sessile stage population among the study months in Kenyatta University mango field (Table 3.15; Appendix 3.11).

The maximum number of eggs recorded per leaf from Kenyatta University mangos was 530. Considerable numbers of leaves contained below 100 eggs whereas the majority didn't bear any. Up to 30 eggs were found under cover of an adult female scale. On the

other hand, a maximum of 30 crawlers were recorded per leaf in one instance; despite they were encountered in very small numbers in this orchard.

Eggs and crawlers were significantly ($p < 0.05$) higher on the upper leaf surface. Mean number of egg was 51.81 ± 1.44 (7.27) on the upper and 2.64 ± 0.38 (1.91) on the lower. Mean numbers of crawler population were 3.24 ± 0.033 (2.06) and 0.49 ± 0.11 (1.22) on upper and lower mango leaf surfaces, respectively. There were significant differences ($p < 0.05$) among months of the study period in number of crawlers recorded, but that of egg didn't show significant difference ($p > 0.05$) (Appendices 3.12-13). Mean numbers of crawlers and eggs in the respective months are presented in Table 3.15.

Table 3. 15 Mean \pm SE of adult scale, egg and crawler populations during the study months at Kenyatta University mango field (number in parenthesis indicates transformed mean value)

	February	March	April	May	June	July	LSD
Sessile stage	2.86 \pm 0.43(1.97) ^a	2.24 \pm 0.25(1.80) ^a	3.58 \pm 0.48(2.14) ^a	3.45 \pm 0.33 (2.11) ^a	1.26 \pm 0.15(1.50) ^a	0.83 \pm 0.15(1.35) ^a	0.81
Egg	36.44 \pm 2.65(6.12) ^a	9.54 \pm 1.26(3.25) ^a	37.68 \pm 2.84(6.22) ^a	16.71 \pm 1.55(4.21) ^a	26.86 \pm 2.25(5.28) ^a	5.02 \pm 0.74(2.45) ^a	5.38
Crawler	1.31 \pm 0.45(1.52) ^{ab}	0.15 \pm 0.07(1.07) ^b	1.51 \pm 0.42(1.58) ^{ab}	5.23 \pm 0.59(2.50) ^a	0.56 \pm 0.16(1.25) ^b	2.66 \pm 0.61(1.91) ^{ab}	1.19

Means followed by the same letter (s) within a row are not significantly different at 5% level, (LSD).

Population abundance of sessile, egg and crawler stages mango scale in Samuru and Kimani orchards

Sessile mango scale was found to be significantly abundant ($p < 0.05$) at Samuru orchard (1.33 ± 0.07) than Kimani (0.52 ± 0.03). Combined data from Samuru and Kimani sites revealed the presence of significantly higher ($p < 0.05$) number of mango scale on the upper mango leaf surface (1.38 ± 0.08) than lower (0.48 ± 0.05). The same data indicated the presence of significantly higher ($p < 0.05$) infestation in February compared to other months (Table 3.16, Appendix 3.14). Combined data of Samuru and Kimani showed the absence of significant difference between mean numbers of male (1.01 ± 0.04) and female (0.80 ± 0.08) mango scale ($p > 0.05$). Sex ratio was found to be 1.71:1.00 for male and female mango scale, respectively, as combined data from Kimani and Samuru depicted.

Table 3. 16 Mean numbers of sessile mango scale in the study months (pooled data, Samuru and Kimani) (number in parenthesis indicates transformed mean value)

Month	Mean± SE
February	$2.45 \pm 0.18(1.86)^a$
March	$1.07 \pm 0.11(1.44)^b$
April	$0.88 \pm 0.13(1.37)^b$
May	$0.30 \pm 0.04(1.14)^b$
June	$0.33 \pm 0.07(1.15)^b$
July	$0.76 \pm 0.10(1.33)^b$
LSD	0.31

Means followed by the same letter within a column are not significantly different at 5% level, (LSD).

In both Samuru and Kimani the levels of white mango scale infestation on mango significantly ($p < 0.05$) varied among some of the cultivars. At Samuru Vandyke was more infested than Apple mango with significant difference ($p < 0.05$) but levels of infestation among the rest of the cultivars were statistically not significant ($p > 0.05$). Kent mango was found to be the most infested of all mango cultivars with significant difference ($p < 0.05$) at Kimani, while there was no significant variation ($p > 0.05$) among the rest of the cultivars at this orchard. Apple mango was among the least infested cultivars in both sites (Table 3.17, Appendices 3.15-3.16). Moreover, there was statistically significant difference ($p < 0.05$) in the level of infestation among the study months in each of the study sites (Table 3.18).

Table 3. 17 Mean numbers of sessile stage mango scale on mango cultivars at Samuru and Kimani (number in parenthesis indicates transformed mean value)

Cultivar	Mean \pm SE	
	Samuru	Kimani
Vandyke	1.94 \pm 0.20 (1.72) ^a	NP
Kent	1.57 \pm 0.16 (1.60) ^{ba}	1.55 \pm 0.20 (1.60) ^a
Tommy Atkins	1.47 \pm 0.15 (1.57) ^{ba}	0.43 \pm 0.07 (1.20) ^b
Apple	0.49 \pm 0.05 (1.22) ^b	0.08 \pm 0.02 (1.04) ^b
Ngoe	NP	0.21 \pm 0.04 (1.00) ^b
LSD	0.39	0.29

Means followed by the same letter (s) within a column are not significantly different at 5% level, (LSD).

NP = the indicated cultivar was not present in the respective orchard

Table 3. 18 Mean numbers of sessile mango scale in the study months at Samuru and Kimani orchards (number in parenthesis indicates transformed mean value)

Mean± SE		
Month	Samuru	Kimani
February	3.56±0.30(2.13) ^a	1.50±0.20 (1.58) ^a
March	2.01±0.20(1.74) ^{ba}	0.30± 0.08(1.14) ^b
April	0.50±0.07(1.22) ^c	1.31±0.24(1.52) ^a
May	0.46±0.06(1.21) ^c	0.14±0.04(1.07) ^b
June	0.65±0.13(1.28) ^{bc}	0.05±0.03(1.03) ^b
July	1.50±0.20(1.58) ^{bc}	0.14± 0.04 (1.07) ^b
LSD	0.48	0.36

Means followed by the same letter(s) within a column are not significantly different at 5% level, (LSD).

Populations of eggs and crawlers in general, and that of crawlers in particular were very low at both Kimani and Samuru orchards. It was in only one instance that a maximum of 35 eggs were found from a leaf of Kent mango at Kimani, of which the maximum number found per female was only 12. Eighty eggs were recorded from a Vandyke mango leaf at Samuru orchard. The maximum number of eggs recorded per female scale at Samuru orchard was 25. This was also observed on a leaf of Vandyke variety. Egg and crawler population abundances didn't show significant ($p>0.05$) difference between Kimani and Samuru orchards.

Mean numbers of eggs were 0.45 ± 0.11 and 0.67 ± 0.05 at Kimani and Samuru respectively. Mean numbers of crawlers were as small as 0.07 ± 0.02 and 0.06 ± 0.01 at Kimani and Samuru orchards, respectively. Both eggs and crawlers didn't show statistically significant differences ($p>0.05$) among the study months at Kimani

orchard (Appendices 3.17-3.18). On the other hand, significantly higher ($p < 0.05$) number of eggs was recorded in February at Samuru orchard. However, the difference in crawler population among the months was statistically not significant ($p > 0.05$) at Samuru (Appendices 3.19-3.20). Monthly data of egg and crawlers of both orchards are presented in Table 3.19 below.

Table 3. 19 Mean numbers of eggs and crawlers of the study months at Kimani and Samuru orchard (number in parenthesis indicates transformed mean value)

Month	Mean± SE			
	Kimani		Samuru	
	Egg	Crawler	Egg	Crawler
February	0.15±0.07(1.07) ^a	0.00±0.00(1.00) ^a	1.48±0.13(1.58) ^a	0.21±0.07(1.10) ^a
March	0.27±0.10(1.13) ^a	0.00±0.00(1.00) ^a	1.10±0.16(1.45) ^{ba}	0.03±0.01(1.01) ^a
April	1.77±0.55(1.66) ^a	0.27±0.13(1.13) ^a	0.22±0.06(1.11) ^c	0.00±0.00(1.00) ^a
May	0.78±0.29(1.33) ^a	0.15±0.07(1.07) ^a	0.75±1.14(1.32) ^{bac}	0.07±0.02(1.04) ^a
June	0.00±0.00(1.00) ^a	0.00±0.00(1.00) ^a	0.26±0.08(1.12) ^c	0.03±0.04(1.02) ^a
July	0.00±0.00(1.00) ^a	0.00±0.00(1.00) ^a	0.40±0.11(1.18) ^{bc}	0.00±0.00(1.00) ^a
LSD	0.72	0.17	0.30	0.19

Means followed by the same letter (s) within a column are not significantly different at 5% level, (LSD).

In both Kimani and Samuru orchards, the eggs and crawlers were relatively more abundant on the upper mango leaf surface than the lower. However, the difference in crawler population was statistically not significant ($p>0.05$) in this regard at both Kimani and Samuru orchards. Mean number of egg was statistically significant ($p<0.05$) on the upper leaf surface than the lower at Samuru, but there was no significant ($p>0.05$) difference at Kimani, in this regard. Table 3.20 shows population abundances of eggs and crawlers on mango leaf surfaces at both study sites.

Table 3. 20 Mean \pm SE of egg and crawler populations on upper and lower leaf surfaces at Kimani and Samuru orchards (number in parenthesis indicates transformed mean value)

Leaf surface	Egg		Crawler	
	Kimani	Samuru	Kimani	Samuru
Upper	0.75 \pm 0.21(1.32) ^a	1.20 \pm 0.09(1.48) ^a	0.14 \pm 0.05(1.07) ^a	0.06 \pm 0.02(1.03) ^a
Lower	0.16 \pm 0.05(1.08) ^a	0.22 \pm 0.04(1.11) ^b	0.00 \pm 0.00(1.00) ^a	0.05 \pm 0.02(1.03) ^a
LSD	0.42	0.17	0.10	0.05

Means followed by the same letter within a column are not significantly different at 5% level, (LSD).

Mango cultivars in Kimani and Samuru orchards contained eggs and crawlers. However, there was no significant ($P>0.05$) difference in the numbers of eggs and crawlers among the cultivars in both orchards (Table 3.21).

Table 3. 21 Mean number \pm SE of egg and crawlers on mango cultivars at Kimani and Samuru orchards
(number in parenthesis indicates transformed mean value)

Mango variety	Egg		Crawler	
	Kimani	Samuru	Kimani	Samuru
Kent	1.08 \pm 0.37(1.44) ^a	0.86 \pm 0.11(1.36) ^a	0.17 \pm 0.08(1.08) ^a	0.11 \pm 0.04(1.05) ^a
Apple	0.41 \pm 0.19(1.19) ^a	0.59 \pm 0.10(1.26) ^a	0.10 \pm 0.05(1.05) ^a	0.05 \pm 0.02(1.02) ^a
Tommy Atkins	0.36 \pm 0.09(1.17) ^a	0.44 \pm 0.08(1.20) ^a	0.00 \pm 0.0(1.00) ^a	0.00 \pm 0.0(1.00) ^a
Vandyke	NP	0.83 \pm 0.10(1.35) ^a	NP	0.07 \pm 0.03(1.03) ^a
Ngoe	0.00 \pm 0.0(1.00) ^a	NP	0.00 \pm 0.0(1.00) ^a	NP
LSD	0.59	0.24	0.14	0.07

Means followed by the same letter within a column are not significantly different at 5% level, (LSD).

NP = the cultivar at the left hand side was not present in the orchard indicated

3.4 Discussions

3.4.1 Ethiopia

Yellow and brownish spots with damaged tissues on mango leaves severely infested by WMS indicate development of chlorosis and eventual necrosis on the leaves (Plates 3.2-3.3), which can reduce photosynthetic capacity of mango plant and result in economic damage to mango production in the study area. Golan *et al.* (2015) showed that severe infestation of scale insects of lemon and fern plants decreased chlorophyll and carotenoid contents as well as values of indicators of photosynthetic activity in the host plants.

Populations of white mango scales in Arjo and Bako began to build up in February and reached their peaks in April in Arjo and in May in Bako. Population peaks of scale crawlers were also evident in these months, a finding very essential for the control of the pest through targeting crawler stage. Crawler is sensitive to both systemic and contact insecticides.

The months in which population of mango scales remained near absence, in western Ethiopia, were those with very low precipitation. Their populations remained at an extremely low level in both Arjo and Bako orchards when average monthly rainfall was below 10mm, implying that white mango scale is highly affected by drought.

The current study identified three phases of mango scale population, in western Ethiopia. In Arjo, the first phase is from February to July, where population begins to build up and reaches its peak. The second phase encompasses August, September and October which is characterized by sharp decline of population. The last one is from November to January. During this last period the population remains inconspicuous.

On the other hand, in Bako, the first phase begins from February, like in Arjo but stays up to only May. In June, July and August population declines abruptly, denoting the second phase. The last phase in which population remained near to absence was from September to January, in Bako.

This study, therefore, underlines decline and build up of mango scale population is affected by rainfall in two ways, even though other contributing factors shall be investigated further. First, minimum amount of average monthly rainfall of about 50mm is required to initiate build up of mango scale population, whereas the optimum rainfall for the insect to reach its peak may vary spatially and temporally, as it was found to be 110mm in April at Arjo and 140mm in May at Bako. Build up of mango scale population coincides with mango fruit physiological maturity; both happening at the beginning of rainy season in the study area. Ofgaa Djirata and Emanu Getu (2015) reported that maturation and ripening of mango fruit begin to take place during the first months of rainy season i.e., as of March-April and continues for few months, vis-à-vis significant infestation of mango fruits by white mango scale, in western Ethiopia.

Secondly, prolonged heavy rainfall affects mango scale population negatively in the study area. The swift population decline of mango scale following prolonged heavy rain took place probably because the heavy rain might wash up them from mango leaves. Most of the leaves observed during and after the months of heavy rain, had yellow blemishes (Ofgaa, personal observation), indicating the spots from where the settled scales had been washed away by heavy rain. This finding is in agreement with Supriadi *et al.* (2015) who reported that scale insect population abundance is affected by rain. Ha *et al.* (2015) also experienced a low density period of white mango scale

from the end of rainy season in Egypt. El-Metwally *et al.* (2011) concluded that low population of white mango scale had been recorded during the period of rainy season. It is evident that strong rain can kill small or immobile stages of insects (Moran, *et al.*, 1987).

Crawler and sessile stage of mango scale populations were more abundant at Bako than Arjo. One possible explanation, among others, may be associated with negative impact of high rain intensity on scale population in Arjo, as this site receives higher amount of annual rainfall than Bako (Ethiomet, 2016). On the other hand, Bako orchard is characterized by its big mango trees with broad canopies bearing dense leaves. Branches of neighbouring mango trees were interlocked in this orchard than that of Arjo. Such shady environment might provide more suitable overwintering habitat for the scale at Bako orchard compared to that of Arjo.

Both minimum and maximum temperatures of the current study sites were more or less stable and this study didn't evaluate the impact of extreme temperatures on population dynamics of white mango scale. However, size of the scale population was higher during the months with relatively higher maximum and minimum temperatures. Peak populations were recorded in the months with maximum monthly temperatures of 35°C and 31°C at Arjo and Bako respectively, indicating that mango scale has tolerance to higher temperatures. This record is not in agreement with conclusion of Labuschagne *et al.* (1995) which underlines that white mango scale had low tolerance to temperature, and as a result its population declined in extreme temperatures above 30°C. In all observed cases population of crawler stage mango scale was matchlessly very small in relation to other developmental stages. One possible explanation is that mango scale stays as crawler stage for shorter period of

time compared to sessile stages (Labuschagne *et al.*, 1995). Moreover, crawlers move about in search of suitable settling sites to different parts of the host plant, and may also disperse away from the plant by various factors.

All developmental stages of mango scale were found to be more abundant on upper mango leaf surface in both study orchards. This finding agrees with the work of Nabil *et al.* (2012) in Egypt that confirmed live white mango scale preferred the upper mango leaf surface compared to the lower one. Investigations as to why white mango scale preferred the upper mango leaf surface to the lower seems overlooked. However, Beardsley and Gonzalez (1975) cited from McLaren (1971) associated the settlement of the majority of California red scale crawlers, *Aonidiella aurantii* (Maskell), on upper surface of citrus leaves with geotaxis behavioural response. On the other hand, crawler of Florida male scale was associated with positive response to light direction (Beardsley and Gonzalez, 1975 cited from Priesner, 1931).

In its population dynamics, white mango scale interacts not only with abiotic factors but also with biotic ones, among which predators and parasitoids are very important. This study recorded predatory larva of *Chilocorus* sp. (Coleoptera: Coccinellidae) preying on white mango scale from Arjo and Bako orchards. Despite some studies performed on white mango scale following its very report of entry in Ethiopia (Mohammad Dawd *et al.*, 2012; Temesgen Fita, 2014; Tesfaye Hailu *et al.*, 2014; Gashawbeza Ayalew *et al.* 2015), there was no report of natural enemy from the pest population. Therefore, the current study recorded *Chilocorus* sp. as natural enemy of mango scale; probably for the first time in Ethiopia. Population size of the predatory larva recorded in the study area is very small. This is probably because since white mango scale was believed to have been introduced to Ethiopia recently (Mohammed

Dawd *et al.*, 2012); association of the predator with this insect pest may also be very recent. Therefore, population of *Chilocorus* sp. may gradually build up, as it gets more and more to the pest through time.

The concurrent rise and decline of white mango scale and larva of *Chilocorus* sp. populations may mean the ecofactors of the study area affected their populations in a similar way. There is not enough evidence from the current study to reach a conclusion that the predator could control white mango scale so far. On the other hand, available literatures underline that some *Chilocorus* spp. were important biological agents for the control of armoured scales. Greathead and Pope (1977) report that *Chilocorus distigma*; *Chilocorus schioedtei* and *Chilocorus nigrinus* could be used in biological control of armoured scales in East Africa. More mushrooming works also witness *Chilocorus* spp. to have been important biological agents for the control of armoured scales (Charles *et al.*, 1995; Boothe and Ponsonby, 2006; Ponsonby, 2009; Entocare, 2015). It is understandable that the *Chilocorus* sp. identified in the current study is a potential biocontrol of white mango scale in Ethiopia, in the years to come.

3.4.2 Kenya

Investigations on abundances of mango scale were performed in Ethiopia and Kenya in different years with marked gaps in time (2013/2014 in Ethiopia and 2015 in Kenya). Moreover, the lengths of study period differed greatly. As a result comparing mean numbers of recorded mango scales from both countries was considered scientifically not sound. However, a brief look at the data from the two countries (Tables 3.5, 3.10 and 3.13(Ethiopia), and 3.15, 3.18 and 3.19 (Kenya)) is enough to understand how mango scale infestation in Ethiopia was more severe than in Kenya. Cultivation of improved mango varieties, pest management practices such as pruning,

removal of mango parts infested by mango scale and use of insecticides in the control of mango scale by some Kenyan mango farmers, as stated by Ofgaa Djirata *et al.* (2016), might have lessened level of infestation of mango by mango scale in Kenya.

All the three study orchards in Kenya showed population peaks in the same or consecutive months. Significantly higher populations of sessile stage mango scales were also concentrated on these months, except absence of significance among the months in this regard only at Kenyatta University mango. On the other hand, amounts of rainfall received in the very months with population peaks were not equal. This indicates mango scales have wide ranges of optimum rainfall in Kenya, on one hand, and other factor (s) may influence population fluctuations of the scale, on the other. More importantly, the current study concludes that mango scale populations build up better at relatively higher maximum temperatures of around 30°C; with a general trend of decline towards the colder and dry months. Since population dynamics of mango scale was investigated in this study for only six months in Kenya, year round study may be required to acquire sufficient information for better understanding of the scale dynamics in the area.

The reason why no natural enemy of white mango scale was found in the entire study area in Kenya needs further research. One possible explanation may be that mango farmers sprayed a variety of synthetic insecticides on mango orchards for the control of mango scale (Ofgaa Djirata *et al.*, 2016), which might have posed negative impact on occurrence of natural enemies in the study area.

All developmental stages of mango scale persisted throughout the study months in Kenyatta University mango whereas in Kimani and Samuru, eggs and crawlers in general, and crawlers in particular were either not recorded at all or recorded in a very

small numbers in most of the study months as shown in Tables 3.15 and 3.19. Even though data on scale population from Kimani and Samuru orchards were not compared statistically with that of Kenyatta University mangos, due to big differences in cultivar types and related factors, it is easily recognized that mango scale at Kenyatta University is relatively more fecund and abundant than the two orchards. This is most likely, because most of mango trees in Kenyatta University are very big and possess broad canopies with dense leaves, as they are of indigenous varieties (Ofgaa personal communication), so may serve as a more suitable habitat for the pest. Mango orchard at Kimani is highly managed through regular insecticide application, cyclic pruning and sustaining host plant sanitation. That abundance of sessile stage mango scale at this orchard was found to be significantly lower compared to that of Samuru may attribute to good management practices. Samuru and Kimani orchards were composed of different improved mango varieties, which exhibited variations in their susceptibility to white mango scale infestation. Cultivar selection in Kenya takes in to account tolerance to pest infestation and disease infection, among other criteria (Griesbach, 2003; <http://www.jkuates.co.ke>). Like in Ethiopia, mango scales preferred the upper surface of mango leaves in most circumstances in Kenya, too, thus, the explanation put forward for similar finding in Ethiopia is possible for this case, as well.

In all study sites of both Ethiopia and Kenya, population of male mango scale outnumbered that of female. It is exceptional to mango scale at Kenyatta University to exhibit significantly higher female population than the male, a subject of further study for explanation.

3.5 Conclusion

This study confirmed that white mango scale existed year round in Ethiopia, with its population fluctuation being highly influenced by the amount of rainfall. Population peaks of all the developmental stages of mango scale were attained in the months around the beginning of rainy season, specifically in April and May in Arjo and Bako, respectively, a finding very essential to plan and implement control of the pest, mainly through targeting its first nymphal instar. On the other hand, impact of rainfall on white mango scale population fluctuation was negligible, in Kenya. Mango scale population tends to increase at a relatively higher maximum monthly temperature in both Kenya and Ethiopia. Controlled experiment, preferably under laboratory condition, may be required to better understand the ranges of optimum temperatures for mango scale. Moreover, year round study is required to get enough information regarding impact of weather conditions on population dynamics of mango scale, as the current study was limited to only six months in Kenya

Larva of a lady bird beetle, *Chilocorus* sp. (Coleoptera: Coccinellidae) was observed preying on white mango scale on mango trees in Ethiopia through the current study. Therefore, it is concluded that the predatory beetle has been newly associated, as a natural enemy, with the exotic pest. Population of the beetle was very small, and there was no enough evidence that it could control the mango scale. However, it is deduced from observed predatory standing of the beetle that it would be a potential biocontrol agent for the control of white mango scale.

Current observations, in both Kenya and Ethiopia, led to conclusion that white mango scale is more concentrated on upper mango leaf surface and its population is male biased.

Level of susceptibility of mango to white mango scale infestation varied among various mango varieties in Kenya. The current study encompassed only five improved varieties and indigenous mango. Therefore, further study that includes more mango varieties is required to come up with varieties that may be less susceptible to white mango scale infestation.

Chapter 4

Distribution and Farmers Management Practices of White Mango Scale

4.1 Introduction

Mango cultivation is a common farming practice in Ethiopia and Kenya. Mango is cultivated in many parts of Ethiopia of which western, south western and the Rift Valley areas are the most known (Yilma Tewodros, 2009; Takele Honja, 2014). However, mango production in Ethiopia has not been supported by modern farming practices (Yilma Tewodros, 2009; Seid Hussen and ZeruYimer, 2013). There is no pruning of bushy branches, and application of pesticides is not practiced in Ethiopia, and hence mango production is constrained by various pests and diseases (Tewodros Bezu *et al.*, 2014). Kenya is among the leading mango producing nations in East Africa, the main growing regions being in Eastern, Central and Coast provinces (HCDA, 2008). Mango farmers in Kenya exercise some agronomic and indigenous knowledge in cultivar selection and pest management (Mulinge *et al.*, 2015).

Occurrence of white mango scale, as a new mango insect pest in Ethiopia was reported for the first time in 2010 (Mohammed Dawd, *et al.*, 2012). Temesgen Fita (2014) stated that white mango scale moved little from a place of its first record. The study assessed distribution of white mango scale in west direction and recorded it from Gimbi district, but not from districts beyond. Hodges and Hamon (2016) pointed out that white mango scale was already present in Kenya in 2002. Germain *et al.* (2008) also added Kenya among list of other African countries from where white mango scale was recorded. There is gap of information regarding the distribution and related severity levels of white mango scale in Ethiopia. Moreover, apart from information on its occurrence, there has been no documented report of study regarding

white mango scale in Kenya. This study was, therefore, designed with the following objectives:

- To assess distribution of white mango scale and severity level of its infestation on mango in western Ethiopia
- To investigate distribution and severity level of white mango scale infestation on mango in central and eastern Kenya
- To assess farmers' knowledge about occurrence of white mango scale and methods of its management in central and eastern Kenya

4.2 Material and methods

4.2.1 Description of the study area

This survey was conducted in 20 localities which were distributed in 15 districts. Accordingly, the survey covered four of the Administrative Zones found in western Ethiopia. The Administrative Zones covered were West Shoa, Illubabor, East and West Wollega of Oromia National Regional State. From Kenya, a total of 75 mango farms located in three counties were included in this study. The counties were Kiambu and Murang'a from central Kenya, and Machakos from eastern Kenya.

4.2.2 Study design and sampling procedure in Ethiopia

Survey on the distribution and severity status of white mango scale was carried out from May 10, 2016 to July 15, 2016. The survey started from, Loko Kebele Administration, Guto Gida District of East Wollega administrative Zone (09° 19.226'N and 036° 31.619'E), the focus where white mango scale was first recorded, and extended in nearly the four cardinal directions (Figure 4.1). Mango farms at series of spots within intervals of 25 to 40 kilometres land distance were considered for sampling purpose. Ten leaves (3 from upper, 3 from centre and 4 from lower canopies) were plucked from every mango tree purposively selected from about

central position within each farm. Female white mango scale was observed by hand lens, and its number recorded. Sampling continued as far as there were mango farms and infestation of the insect pest along with mango farm. Sampling was terminated when it was confirmed that there was no mango plantation or no infestation, over land distance of about 50 Km from the spot of the last sampling. However, considering a report on quick spread of the pest to the west (Temesgen Fita, 2014), survey continued to the west up to a distance of about 100km from the last spot of infestation. Coordinates and altitudes of each sampling site were recorded by the use of GPS.

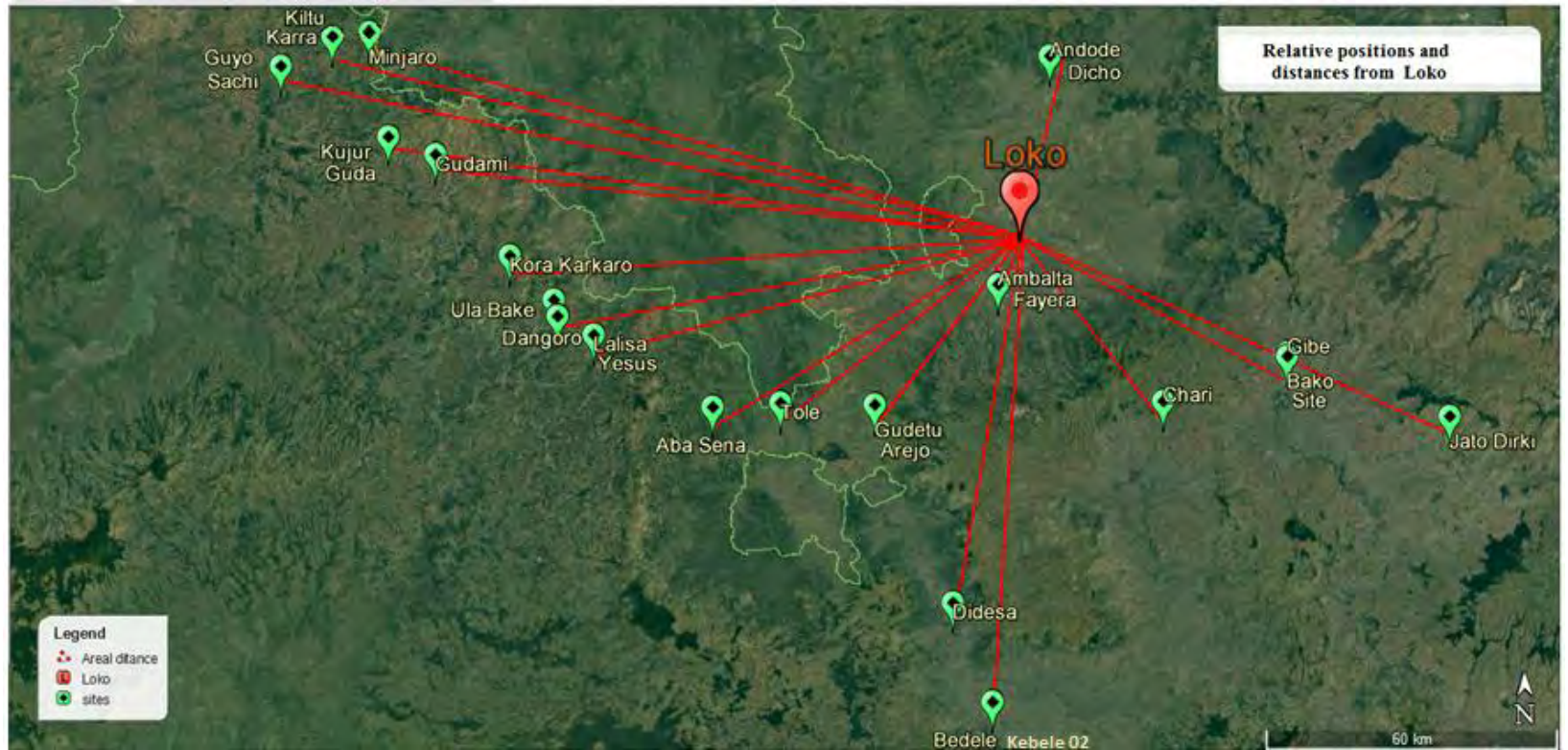


Figure 4. 1 Spatial design of WMS distribution survey in western Ethiopia

4.2.3 Study design and sampling procedure in Kenya

This survey was performed from January 10, 2015 to March 30, 2015. A total of 75 respondents, each possessing a minimum of 10 mango trees in his/her orchard, were considered as source of data from three counties in eastern and central Kenya. Proportionate sampling method was followed to allocate number of respondents (with respective orchards) to each county. Accordingly, 35 from Murang'a, 25 from Machakos and 15 from Kiambu were selected purposively by the help of elderly mango farmers in the study area. This allocation was in accordance with the proportion of average weight of mango produced from eastern and central Kenya, whose ratio was 6.9 to 1, respectively (HCDA, 2008). But since Machakos occupies very small proportion of the former eastern province land area (<http://www.softkenya.com>), 33.33% of the total respondents were allocated to it. Additionally, the area of land cultivated for horticultural crops and the volume of their production during 2012-2014 were considered (Kenya Bureau of Standards, 2014). The area of land cultivated in this regard was 80% for Murang'a and Kiambu and 20% for Machakos.

Open and close-ended interview questions were used to get baseline information from mango growers regarding their knowledge, management practices and related aspects of white mango scale (Appendix 4.1). The interview was executed while the respondents were in their respective mango fields. Therefore, face-to face survey method was conducted during data collection.

Mango farms of the respondents mentioned above were used for white mango scale sample collection. Within each orchard of survey, one mango tree was selected from nearly central position. Ten leaves (3 from top, 3 from middle and 4 from lower canopies) were plucked and the presence or absence of female white mango scale observed by use of hand lens on both upper and lower surfaces, and the numbers

recorded. Coordinates and altitudes of each survey site were recorded by the use of GPS.

Data analysis

ArcGIS 10.4 was used for spatial data management and mapping of white mango scale distribution (<http://www.esri.com/arcgis>). Relative frequency of WMS occurrence at each locality (mango farm) was calculated by the use of equation adopted from Kataria and Kumar (2012). This value was used to define severity index from which severity status at each farm was determined, as follows:

$$\text{Relative frequency of WMS occurrence} = \frac{\text{Number of WMS recorded per mango farm}}{\text{Total number of WMS recorded from survey area}} \times 100$$

Relative frequency of mango scale occurrence	Severity Index	Grades of Severity Status
0	0	No infestation
1-5	1	Mild infestation
6-10	2	High Infestation
≥ 11	3	Very High Infestation

Data obtained from survey questionnaires and mango scale count were analysed by descriptive statistics using SPSS software, version 20. Mean numbers and standard deviations were used to show the spread of mango scale within each county and administrative zone in Kenya and Ethiopia, respectively.

4.3 Results

4.3.1 Survey on the distribution and severity of white mango scale in western Ethiopia

From 20 localities of the 15 districts surveyed for white mango scale in western Ethiopia, 13 localities found in 11 districts were confirmed to have been infested by the pest (Figure 4.2). From the current survey, it was noted that white mango scale has already spread to the surrounding areas of Loko, up to maximum air distances of 97 km, 98 km, 92 km and 43 Km to east, south, west and north directions, respectively. Mango farms were not encountered in north direction beyond Andode Dicho of Gida Ayana District, and in east direction beyond Jato Dirki of Illu Gelan District.

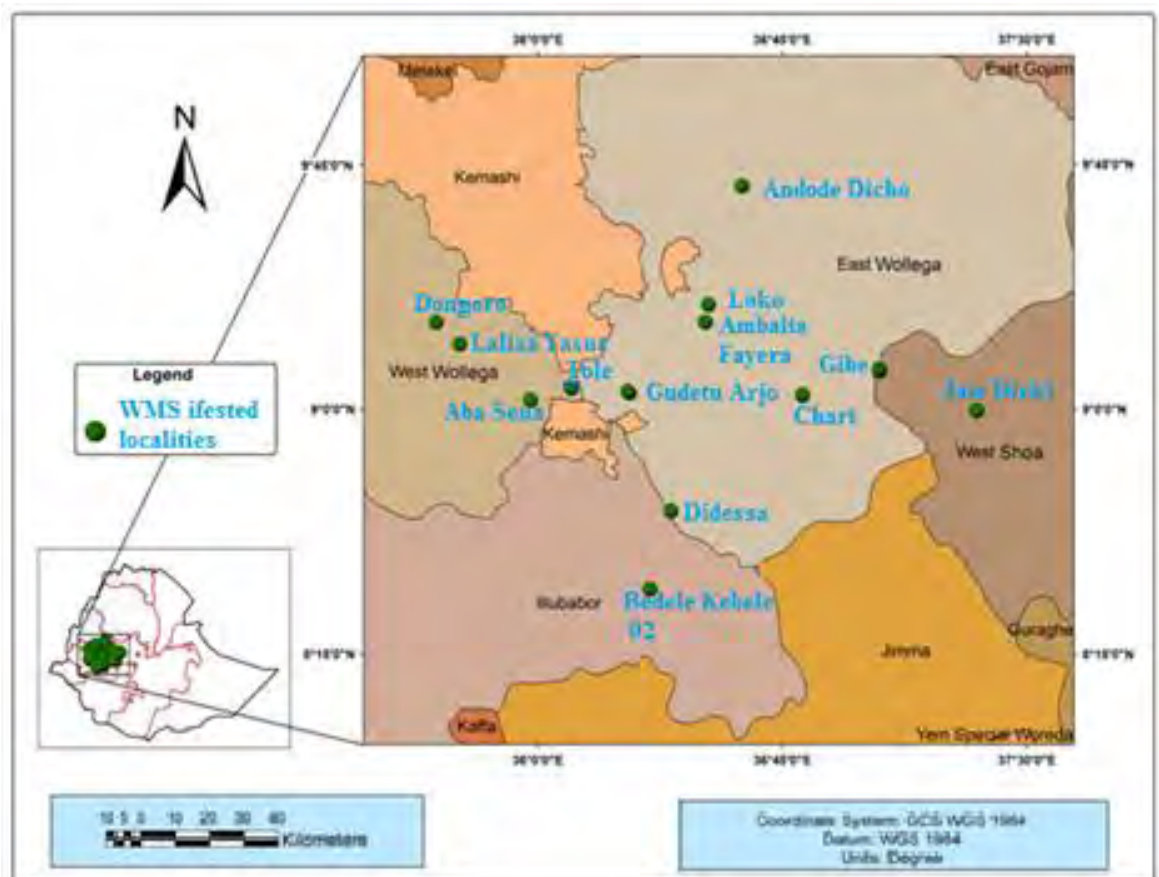


Figure 4. 2 Distribution map of WMS in western Ethiopia

The pattern of white mango scale spread within each administrative zone was found to be irregular as can be seen from relative sizes of means and their standard deviations (Table 4.1, Appendix 4.2 a-b). Such irregular distribution was found to be more evident in West Wollega.

Table 4. 1 Mean numbers of female WMS per leaf within each administrative zone in western Ethiopia

Administrative Zone	Mean±SD
East Wollega	35.00±26.10
Illubabor	45.90 ±19.03
West Shoa	5.00±5.40
West Wollega	16.90±24.50

Severity status of white mango scale in western Ethiopia

Severity status of white mango scale was found to be high and very high in most of the survey localities in all the directions, except to the east where infestation was only mild (Table4.2). The numbers of female white mango scale recorded per 10 leaves showed big differences among the localities, the maximum being 723 at Didessa locality while the minimum was 32, at Chari locality (Appendix 4.3).

Table 4. 2 Severity status of white mango scale in western Ethiopia

Locality/ mango farm	Severity Index	Severity Status	Air distance (Km)
Loko	3	Very high	Locus of first record
Ambalta Fayera	3	Very High	5.91
Chari	1	Mild	43.83
Andode Dicho	2	High	43.20
Gudetu Arjo	2	High	48.4
Jato Dirki	1	Mild	96.98
Gibe	1	Mild	61.76
Didessa	3	Very High	70.30
Bedele_Kebele 02	3	Very High	97.95
Tole	3	Very High	53.7
Aba Sena	2	High	68.43
Lalisa Yasus	1	Mild	84.82
Ula Bake	0	No Infestation	91.54
Dongoro	1	Mild	91.90
Kora Karkaro	0	No Infestation	104.03
Gudami	0	No Infestation	117.83
Kujur Guda	0	No Infestation	127.74
Minjako	0	No Infestation	138.10
Kiltu Karra	0	No Infestation	145.6
Guyo Sachi	0	No Infestation	153.14

4.3.2 Survey on farmers' knowledge and management practices of white mango scale in central and eastern Kenya

Demographic characteristics of respondents

From the total number of participants intended to be interviewed, the response rate obtained was 100 % (n=75). From the total respondents 59% were male. Most of the participants (89%) were married and the rest were unmarried. Age structure of the respondents showed that about 61% were 51 years old and above (Table 4.3).

Table 4. 3 Age structure of respondents in Kiambu, Machakos and Murang'a counties

Age group (in years)	Frequency	% Response
Below 30	4	5.3
30-40	16	21.3
41-50	9	12.0
51-60	12	16.0
Above 60	34	45.3
Total	75	100

Family size of the respondents' household greatly varied, i.e. those having below 2 members were 9.3 % (7), 3-6 members 68 % (51), 7-10 members 10.7 % (8) and above 10 were 12 % (9). About 88% of the participants attended at least basic education, of which two graduated from higher learning institutes, i.e. one with diploma and another with university degree (Table 4.4).

Table 4. 4 Education levels of respondents in Kiambu, Machakos and Murang'a counties

Variables	Number of respondents	% response
Never attended school or attended only kindergarten	9	12.0
Basic education (lower or upper primary)	47	62.7
Attended 1 st or 2 nd year high school	8	10.7
Attended 3 rd or 4 th year high school	9	12.0
Diploma	1	1.3
University degree	1	1.3
Total	75	100.0

Mango production and farmers' knowledge about white mango scale in Kenya

Information obtained from the respondents indicated that mango production was a common farming practice in Kiambu, Machakos and Murang'a counties in central and eastern Kenya. Sixteen percent of respondents informed that mango production started before 40 years, 20% said 31-40 years ago, and 19% said between 21 and 30 years back. About 23% of the total respondents said they experienced mango production since the last 20 year, while about 22% claimed their experience in mango production was below 10 years. Various mango cultivars were grown in central and eastern Kenya, among which apple mango was said to have been grown by about 68% of the total respondents (Table 4.5, Appendix4.4)

Table 4. 5 Mango cultivars commonly grown in central and eastern Kenya

Mango cultivar	Response Frequency	% Response
Apple	160	67.8
Indigenous	35	14.83
Tommy Atkins	10	4.24
Kent	5	2.12
Van dyke	4	1.69
Haden	4	1.69
Ngoe	4	1.69
Sensation	3	1.27
Others	6	2.54
Not Aware	5	2.12
Total	236	100

About 67 % of the total respondents knew white mango scale in their fields while 33 % didn't know. Of those who knew white mango scale, 70% said their experience of it was below 10 years, whereas 18% and 12% said experienced within the past 10-20 and 21-30 years, respectively. Moreover, 14% of those who knew white mango scale didn't consider it as mango pest. This indicated that only about 57% of the total population considered white mango scale as a mango pest. They listed major damages inflicted on mango by white mango scale as spots on fruits, yellow spots on leaves, drying and falling of leaves, and drying of young twigs. Most of the respondents asserted that apple mango was affected the most by white mango scale, Kent and Van dyke being on the second line in being damaged by the pest (Figure 4.3).

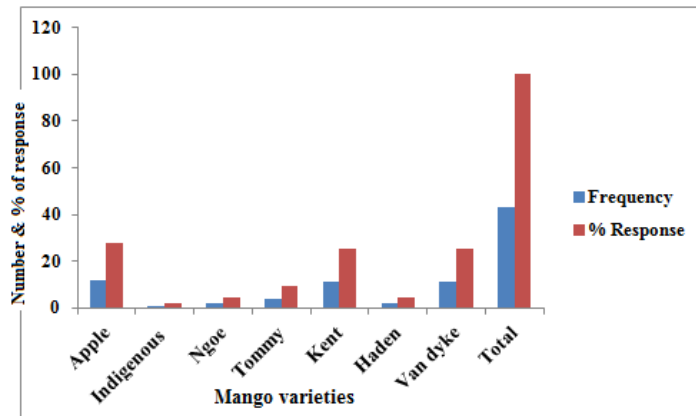


Figure 4. 3 Levels of damage caused by WMS to mango varieties

Among the respondents who were familiar with white mango scale and said it caused damages to mango plantation, considerable percentage indicated the level of damage showed variations over time since first recognized. They asserted the level was increasing (37.21%), decreasing (27.91%) and showed no difference (34.88%) (Appendix4.5). The participants were asked to inform whether damages caused by the pest to mango may affect their income or not, of those who considered white mango scale as mango pest, 23.26% replied it affected, 39.53% said not affected and 37.21% replied they were not aware of the pest’s impact on their income (Appendix 4.6). The respondents mentioned market resistance to buy infested fruits (less marketable) and expense of control of white mango scale as factors that affected their incomes.

Management practices of white mango scale in Kenya

Of all population participated in the interview, about 57% attempted to control white mango scale. According to their responses, some of them used either cultural or chemical method, while others preferred to have used both methods as required (Figure 4.4).

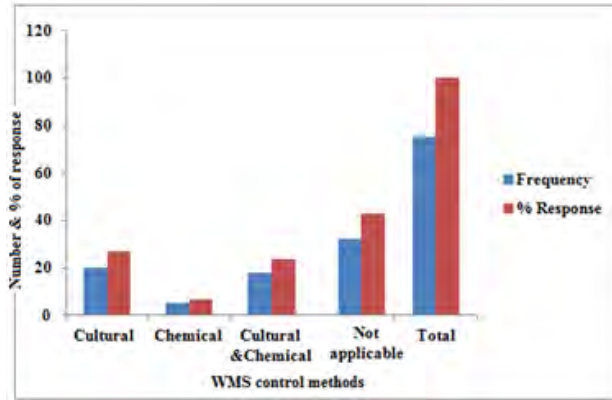


Figure 4. 4 Methods used to control WMS damage of mango

The respondents said regular pruning, and scouting and removal of infested parts of mango tree were the major cultural methods they practiced to control the pest. A farm with mango trees pruned in previous years and undergoing pruning during this survey, as a cultural management practice of white mango scale and other insect pests, was observed and pictures were taken at Kimani Village, Machakos County (Ofgaa personal observation ,and communication with Mr. John M. Kioko, farm owner) (Plate 4.1). Furthermore, the respondents listed insecticides they applied to control white mango scale as Folimat, Actara, Applaud chemicals and white oil.



Plate 4. 1 Mango trees pruned in previous years (a) and undergoing pruning during this survey (b) (Picture taken by the investigator on March 21, 2015).

Asked to elucidate whether the control methods they used could help control white mango scale, the respondents gave their responses as indicated below (Table 4.6).

Table 4. 6 Response on success of WMS control methods

Variables	Frequency	% Response
Yes	6	13.95
To some extent	3	6.98
No	8	18.60
Not aware	26	60.47
Total	43	100.0

Distribution of white mango scale

Distribution of white mango scale covered almost all of the farms surveyed in Kiambu, Machakos and Murang'a counties. The scale infestation was confirmed to have taken place in 71 of the 75 surveyed mango farms in central and eastern Kenya (Figures 4.5 1-3).

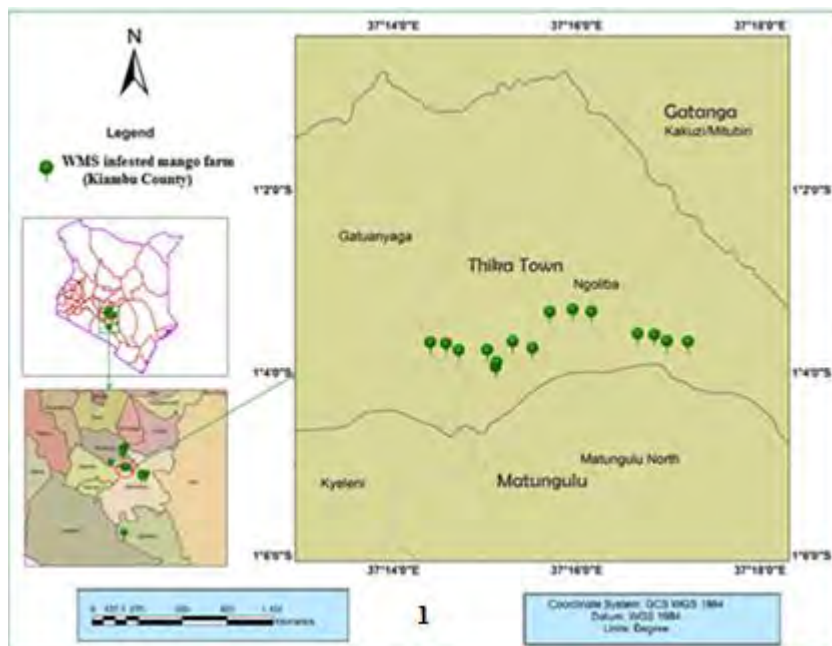


Figure 4.5. 1 WMS infested mango farms in Kiambu County

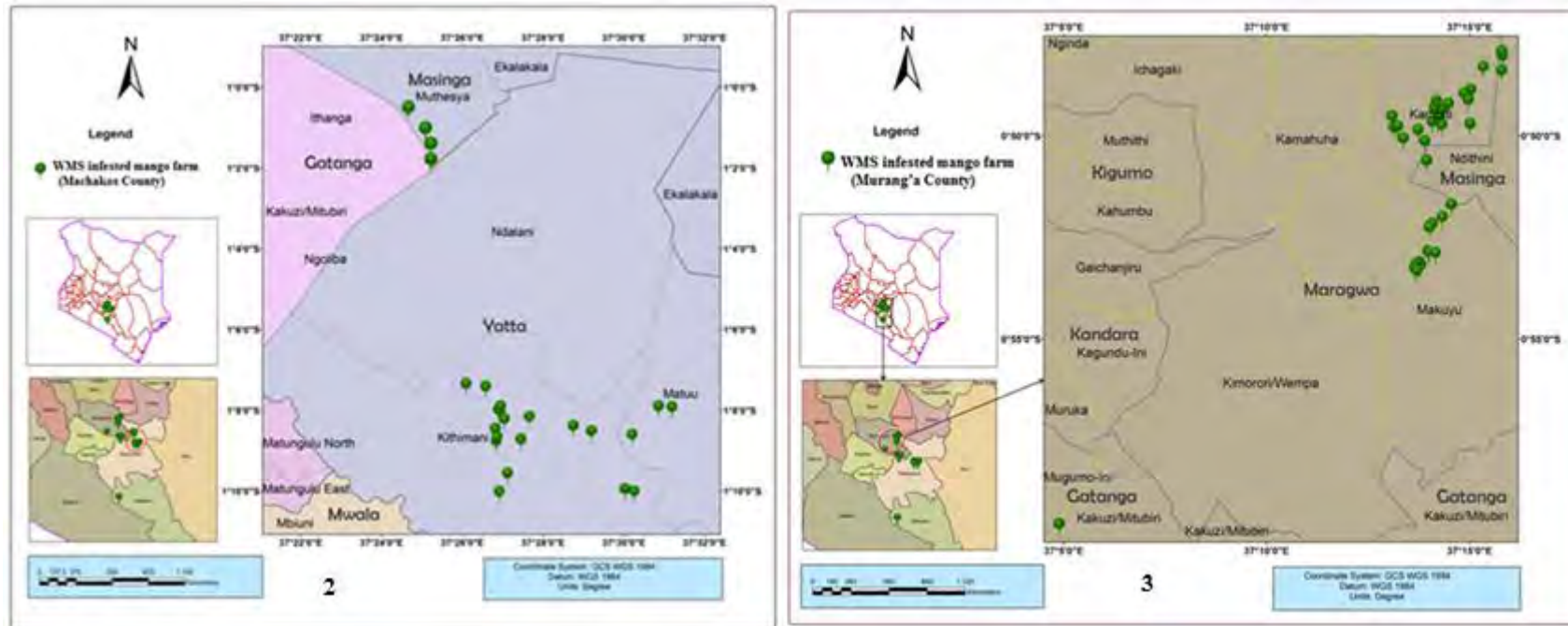


Figure 4.5. 2-3 WMS infested mango farms in Machakos County (2) and Murang'a County (3)

It was known from means and standard deviations of female white mango scale at Kiambu County (1.35 ± 0.81) that distribution of white mango scale among mango farms in the county was more or less regular; whereas that in Machakos (2.75 ± 3.17) and Murang'a (1.47 ± 1.49) exhibited big variations (Appendices 4.7a-4.7b).

Severity status

From 71 mango farms known to have been infested by white mango scale in central and eastern Kenya, only one very high severity and four high severity cases were observed while all the rest showed mild infestation (Appendices 4.8a-4.8c). All of the villages in Kiambu County exhibited mild infestation. Limited numbers of mango farms in Machakos and Murang'a showed heavy infestation as compared to Kiambu (Plate 4.2). In Machakos County, high severity statuses were recorded from Kauukuni-2, Mukalala-1 and Mukalala-2, and very high severity was recorded at Kekwaa. In Murang'a County, except a high severity status encountered at Chamba, all surveyed farms showed mild infestation.



Plate 4. 2 Heavy infestation of white mango scale on mango leaves, Chamba village in Murang'a (a) and Kekwaa village in Machakos (b)

4.4 Discussion

White mango scale has spread from, Loko, the locus of first record to all cardinal directions. Spread of white mango scale in south direction covered about 98 km air distance. In the west, it was recorded from Dongoro locality in Lalo Assabi district, which is found at air distance of about 92 km from Loko. However, Temesgen Fita (2014) reported Jogir Kebele of Gimbi district located at air distance of 67 km from Loko was the extreme west spot the insect pest reached. The absence of mango farm past Andode Dicho to north and Jato Dirki to east directions restricted spread of white mango scale beyond these localities. It is, therefore, possible to realize that there are enabling conditions for white mango scale to spread to any habitat and establish its population in western Ethiopia, as far as there is mango plantation. The rate of establishment, dispersal and colonization of alien invasive species in a new habitat is likely to become tremendous when the new environment is bioclimatically favourable to the pest, in general (Satti, 2011; Pratt, 2017).

Even though mechanisms by which white mango scale could spread within west Ethiopia was not assessed under the current study, active wandering of the crawler alone cannot be a possible explanation for dispersal of the pest over such long distances. Magsig-Castillo *et al.* (2010) stated that first instar active crawlers of diaspidides can wander a distance of less than one metre before settling to establish a new population. Beardsley and Gonzalez (1975), on the other hand, stated that wind, birds, insects and other animals including man can serve as accidental dispersal carriers for armoured scale crawlers. White mango scale may also be dispersed through mango fruit marketing among localities in western Ethiopia. It was depicted that female white mango scale infestation of mango fruit is at its peak when the fruit is ripe and ready for sale in western Ethiopia (Ofgaa Djirata and Emanu Getu, 2015).

Distribution patterns of white mango scale within each administrative zone were not regular. Moreover, there were differences in severity status of the white mango scale among the localities, which may indicate the probable presence of factors that may affect the insect pest populations at local habitat level, differently. The fact that, most of the observed very high severity status was localized at relatively lower altitudes, except at Bedele Kebele 02 of Illubabor Zone, may be a clue for further study in this regard.

Most of the mango farmers included in the current survey, in Kenya, knew white mango scale as a mango pest for many years. However, there is sound difference among them in understanding the extents of damages caused by the pest to mango production and its impact on their incomes. This is probably because there may be difference in keenness during scouting mango farm, to be able to distinguish the pest and take action before it is conspicuous enough. The cryptic size and shape of diaspidids help them remain undetected until economically damaging levels are reached (Hodges *et al.*, 2005). The observed differences in severity status among the study farms may be related to marked variations in implementing control measures, even though severity of infestation was mild in most cases.

The farmers could know that some mango cultivars are more susceptible to white mango scale infestation, and believed that apple mango is the most damaged variety followed by Kent and Vandyke. However, data on live white mango scale collected from Kimani and Samuru mango trees, in the current study, revealed that Kent and Vandyke were the most infested varieties, whereas apple was the least infested. Kenyan mango farmers like to produce more of Apple mango pertaining to its quality features which attract market (Boersma, 2006; HCDA, 2008). Therefore, the response

that indicated white mango scale infested apple mango the most, may be presumption associated with attention given to apple mango more than to other varieties, by mango farmers.

4.5 Conclusion

It is possible to see that white mango scale is spreading very fast; and has already covered mango farms over large geographical areas in western Ethiopia, with high and very high severity status in most cases. The current trend of spread of white mango scale, across western Ethiopia, is a reminder of urgency for devising and implementing control measures. In central and eastern Kenya, too, white mango scale covered most of the study farms but severity status were mild in most cases, unlike in Ethiopia. Compared to its long history in Kenya, attention given to white mango scale is low. However, it is noticeable that some proactive farmers in Kenya could manage white mango scale, and hence their management practices can be a good lesson for Ethiopian mango farmers to control the pest.

Chapter 5

Host Range of White Mango Scale

5.1 Introduction

The first report of white mango scale infestation of mango in Ethiopia has now been near to a decade (Mohammed Dawd *et al.*, 2012). White mango scale spread and has caused damages to mango production in western Ethiopia (Tesfaye Hailu *et al.*, 2014; Temesgen Fita, 2014; Ofgaa Djirata and Emanu Getu, 2015). Reports from countries other than Ethiopia indicated that white mango scale is a polyphagous pest that inflicts damage to many host plants (Erichsen and Schoeman, 1992; Malumphy, 2014). There has been no documented study performed on host range of the pest in Ethiopia so far. Knowledge regarding presence or absence of alternative host to white mango scale is vital in attempts made to manage the pest. Therefore, this study was designed with the objective of investigating host range of white mango scale in western Ethiopia.

5.2 Materials and Method

5.2.1 Description of the study area

The survey was carried out in West Shoa, East Wollega, Illubabor and West Wollega Administrative Zones in western Ethiopia (Figure 5.1), from May 2016 to July 2016.

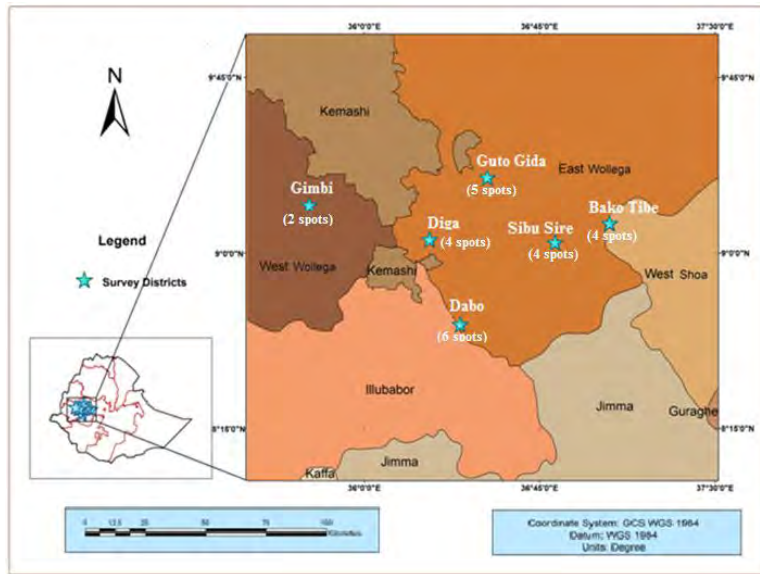


Figure 5. 1 Survey area of WMS alternative host in western Ethiopia

5.2.2 Study design and sampling procedure

Survey on presence/absence of white mango scale on vascular plants other than mango tree was assessed in purposively selected fields covered with vegetation. Altitudinal variation was the main reference used to select survey fields. This was to include as many vascular plant species as possible in view of the fact that plant species abundance and diversity show changes along altitudinal gradients (Hurni, 1998; Cavieres *et al.*, 2000; Fosaa, 2004; Habib *et al.*, 2011). Natural forest areas and agricultural fields were included in the assay. The survey began from Loko Kebele in Gida Ayana District in East Wollega, from where white mango scale was first recorded and addressed five additional districts in western Ethiopia. Fifty leaves, 10 twigs and 5 fruits (when present) found at different heights were cut from every plant obtained within proximity of infested mango trees, and presence/absence of white mango scale checked by hand lens. Assessment diameter was broadened in all directions by 10 meters successive intervals until riverine vegetation was encountered. When there was no riverine vegetation in that direction, visual observation was made

to check if there was plant with apparently white spots (with thought of probable infestation of WMS) and examined when encountered. Assessment was terminated at about 100 meters distance from the starting spot. Altitude and coordinates of each sampling site were recorded from central point of each field. Samples of plants investigated for probability of infestation of white mango scale were collected, pressed and mounted (Queensland Herbarium, 2016), and taken to Addis Ababa University, Department of Plant Biology and Biodiversity Management, National Herbarium of Ethiopia for identification. In addition to the fields selected from the six districts for systematic survey, presence/absence of white mango scale on vascular plants found within or in the vicinity of infested mango farms was checked at roadside farms, as convenient, while travelling within the study area for the current survey.

Data analysis

Plant samples were sorted out and classified to species level. Summarized data regarding presence/absence of white mango scale on the plants was presented.

5.3 Results

White mango scale infestation was not detected from any of the plants checked in the whole survey area. A total of 120 plant samples which were checked for white mango scale infestation were collected from fields located within altitudinal gradients ranging from 1150 m.a.s.l to 1755 m.a.s.l. The plants were classified into 25 species (Table5.1, Appendix 5.1).

Table 5. 1 Vascular plants checked for WMS infestation in Western Ethiopia

Botanical Name	Family Name	WMS
<i>Cordia africana</i> Lam.	Boraginaceae	Nr
<i>Solanum incanum</i> L.	Solanaceae	Nr
<i>Croton macrostachyus</i> Del.	Euphorbiaceae	Nr
<i>Jacaranda mimosifolia</i> D. Don	Bignoniaceae	Nr
<i>Casimiroa edulis</i> La Llave	Rutaceae	Nr
<i>Persea americana</i> Mill.	Lauraceae	Nr
<i>Coffea arabica</i> L.	Rubiaceae	Nr
<i>Psidium guajava</i> L.	Myrtaceae	Nr
<i>Carica papaya</i> L.	Caricaceae	Nr
<i>Vernonia amygdalina</i> Del.	Asteraceae	Nr
<i>Syzygium guineense</i> (Willd.) DC.	Myrtaceae	Nr
<i>Sapium ellipticum</i> (Krauss) Pax	Euphorbiaceae	Nr
<i>Trichilia dregeana</i> Sond.	Meliaceae	Nr
<i>Euphorbia cotinifolia</i> L.	Euphorbiaceae	Nr
<i>Lonchocarpus laxiflorus</i> Guill. & Perr.	Fabaceae	Nr
<i>Senna didymobotrya</i> (Fresen.) Irwin & Barneby	Fabaceae	Nr
<i>Ficus sycomorus</i> L.	Moraceae	Nr
<i>Grewia mollis</i> A. Juss.	Tiliaceae	Nr
<i>Piliostigma thonningii</i> (Schumach.) Milne-Redh.	Fabaceae	Nr
<i>Ficus carica</i> L.	Moraceae	Nr
<i>Combretum</i> sp.	Combretaceae	Nr
<i>Bridelia micrantha</i> (Hochst.) Baill.	Euphorbiaceae	Nr
<i>Flueggea virosa</i> (Willd.) Voigt.	Euphorbiaceae	Nr
<i>Bridelia micrantha</i> (Hochst.) Baill.	Euphorbiaceae	Nr
<i>Blighia unijugata</i> Bak.	Sapindaceae	Nr

Nr=Not recorded

5.4 Discussion

The present study showed that mango is currently the only host plant for white mango scale in western Ethiopia. However, white mango scale was reported to have been

infesting plants other than mango in different countries (Erichsen and Schoeman, 1992; Hodges *et al.*, 2005; Malumphy, 2014). According to Hodges and Hamon (2016) plant species found under families Sapindaceae and Rutaceae served as host plants for white mango scale. In the current study, however, it was known that plants from these two families were not infested by the white mango scale. Moreover, Erichsen and Schoeman (1992) listed avocado (*Persea americana* Mill.) among fruits damaged by white mango scale in South Africa, which was again confirmed by the current study not to have been infested, though found intercropped with mangos already infested by white mango scale at Chari field in Sibu Sire district of East Wollega, and in other observed roadside farms.

Abundance of mango plantation may be one possible explanation to have been the only colonized plant by white mango scale in western Ethiopia. Host plant abundance is known to positively influence host plant use, in both specialist and generalist herbivorous insects (West and Cunningham, 2002; Nobre *et al.*, 2016). The rate at which a dispersing or foraging insect finds a host plant can be limited by relative abundance of the plant. It is obvious that western Ethiopia is one of the most known mango producing regions in the country (Ethiopian Ministry of Agriculture and Rural Developmant, 2009; Takele Honja, 2014). In another explanation, there can be a room to believe that white mango scale has switched its host to mango in preference to nutritional quality. Field and laboratory trials confirmed that some phytophagous insects showed host switching between plants in relation to nutritional quality for survival, nymphal development and reproductive performances of adults (Velasco and Walter, 1993; Mody *et al.*, 2007). Comparative analysis of nutritional quality of mango and other plants was not within the scope of the current study. However, the fact that only mango was infested by white mango scale within farms containing other

plants reported to have been host of white mango scale in other countries may mean mango is a preferred host for white mango scale in western Ethiopia.

5.5 Conclusion

The current study concludes that white mango scale had no alternative host in western Ethiopia. Further studies are required to elucidate the reason for such single host preference of the pest in presence of other potential host plants in the study area.

Chapter 6

Efficacy Test of Insecticides for the Control of White Mango Scale

6.1 Introduction

White mango scale was reported to have been a very noxious pest affecting commercial value of mango in many countries (Labuschagne *et al.*, 1995; Pena *et al.*, 1998; Nabil *et al.*, 2012; Mazzeo *et al.*, 2014; Ofgaa Djirata *et al.*, 2016). This pest inserts its stylets in and saps sap from leaf, fruit, twigs and other young mango parts causing damages to the plant (Juárez-Hernández *et al.*, 2014). In western Ethiopia, white mango scale is reportedly posing severe threat to mango production (Tesfaye Hailu *et al.*, 2014; Ofgaa Djirata and Emanu Getu, 2015). However, there is no or less study carried out, or documented report regarding insecticide efficacy test for the control of white mango scale in same area as above. Therefore, this study was performed with the objective of screening effective insecticides for control of white mango scale.

6.2 Materials and Method

6.2.1 Description of the study area

This test was performed at Arjo mango orchard (09° 03'N and 036° 17'E) found in Diga District, East Wollega Administrative Zone of Oromia National Regional State in western Ethiopia (Figure 6.1).

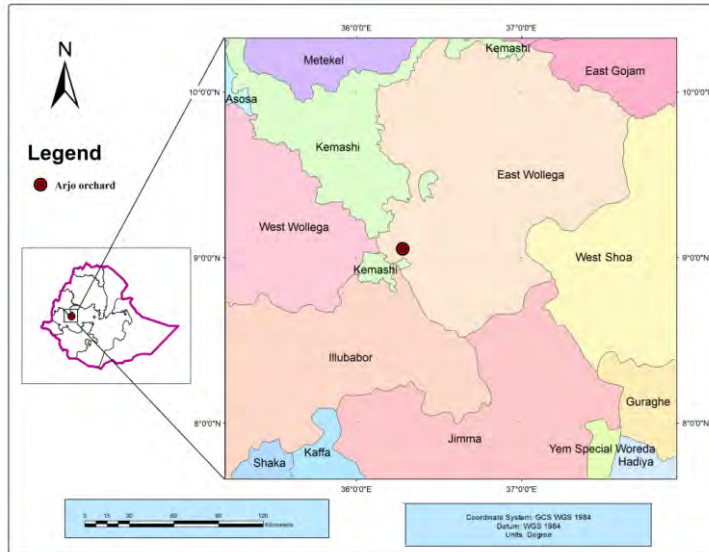


Figure 6. 1 Arjo orchard in western Ethiopia

6.2.2 Study design and sampling procedure

Field experiment was carried out to evaluate efficacy of three insecticides for the control of white mango scale on mango. Closer 240 SC (Sulfoxaflor) was registered for the control of cabbage aphids on cabbage in Ethiopia (Federal Democratic Republic of Ethiopia Ministry of Agriculture and Natural Resources, 2016). D-C-Tron Plus (mineral oil) and Folimat 500SL (Omethoate 500g/L or 47.5% m/m) were registered in Kenya (Pest Control Product Board, 2010). D-C-Tron Plus was used for the control of leaf miners and scales in coffee, mites and aphids in flower and aphids in beans, whereas Folimat was used for the control of aphids in coffee, citrus and flowers, and mealy bugs in coffee.

The tested insecticides, rate of application and their sources are shown below (Table 6.1).

Table 6. 1 Test compounds, rate of application and their sources

Insecticide	Rate of application/ tree	Source (Company)
D-C-Tron Oil	100ml.	Caltex Oil (K) ltd, Nairobi-Kenya
Folimat 500SL	25ml.	Arysta Lifescience Corporation(K), Nairobi, Kenya
Closer 240 SC	6ml.	Chemtex Plc, Addis Ababa, Ethiopia

The experiment was laid in a Randomised Complete Block Design (RCBD) with three replications. Allocation of each treatment and the control within each replication was done randomly. All the mango trees were almost equal in size, and were spaced at distance of 10 metres from each other (Ofgaa, personal observation). No insecticide was applied to Arjo mango orchard prior to this study.

Before application of the formulations, the volume of water enough to completely cover a mango tree was calibrated. Mean volume of water enough per tree was found to be 20 litres. The mango trees were tall and bushy. As a result telescopic knapsack sprayer with extension lance of 3.2 meters was used for spraying, the spray man being supported by scaffold fixed on tractor back for ease of reaching mango tree parts (Plate 6.1). Treatments were applied every 14 days for a total of three times, starting from May 19, 2016.



Plate 6. 1 Insecticide applications from tractor back at Arjo orchard

A total of ten leaves were plucked from top, middle and lower canopies of each tree, one day prior to each treatment and on the 5th and 10th days after each treatment. The leaves from each tree were placed in separate cloth bag, labelled, kept in a plastic bag and taken to a temporary lab established around the trial area. Live crawler, male and female white mango scales were counted by the use of stereo microscope, and numbers were recorded.

Data analysis

Sum of live crawler, female and male white mango scale was taken as white mango scale count data and subjected to analysis. Proc ANOVA of SAS software v9 was applied for data analysis. Significant means were separated by Fisher's Least Significant Difference (LSD) at 5% error level. Percent reduction in white mango scale population over control was worked out after each treatment using Henderson and Tilton (1955) formula of mortality correction.

$$\text{Mortality Correction} = \left(1 - \frac{n \text{ in Co before treatment} \times n \text{ in T after treatment}}{n \text{ in Co after treatment} \times n \text{ in T before treatment}} \right) * 100$$

Where n = white mango scale population

T= treated, and Co=control

6.3 Results

Mean numbers of white mango scale recorded per 10 leaves before the first treatment was 297, 333, 1084 and 155 for D-C-Tron, Closer, Folimat and Control. Post first spray, first and second records were 300 and 298 for D-C-Tron, 330 and 320 for Closer, 1070 and 1066 for Folimat, and 157 and 158 for control, respectively. Mortalities were recorded starting from post second spray for treatments, whereas population build up was recorded for control. Mean numbers of live white mango scale per 10 leaves from pre second spray onward are shown below (Figure 6.2-6.3).

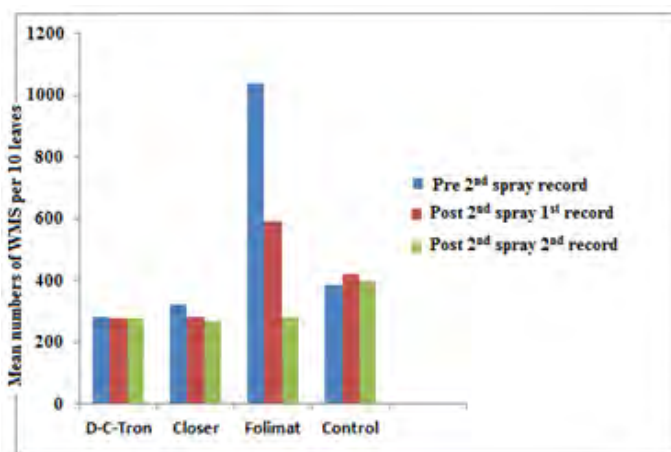


Figure 6. 2 White mango scales population before and after second round insecticide spray

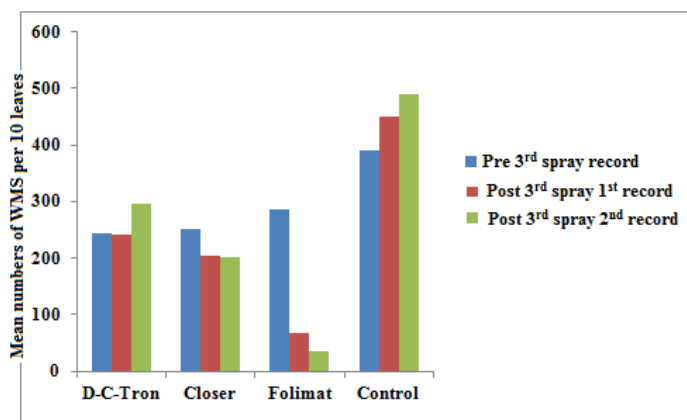


Figure 6. 3 White mango scale population before and after third round insecticide spray

In the course of observing live white mango scale following each treatment, dead *Chilocorus* sp. was frequently encountered, peculiarly, on mango leaves treated with Folimat, while those on leaves treated by the rest two insecticides were live and active, in most observed cases.

Percent mortality of white mango scale in response to successive treatments were shown below (A and B for first and second responses after spray 1, C and D for first and second responses after spray 2, and E and F denoting first and second responses after spray 3, respectively) (Figure 6.4).

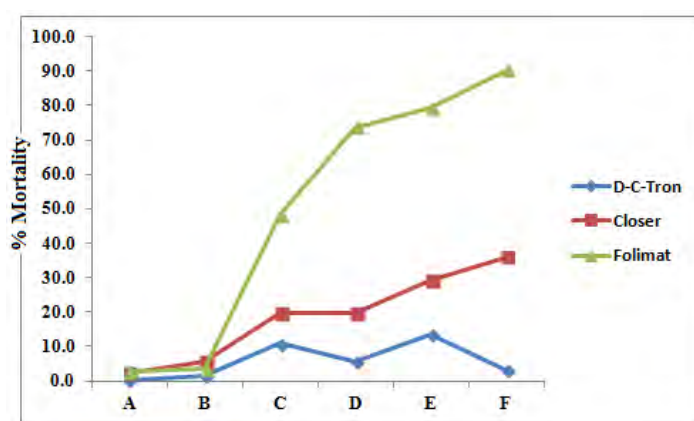


Figure 6. 4 White mango scale mortality in response to treatment

Efficacy trial of the test insecticides against white mango scale showed that Folimat (49.52 ± 15.74) was significantly different ($p < 0.05$) from Closer (18.72 ± 5.32) and D-C-Tron (5.90 ± 2.15) at 5% error level ($LSD = 29.15$) (Appendix 6.1).

6.4 Discussions

Folimat 500SL was found to be the most effective of the three insecticides. It was reported that mango farmers in central and eastern Kenya were using this product to have controlled white mango scale (Ofgaa Djirata, *et al.*, 2016). However, extermination of a non target insect from leaves treated particularly with Folimat, in addition to its superior efficacy, probably demonstrates its strong toxicity which

renders it worrisome profile to be considered for white mango scale control in the context of this study. However, whether death of the non target insect was purely due to Folimat had not been evaluated in this study. Although efficacy of Closer 240 SC was lower than that of Folimat 500 SL, minimizing white mango scale by nearly 50% in big mango trees with bushy canopy, like that in Arjo orchard, can't be underestimated. Because it is practically impossible to completely cover such mango trees during insecticide application.

6.5 Conclusion

An insecticide with best efficacy in controlling white mango scale was identified. However, highly toxic insecticides should not be used for white mango scale control purposes from ecological concerns point of view. It is almost impossible to completely cover the indigenous big mango trees with insecticides by manual spraying methods. Therefore, after heavy infestation has taken place, controlling white mango scale is highly challenging, particularly at small scale farmers level.

Chapter 7

General Conclusion and Recommendations

7.1 Conclusion

Temperature and rainfall might be the main factors that determined population dynamics of white mango scale. Peak season of white mango scale population was identified, and this would assist in designing control strategy.

Identifying a native predatory beetle, *Chilocorus* sp preying on white mango scale in western Ethiopia, probably for the first time in Ethiopia, can provide a roadmap for designing biological control of white mango scale. Population of *Chilocorus* sp was found to be very low and couldn't control mango scale so far. However, the fact that mango scale population persisted year-round can be a favourable environment for the predator population to sustain and build up gradually. Further study regarding ecology of this newly associated natural enemy to white mango scale would be vital to conserve its population.

White mango scale infestation of mango in central and eastern Kenya was very low, and hence can't be compared with that in Ethiopia. Indigenous management practices and use of various insecticides were believed to have minimized white mango scale infestation in Kenya. Moreover, growing improved mango varieties which were found to be less susceptible to white mango scale infestation contributed in minimizing white mango scale severity in the Kenyan study areas.

The rate at which white mango scale has spread in all geographical directions in western Ethiopia is a reminder that status of this insect pest has become beyond internal quarantine, although it is a new insect pest to the country.

It could be known that mango has been the only host of white mango scale in western Ethiopia. Knowledge of this may assist as an input in designing and implementation of white mango scale control methods.

Folimat was found to exhibit high efficacy in killing white mango scale. However, it has been noted that insecticide with high level of toxicity should not be used to control white mango scale in the study area. Moreover, tree stature and canopy shapes of mango in western Ethiopia were not suitable for maximum penetration of sprays, and hence insecticide control alone may not be dependable.

7.2 Recommendations

- *Chilocorus* sp. was found preying ravenously on live white mango scale, signifying its association as a native predator with the exotic white mango scale. However, the predator population didn't build up in mango orchard yet, and hasn't controlled the pest. It is recommended that through further study of ecology of the predator and implementing conservation and augmentation biological controls, its population should increase to be able to play significant role in the control of white mango scale.
- White mango scale has been introduced to Ethiopia, recently. Therefore, further studies that help trace its origin and related natural enemies should be conducted for the designing and implementation of classical biological control.
- White mango scale was found spreading very fast in western Ethiopia, on one hand, and yet mechanisms of its dispersal in the region have not been known, on the other. Therefore since implementation of internal quarantine may be unfounded, it is recommended that mango farmers in the country should be trained to scout their mangos for white mango scale infestation as early as

possible, and remove any infested part before incidence of heavy infestation that would make its control difficult.

- Taking the current distribution of white mango scale in Ethiopia in to account, its country-wide distribution should be surveyed.
- Population dynamics of white mango scale and its possible natural enemy should be exhaustively studied, in both Ethiopia and Kenya.
- Cultural practices such as cyclic pruning and consistent scouting for white mango scale infestation and removal of infested parts are essential management practices that Ethiopian mango farmers should learn from their Kenyan counterparts.
- It was known that some improved mango varieties were less susceptible to white mango scale infestation in central and eastern Kenya. Such mango varieties should be looked for, studied systematically and introduced to Ethiopia by taking all necessary precautions.
- Insecticides with known high toxicity that may impede performance of natural enemies should not be used to control white mango scale in western Ethiopia.
- The best period for application of insecticide for the control of white mango scale is from April to June, when white mango scale, in general and the crawlers in particular, are more abundant in western Ethiopia.
- Integrated Pest Management should be implemented for the control of white mango scale.

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APPENDICES

Appendix 3. 1 Simple statistics for correlation between WMS and LBB

Appendix 3.2 Simple Statistics of Correlation coefficient between WMS and LBB at Arjo orchard

The Corr Procedure						
4 Variables : LBB Male_WMS Female_WMS Total_WMS						
Variable	N	Mean	Std dev	Sum	Minimum	Maximum
LBB	12	6.50	6.93	78	0	20
Male_WMS	12	672.92	775.07	8075	0	1623
Female_WMS	12	347.33	362.24	4168	30	1340
Sum	12	1020	1048	12243	33	2693
Male_Female WMS						

Appendix 3.1b Simple statistics of correlation coefficient between WMS and LBB at Bako orchard

The Corr Procedure						
4 Variables : LBB Male_WMS Female_WMS Total_WMS						
Simple Statistics						
Variable	N	Mean	Std dev	Sum	Minimum	Maximum
LBB	12	3.17	6.34	38	0.00	20
Male_WMS	12	813.75	1345	9765	0.00	3674
Female_WMS	12	283.58	429.02	3403	2.00	1501
Sum	12	1097	1713	13168	2.00	4810
Male_Female WMS						

Appendix 3. 2 ANOVA Table for sessile stage mango scale, pooled data of Arjo and Bako

The GLM Procedure					
Dependent Variable: Sessile stage mango scale					
Source	DF	Sum of Squares	Mean square	F value	Pr > F
Model	54	10034.37967	185.82185	15.48	<.0001
Error	425	5102.10284	10.55345		
Corrected Total	479	15136.48251	12.00495		
	R-Square	Coeff Var	Root MSE	Sessile mango scale mean	
	0.662927	72.89129	3.464816	4.753402	

Appendix 3. 3 ANOVA Table for male and female mango scale at Arjo orchard

The GLM Procedure					
Dependent Variable: Sessile stage mango scale					
Source	DF	Sum of Squares	Mean square	F value	Pr > F
Model	40	3736.475533	93.411888	4.52	<.15
Error	199	4111.665050	20.661633		
Corrected Total	239	7848.140583			
	R-Square	Coeff Var	Root MSE	Sessile stage scale mean	
	0.476097	102.8162	4.545507	4.421001	

Appendix 3. 4 ANOVA Table for male and female mango scale at Bako orchard

The GLM Procedure					
Dependent Variable: Sessile stage mango scale					
Source	DF	Sum of Squares	Mean square	F value	Pr > F
Model	40	6974.553474	174.363837	133.07	<.0001
Error	199	260.753054	1.310317		
Corrected Total	239	7235.306528			
	R-Square	Coeff Var	Root MSE	Sessile stage scale mean	
	0.963961	22.50757	1.144691	5.085803	

Appendix 3. 5 ANOVA Table for WMS crawler population among months and between mango leaf surfaces, pooled data of Arjo & Bako

The GLM Procedure					
Dependent Variable: Crawler					
Source	DF	Sum of Squares	Mean square	F value	Pr > F
Model	40	303.0107466	7.5752687	7.23	<.0001
Error	199	208.5290245	1.0478845		
Corrected Total	239	511.5397712			
	R-Square	Coeff Var	Root MSE	Crawler mean	
	0.592350	66.46129	1.023662	1.540238	

Appendix 3. 6 ANOVA Table for WMS crawler at Arjo orchard among months

The GLM Procedure					
Dependent Variable: Crawler					
Source	DF	Sum of Squares	Mean square	F value	Pr > F
Model	27	44.3106003	1.6411333	2.21	0.0028
Error	92	68.4213084	0.7437099		
Corrected Total	119	112.7319086			
	R-Square	Coeff Var	Root MSE	Crawler mean	
	0.393062	62.16077	0.862386	1.387348	

Appendix 3. 7 ANOVA Table for WMS crawler at Bako orchard among months

The GLM Procedure					
Dependent Variable: Crawler					
Source	DF	Sum of Squares	Mean square	F value	Pr > F
Model	27	280.5703967	10.3914962	8.49	<.0001
Error	92	112.6273429	1.2242102		
Corrected Total	119	393.1977397			
	R-Square	Coeff Var	Root MSE	Crawler mean	
	0.713561	65.34885	1.106440	1.693129	

Appendix 3. 8 ANOVA Table for WMS egg population, pooled data of Arjo & Bako among months

The GLM Procedure					
Dependent Variable: Egg					
Source	DF	Sum of Squares	Mean square	F value	Pr > F
Model	40	6570.425514	164.260638	19.51	<.0001
Error	199	1675.126482	8.417721		
Corrected Total	239	8245.551995			
	R-Square	Coeff Var	Root MSE	Egg mean	
	0.796845	57.92607	2.901331	5.008679	

Appendix 3. 9 ANOVA Table of WMS egg among months and between mango leaf surfaces at Arjo orchard

The GLM Procedure					
Dependent Variable: Egg					
Source	DF	Sum of Squares	Mean square	F value	Pr > F
Model	27	3228.194260	119.562750	17.89	<.0001
Error	92	614.717415	6.681711		
Corrected Total	119	3842.911674			
	R-Square	Coeff Var	Root MSE	Egg mean	
	0.840039	45.31087	2.584901	5.704814	

Appendix 3. 10 ANOVA Table of WMS egg among months and between mango leaf surfaces at Bako orchard

The GLM Procedure					
Dependent Variable: Egg					
Source	DF	Sum of Squares	Mean square	F value	Pr > F
Model	27	3690.986673	136.703210	21.12	<.0001
Error	92	595.348750	6.471182		
Corrected Total	119	4286.335423			
	R-Square	Coeff Var	Root MSE	Egg mean	
	0.861105	58.98726	2.543852	4.312544	

Appendix 3. 11 ANOVA Table for sessile WMS among months at Kenyatta University mango yard

The GLM Procedure					
Dependent Variable: Sessile stage mango scale					
Source	DF	Sum of Squares	Mean square	F value	Pr > F
Model	22	87.1298545	3.9604479	2.37	0.2871
Error	97	161.9534297	1.6696230		
Corrected Total	119	249.0832842			
	R-Square	Coeff Var	Root MSE	Sessile mango scale mean	
	0.349802	71.31775	1.292139	1.811806	

Appendix 3. 12 ANOVA Table for WMS egg among months at Kenyatta University mango yard

The GLM Procedure					
Dependent Variable: Egg					
Source	DF	Sum of Squares	Mean square	F value	Pr > F
Model	15	779.955204	51.997014	1.46	0.1636
Error	44	1568.392575	35.645286		
Corrected Total	59	2348.347778			
	R-Square	Coeff Var	Root MSE	Egg mean	
	0.332129	130.1472	5.970367	4.587396	

Appendix 3. 13 ANOVA table for WMS crawler among months at Kenyatta University mango yard

The GLM Procedure					
Dependent Variable: Crawler					
Source	DF	Sum of Squares	Mean square	F value	Pr > F
Model	15	38.1847684	2.5456512	1.46	0.022
Error	44	76.6171026	1.7412978		
Corrected Total	59	114.8018711			
	R-Square	Coeff Var	Root MSE	Crawler mean	
	0.332615	80.50672	1.319582	1.639096	

Appendix 3. 14 ANOVA Table for sessile stage mango scale among months, pooled data of Samuru & Kimani

The GLM Procedure					
Dependent Variable: Sessile stage mango scale					
Source	DF	Sum of Squares	Mean square	F value	Pr > F
Model	35	176.678450	5.047956	3.26	<.0001
Error	732	1131.785889	1.546156		
Corrected Total	767	1308.464339			
	R-Square	Coeff Var	Root MSE	Sessile stage scale mean	
	0.135027	90.07527	1.243445	1.380451	

Appendix 3. 15 ANOVA Table for sessile stage mango scale among cultivars at Samuru orchard

The GLM Procedure					
Dependent Variable: Sessile stage mango scale					
Source	DF	Sum of Squares	Mean square	F value	Pr > F
Model	45	202.9630613	4.5102903	2.39	<.0001
Error	338	636.8405577	1.8841437		
Corrected Total	383	839.8036190			
	R-Square	Coeff Var	Root MSE	Sessile stage scale mean	
	0.241679	89.85061	1.372641	1.527693	

Appendix 3. 16 ANOVA Table for means of sessile stage mango scale among cultivars at Kimani orchard

The GLM Procedure					
Dependent Variable: Sessile stage mango scale					
Source	DF	Sum of Squares	Mean square	F value	Pr > F
Model	45	97.8856138	2.1752359	2.08	<.0001
Error	338	354.1248289	1.0477066		
Corrected Total	383	452.0104427			
	R-Square	Coeff Var	Root MSE	Sessile scale mean	
	0.216556	83.00092	1.023575	1.233210	

Appendix 3. 17 ANOVA Table for means of WMS egg among months at Kimani orchard

The GLM Procedure					
Dependent Variable: WMS Egg					
Source	DF	Sum of Squares	Mean square	F value	Pr > F
Model	38	86.8519975	2.2855789	1.08	0.3662
Error	153	324.7080333	2.1222747		
Corrected Total	191	411.5600308			
	R-Square	Coeff Var	Root MSE	Egg mean	
	0.211031	121.4090	1.456803	1.199913	

Appendix 3. 18 ANOVA Table for WMS crawler among months at Kimani orchard

The GLM Procedure					
Dependent Variable: WMS crawler					
Source	DF	Sum of Squares	Mean square	F value	Pr > F
Model	35	3.60540245	0.10301150	0.92	0.6078
Error	156	17.55353678	0.11252267		
Corrected Total	191	21.15893923			
	R-Square	Coeff Var	Root MSE	Crawler mean	
	0.170396	32.47597	0.335444	1.032899	

Appendix 3. 19 ANOVA Table for WMS egg among months at Samuru orchard

The GLM Procedure					
Dependent Variable: WMS Egg					
Source	DF	Sum of Squares	Mean square	F value	Pr > F
Model	38	32.16222463	0.84637433	2.31	0.0002
Error	153	56.09432108	0.36662955		
Corrected Total	191	88.25654571			
	R-Square	Coeff Var	Root MSE	Egg mean	
	0.364417	46.79636	0.605499	1.293903	

Appendix 3. 20 ANOVA Table for means of WMS crawler among months at Samuru orchard

The GLM Procedure					
Dependent Variable: WMS Crawler					
Source	DF	Sum of Squares	Mean square	F value	Pr > F
Model	35	1.00808392	0.02880240	1.00	0.4736
Error	156	4.48083851	0.02872332		
Corrected Total	191	5.48892244			
	R-Square	Coeff Var	Root MSE	Crawler mean	
	0.183658	16.49412	0.169480	1.027515	

reddish (pink) spots on fruits and yellowish/brown spots on leaves of mango?

- A) Below 10 years _____ B) 10 – 20 years _____
C) 21 – 30 years _____ D) Above 30 years _____ E) Not applicable _____

9. What damages did White Mango Scale cause to your mango?

_____.

10. Which of your mango varieties is damaged the most by White Mango Scale?

_____.

11. Did the damage that White Mango Scale cause to mango increase, decrease or doesn't show any difference from time to time?

- A) Increased ___ B) Decreased ___ C) No difference ___ D) Not applicable ___

12. Did the damage of White Mango Scale to mango plantation affect the income you may get from mango?

- A) Yes _____ B) No _____ C) I do not know _____ D) Not applicable _____

13. If it affected your income how did it do?

_____.

14. What method(s) have you been using to control White Mango Scale?

- A) Cultural (traditional) methods _____ C) Both cultural & insecticides _____
B) B) Insecticides (Chemicals) _____
D) Other (please, specify): _____

15. If you used cultural methods, what are the major ones?

_____.

16. If you used insecticides, please list down the names of the chemicals.

_____.

17. With the methods you used to control white mango scale, could you manage to control the pest?

- A) Yes _____ B) No _____ C) To some extent _____
D) I do not know _____ E) Not applicable _____

19. Any idea:

_____.

Appendix 4. 2 WMS Distribution in western Ethiopia summary statistics

Appendix 4.2a WMS Distribution in western Ethiopia (Case Processing Summary)

Administrative Zone	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Count East Wollega	50	100.0%	0	.0%	50	100.0%
Illubabor	20	100.0%	0	.0%	20	100.0%
West Shoa	20	100.0%	0	.0%	20	100.0%
West Wollega	40	100.0%	0	.0%	40	100.0%

Appendix 4.2b Distribution of WMS in western Ethiopia (Descriptive statistics)

Administrative Zone	N	Mean	SD	Minimum	maximum
Count East Wollega	50	35.00	26.10	0	95
Illubabor	20	45.90	19.03	13	80
West Shoa	20	5.00	5.40	0	21
West Wollega	40	16.90	24.50	0	90

Appendix 4. 3 Severity of WMS at mango farms in western Ethiopia

AZ	District	Locality/ mango farm	Altitude (m.a.s.l.)	Location		Female WMS /10 leaves	Severity Index	Severity Status
				North	East			
WS	Ilu Gelan	Jato Dirki	1747 m.a.s.l	08° 59.74'	037° 20.973'	58	1	Mild
WS	Bako Tibe	Gibe	1612 m.a.s.l	09° 07.409'	037° 03.025'	58	1	Mild
EW	Sibu Sire	Chari	1748 m.a.s.l	09° 02.567'	036° 48.935'	32	1	Mild
EW	Sasiga	Ambalta Fayera	1565 m.a.s.l	09° 16 .006'	036° 31.032'	418	3	Very High
EW	Guto Gida	Loko	1375 m.a.s.l	09° 19 .226'	036° 31.619'	596	3	Very High
EW	Gida Ayana	Andode Dicho	1483 m.a.s.l	09° 41.013'	036° 37.794'	336	2	High
EW	Diga	Gudetu Arjo	1320 m.a.s.l	09° 03.277'	036° 16.824'	368	2	High
IA	Dabo	Didessa	1278 m.a.s.l	08° 41.339'	036° 24.72'	723	3	Very High
IA	Bedele	Bedele Kebele 02	1988 m.a.s.l	08° 27.001'	036° 20.863'	431	3	Very High
WW	Gimbi	Tole	1150 m.a.s.l	09° 03.840'	036° 06.364'	425	3	Very High
WW	Gimbi	Aba Sena	1698 m.a.s.l	09° 01.687'	035° 58.88'	311	2	High
WW	Gimbi	Lalisa Yasus	1821 m.a.s.l	09° 11.971'	035° 45.855'	37	1	Mild
WW	Lalo Assabi	Ula Bake	1887 m.a.s.l	09° 14.146'	035° 41.893'	0	0	No Infestation
WW	Lalo Assabi	Dongoro	1857 m.a.s.l	09° 15.957'	035° 41.524'	47	1	Mild
WW	Boji Dirmaji	Kora Karkaro	1800 m.a.s.l	09° 20.964'	035° 36.774'	0	0	No Infestation

AZ	District	Locality/ mango farm	Altitude (m.a.s.l.)	Location		Female WMS /10 leaves	Severity Index	Severity Status
				North	East			
WW	Nedjo	Gudami	1936 m.a.s.l	09° 32.397'	035° 28.770'	0	0	No Infestation
WW	Nedjo	Kujur Guda	1713 m.a.s.l	09° 34.535'	035° 23.538'	0	0	No Infestation
WW	Kiltu Karra	Minjako	1647 m.a.s.l	09° 41.123'	035° 19.601'	0	0	No Infestation
WW	Kiltu Karra	Kiltu Karra	1635 m.a.s.l	09° 41.490'	035° 15.817'	0	0	No Infestation
WW	Manasibu	Guyo Sachi	1597 m.a.s.l	09° 42.789'	035° 11.635'	0	0	No Infestation

AZ=Administrative Zone, EW=East Wollega, WS= West Shoa, IA=Illubabor, WW=West Wollega

Appendix 4. 4 Frequency table of mango cultivars grown in central and eastern Kenya (Data Cross tabulated)

	County	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	KIAMBU	25	10.6	10.6	10.6
	MACHAKOS	85	36.0	36.0	46.6
	MURANG'A	126	53.4	53.4	100.0
	Total	236	100.0	100.0	

Appendix 4. 5 Variations in levels of damage caused by WMS to since the pest was recognized

Variable		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Increased	16	21.3	21.3	21.3
	Decreased	12	16.0	16.0	37.3
	No difference	15	20.0	20.0	57.3
	N/A	32	42.7	42.7	100.0
	Total	75	100.0	100.0	

Appendix 4. 6 Response on whether WMS Affects farmers' income or not

Variable		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	10	13.3	13.3	13.3
	No	17	22.7	22.7	36.0
	Not aware	16	21.3	21.3	57.3
	Not applicable	32	42.7	42.7	100.0
	Total	75	100.0	100.0	

Appendix 4. 7 WMS distribution in central and eastern Kenya, summary statistics
 Appendix 4.7a WMS Distribution in central and eastern Kenya (Case Processing
 Summary)

	Cases					
	Included		Excluded		Total	
	N	Percent	N	Percent	N	Percent
Average * County	75	100.0%	0	0.0%	75	100.0%

Appendix 4.7b Distribution of WMS in central and eastern Kenya (Descriptive
 statistics)

County	Frequency	Mean	SD	Minimum	maximum
Kiambu	15	1.35	.81	0.4	2.9
Machakos	25	2.75	3.17	0	14.8
Murang'a	35	1.47	1.49	0	14.8

Appendix 4. 8 WMS distribution and severity status in central and eastern Kenya

Appendix 4.8a WMS distribution and severity status in KIAMBU

County	Locality/ Mango farm	Altitude	Coordinates		Female WMS /10 leaves	Severity index	Severit y status
			South	East			
Kiambu	Kilimanbogo	1438	01° 03.695'	037° 14.398'	15	1	Mild
Kiambu	Mukuneke1	1439	01° 03.706'	037° 14.570'	21	1	Mild
Kiambu	Mukuneke2	1423	01° 03.781'	037° 14.708'	13	1	Mild
Kiambu	Mukuneke3	1412	01° 03.964'	037° 15.111'	15	1	Mild
Kiambu	Mukuneke4	1424	01° 03.911'	037° 15.121'	15	1	Mild
Kiambu	Mukuneke5	1436	01° 03.779'	037° 15.020'	18	1	Mild
Kiambu	Magogoni1	1444	01° 03.688'	037° 15.297'	13	1	Mild
Kiambu	Magogoni2	1442	01° 03.757'	037° 15.512'	17	1	Mild
Kiambu	Magogoni3	1428	01° 03.362'	037° 15.703'	14	1	Mild
Kiambu	Magogoni4	1428	01° 03.335'	037° 15.952'	16	1	Mild
Kiambu	Magogoni5	1424	01° 03.360'	037° 16.155'	13	1	Mild
Kiambu	Magogoni6	1417	01° 03.602'	037° 16.660'	14	1	Mild
Kiambu	Neema1	1417	01° 03.611'	037° 16.842'	18	1	Mild
Kiambu	Neema2	1412	01° 03.680'	037° 16.979'	15	1	Mild
Kiambu	Neema3	1429	01° 03.686'	037° 17.210'	14	1	Mild

Appendix 4.8b WMS distribution and severity status in Machakos

County	Mango Farm	Altitude	Coordinates		Female WMS /10 leaves	Severity index	Severity status
			South	East			
Machakose	Kiimani1	1276	01° 10.009'	037° 30.017'	11	1	Mild
Machakose	Kiimani2	1266	01° 10.064'	037° 30.250'	11	1	Mild
Machakose	Kauukuni1	1231	01° 08.637'	037° 29.378'	0	0	No Infestation
Machakose	Kauukuni2	1244	01° 08.575'	037° 29.191'	92	2	High
Machakose	Mukalala1	1251	01° 08.664'	037° 30.200'	97	2	High
Machakose	Mukalala2	1224	01° 07.958'	037° 30.854'	102	2	High
Machakose	Kekwaa	1225	01° 07.982'	037° 31.187'	176	3	Very High
Machakose	Kuwukuni	1210	01° 08.446'	037° 28.741'	27	1	Mild
Machakose	Kiliku	1233	01° 08.273'	037° 27.034'	19	1	Mild
Machakose	Kangemi1	1287	01° 08.515'	037° 26.811'	15	1	Mild
Machakose	Kangemi2	1261	01° 08.829'	037° 26.835'	11	1	Mild
Machakose	Kangemi3	1252	01° 08.729'	037° 26.855'	8	1	Mild
Machakose	Kiliku1	1239	01° 08.046'	037° 26.890'	15	1	Mild
Machakose	Kiliku2	1235	01° 08.085'	037° 26.931'	13	1	Mild
Machakose	Kiliku3	1229	01° 07.958'	037° 26.938'	23	1	Mild

County	Mango Farm	Altitude	Coordinates		Female WMS /10 leaves	Severity index	Severity status
			South	East			
Machakose	Ianguni	1209	01° 08.216'	037° 27.658'	18	1	Mild
Machakose	Iviani	1249	01° 08.779'	037° 27.446'	11	1	Mild
Machakose	Kondo	1290	01° 09.617'	037° 27.114'	14	1	Mild
Machakose	Kithyoki1	1284	01° 10.075'	037° 26.913'	12	1	Mild
Machakose	Kithyoki2	1306	01° 10.248'	037° 26.666'	0	0	No Infestation
Machakose	Mananje	1074	00° 48.097'	037° 15.803'	13	1	Mild
Machakose	Murifarm1	1306	01° 51.320'	037° 14.045'	12	1	Mild
Machakose	Murifarm2	1344	01° 51.765'	037° 14.588'	16	1	Mild
Machakose	Kayole1	1288	01° 51.684'	037° 14.761'	15	1	Mild
Machakose	Kayole2	1365	01° 51.505'	037° 14.896'	14	1	Mild

Appendix 4.8c WMS distribution and severity status in Murang'a

County	Mango Farm	Altitude	Coordinates		Female WMS /10 leaves	Severity index	Severity status
			South	East			
Murang'a	Chamba	1074	00° 47.984'	037° 15.790'	86	2	High
Murang'a	Kiambaa	1086	00° 48.455'	037° 15.780'	14	1	Mild
Murang'a	Kambiti	1133	00° 48.932'	037° 15.023'	13	1	Mild
Murang'a	Plasta1	1157	00° 49.021'	037° 14.862'	13	1	Mild
Murang'a	Plasta2	1156	00° 49.175'	037° 14.966'	13	1	Mild
Murang'a	Samurru	1527	00° 59.617'	037° 04.888'	21	1	Mild
Murang'a	Kaseve2	1175	00° 49.275'	037° 14.475'	14	1	Mild
Murang'a	Kaseve1	1160	00° 49.329'	037° 14.41'	0	0	No Infestation
Murang'a	Kaseve3	1190	00° 49.431'	037° 14.287'	13	1	Mild
Murang'a	Kihaini	1170	00° 49.383'	037° 14.129'	12	1	Mild
Murang'a	Ndibu	1184	00° 49.211'	037° 14.183'	10	1	Mild
Murang'a	Machina	1290	00° 49.718'	037° 14.079'	14	1	Mild
Murang'a	Kanoo1	1191	00° 49.704'	037° 14.216'	12	1	Mild
Murang'a	Kanoo2	1176	00° 49.782'	037° 14.314'	10	1	Mild
Murang'a	Kanoo3	1206	00° 49.609'	037° 14.230'	14	1	Mild
Murang'a	Karia'ini1	1265	00° 50.127'	037° 13.364'	9	1	Mild
Murang'a	Karia'ini2	1254	00° 49.857'	037° 13.135'	14	1	Mild

County	Mango Farm	Altitude	Coordinates		Female WMS /10 leaves	Severity index	Severity status
			South	East			
Murang'a	Maranjau	1234	00° 49.580'	037° 13.083'	13	1	Mild
Murang'a	Karai'ani3	1232	00° 49.838'	037° 13.221'	12	1	Mild
Murang'a	Kambiti	1208	00° 49.918'	037° 13.728'	12	1	Mild
Murang'a	Machiana	1231	00° 50.194'	037° 13.892'	11	1	Mild
Murang'a	Babito	1321	00° 50.679'	037° 13.934'	9	1	Mild
Murang'a	Marema1	1345	00° 51.758'	037° 14.545'	10	1	Mild
Murang'a	Marema2	1350	00° 52.057'	037° 14.326'	9	1	Mild
Murang'a	Marema3	1353	00° 52.226'	037° 14.075'	9	1	Mild
Murang'a	Mungetho	1356	00° 52.315'	037° 14.001'	10	1	Mild
Murang'a	Mahinde1	1366	00° 52.907'	037° 13.970'	8	1	Mild
Murang'a	Mahinde2	1378	00° 52.924'	037° 14.003'	8	1	Mild
Murang'a	Githima1	1377	00° 53.261'	037° 13.828'	0	0	No Infestation
Murang'a	Githima2	1314	00° 53.245'	037° 13.792'	9	1	Mild
Murang'a	Githima3	1379	00° 53.204'	037° 13.768'	8	1	Mild
Murang'a	Githima4	1385	00° 53.176'	037° 13.758'	9	1	Mild
Murang'a	Huhoini	1399	00° 53.230'	037° 13.678'	9	1	Mild
Murang'a	Litaya	1406	00° 53.322'	037° 13.648'	10	1	Mild
Murang'a	Litaya	1392	00° 53.381'	037° 13.698'	9	1	Mild

Appendix 5. 1 Vascular plants checked for WMS infestation in Western Ethiopia

AZ	District	Sampling spot	Coordinate		Altitude (m.a.s.l.)	Botanical Name	Family Name
			North	East			
WS	Bako Tibe	Gibe	09° 07.409'	037° 03.025'	1612	<i>Cordia africana</i> Lam.	Boraginaceae
WS	Bako Tibe	Gibe	09° 07.409'	037° 03.025'	1612	<i>Solanum incanum</i> L.	Solanaceae
WS	Bako Tibe	Gibe	09° 07.409'	037° 03.025'	1612	<i>Croton macrostachyus</i> Del.	Euphorbiaceae
WS	Bako Tibe	Gibe	09° 07.409'	037° 03.025'	1612	<i>Jacaranda mimosifolia</i> D. Don	Bignoniaceae
EW	Sibu Sire	Chari	09° 02.542'	036° 48.940'	1755	<i>Casimiroa edulis</i> La Llave	Rutaceae
EW	Sibu Sire	Chari	09° 02.567'	036° 48.935'	1748	<i>Persea americana</i> Mill.	Lauraceae
EW	Sibu Sire	Chari	09° 02.567'	036° 48.935'	1748	<i>Coffea arabica</i> L.	Rubiaceae
EW	Sibu Sire	Chari	09° 02.567'	036° 48.935'	1748	<i>Psidium guajava</i> L.	Myrtaceae
EW	Guto Gida	Loko	09° 19.226'	036° 31.619'	1375	<i>Carica papaya</i> L.	Caricaceae
EW	Guto Gida	Loko	09° 19.226'	036° 31.619'	1375	<i>Vernonia amygdalina</i> Del.	Asteraceae
EW	Guto Gida	Loko	09° 19.226'	036° 31.619'	1375	<i>Syzygium guineense</i> (Willd.) DC.	Myrtaceae
EW	Guto Gida	Loko	09° 19.226'	036° 31.619'	1375	<i>Sapium ellipticum</i> (Krauss) Pax	Euphorbiaceae
EW	Guto Gida	Loko	09° 19.226'	036° 31.619'	1375	<i>Trichilia dregeana</i> Sond.	Meliaceae
IA	Dabo	Didessa	08° 41.339'	036° 24.702'	1278	<i>Euphorbia cotinifolia</i> L.	Euphorbiaceae
IA	Dabo	Didessa	08° 41.339'	036° 24.702'	1278	<i>Lonchocarpus laxiflorus</i> Guill. & Perr.	Fabaceae
IA	Dabo	Didessa	08° 41.339'	036° 24.702'	1278	<i>Senna didymobotrya</i> (Fresen.) Irwin & Barneby	Fabaceae
IA	Dabo	Didessa	08° 41.339'	036° 24.702'	1278	<i>Ficus sycomorus</i> L.	Moraceae

AZ	District	Sampling spot	Coordinate		Altitude (m.a.s.l.)	Botanical Name	Family Name
			North	East			
IA	Dabo	Didessa	08° 41.339'	036° 24.702'	1278	<i>Grewia mollis</i> A. Juss.	Tiliaceae
IA	Dabo	Didessa	08° 41.339'	036° 24.702'	1278	<i>Piliostigma thonningii</i> (Schumach.) Milne-Redh.	Fabaceae
EW	Diga	Gudetu Arjo	09° 03.227'	036° 16.824'	1320	<i>Ficus carica</i> L.	Moraceae
EW	Diga	Gudetu Arjo	09° 03.227'	036° 16.824'	1320	<i>Combretum</i> sp.	Combretaceae
EW	Diga	Gudetu Arjo	09° 03.227'	036° 16.824'	1320	<i>Bridelia micrantha</i> (Hochst.) Baill.	Euphorbiaceae
EW	Diga	Gudetu Arjo	09° 03.227'	036° 16.824'	1320	<i>Flueggea virosa</i> (Willd.) Voigt.	Euphorbiaceae
WW	Gimbi	Tole	09° 03.840'	036° 06.364'	1150	<i>Bridelia micrantha</i> (Hochst.) Baill.	Euphorbiaceae
WW	Gimbi	Tole	09° 03.840'	036° 06.364'	1150	<i>Blighia unijugata</i> Bak.	Sapindaceae

AZ= Administrative Zone, WS=West Shoa, EW=East Wollega, IA=Illubabor, WW= West Wollega

Appendix 6. 1 ANOVA table for WMS mortality in response to test insecticides

The ANOVA Procedure					
Dependent Variable: % Mortality					
Source	DF	Sum of Squares	Mean square	F value	Pr > F
Model	2	6030.64	3015.32	5.37	0.02
Error	15	8419.17	561.28		
Corrected Total	17	14449.83			
	R-Square	Coeff Var	Root MSE	Mortality mean	
	0.417350	95.87319	23.69133	24.71	

Declarations

I, hereby declare that this PhD Dissertation is my original work and has not been presented for any degree in any other University, and all sources of material used for this dissertation has been duly acknowledged.

Name: Ofgaa Djirata Dako

Signature _____

Date _____

This PhD Dissertation is submitted for examination with my approval as an advisor.

Name: Emana Getu Degaga (Professor)

Signature _____

Date _____