2019-09-03

POPULATION DYNAMICS OF WHITE MANGO SCALE (AULACASPIS TUBERCULARIS (HEMIPTERA: DIASPIDIDAE) AND ITS NATURAL ENEMIES AT SELECTED SITES IN BAHIR DAR AREA, NORTH WEST ETHIOPIA

GETIE, MELIS

BAHIR DAR UNIVERSITY COLLEGE OF SCIENCE

DEPARTMENT OF BIOLOGY

POPULATION DYNAMICS OF WHITE MANGO SCALE (*AULACASPIS TUBERCULARIS* (HEMIPTERA: DIASPIDIDAE) AND ITS NATURAL ENEMIES AT SELECTED SITES IN BAHIR DAR AREA, NORTH WEST ETHIOPIA

A Thesis Submitted for Partial Fulfillment of the Requirements for the Degree of Master Science in Biology (Zoological Science) in Bahir Dar University

By:

GETIE MELIS YEHUALA

Advisor:

MELAKU WALE (PhD)

.

June, 2019

BAHIR DAR, ETHIOPIA

Approval sheet

This is to certify that the thesis research prepared by Getie Melis, entitled, "Population dynamics of white mango scale [*Aulacaspis tubercularis* (Hemiptera: *Diaspididae*)] and its natural enemies at selected sites in Bahir Dar area, North West Ethiopia", submitted for partial fulfillment of the requirements for the degree of Master of Science in Biology (Zoological Science) in Bahir Dar University.

Submitted by:

Name of Student	Signature	Date

Approved by:

1	Name of Advisor	Signature	Date
2	Name of Internal Examiner	Signature	Date
3	Name of External Examiner	Signature	Date
4	Name of the Department Head	Signature	Date

Acknowledgements

My first and foremost thanks go to the Almighty God for His mercies and love that sustained me throughout the period of my study. Next to God I would like to express the deepest appreciation to my advisor Dr Melaku Wale for his substantial guidance, continuous inspiration, invaluable assistance and suggestions from initial planning of the thesis to its present form.

I would like to say thank you my brothers Tadele Melis and Atnkut Melis and for my sisters Emebiet Yihun and Tsehaynesh Endaye for their encouragement and moral supports. In general, I would like to say thanks my family members and all individuals that supported me directly or indirectly for the completion of this research.

I would like to acknowledge Bahir Dar University which gives to me scholarship for my masters degree in Biology (Zoolgical science). In general, I would like to say Thank You College of science and department of Biology for providing scholarship in zoological science for fulfillment of masters degree in Bahir Dar University.

Dedication

I dedicated this research for my mother Hzbuayesh Ademe (1955 -1996) and my father Melis Yehula.

Abbreviations and Acronyms

ANOVA	Analysis of Variance
BoARD	Bureau of Agriculture and Rural Development
℃	Degree Celsius
E.C	Ethiopian Calender
F	F Ratio
FAOSTAT	Food and Agriculture Organization Statistics
FAO	Food and Agriculture Organization of the United Nations
GPS	Global Positioning System
Ha	Hectare
IFAS	Institute of Food and Agricultural Sciences
LDC	Lower Division Clerks
Mt	Metric tones
NSW	New South Wales
r	Correlation coefficient
p	Probabilty Value
SAS	Statistical Analysis System
SNNPR	South Nation Nationalities and Peoples Region
UAAIE	Upper Awash Agro Industry Enterprise
UNCTAD	United Nations Conference on Trade and Development
USA	United States of America
USDA	United States Department of Agriculture
WMS	White Mango Scale

Abstract

Data on white mango scale and its natural enemies was collected from October to May 2011 E.C (2018/19) in Bahir Dar area, north western Ethiopia. Mango trees were randomly selected and leaves sampled from upper, middle and lower portions of the tree once a month and in four directions from which number of scales and their natural enemies were counted and recorded. Significantly more male colonies (F=6.7, p=0.001), live males (F=12.4, p=0.001), live females (F=34.4, P=0.001) and number of eggs (F=25.1, p=0.001) were recorded in October than in other months. In contrast, significantly high population peaks of dead female (F=28.5, p=0.001) and leaf area coverage of white mango scale (F=7.9, p=0.001) were recorded in May. White mango scale population was low during the other months. The number of dead female was significant and positively correlated with rainfall (r=0.6, p=0.02), maximum temperature(r=0.34, p =0.05), minimum temperature (r=0.70, p=0.00) and wind (r=0.5, p=0.20). On the other hand, significant and negative correlation was observed in live female (r=0.64, p=0.001) and eggs (r=0.64, p=0.001) with humidity. Live females were significant and negatively correlated with maximum temperature(r=-0.68, p=0.00), and wind (r=-0.79, p =0.00). The rest of other white mango scales and its natural enemies did not show correlations with any of the weather variables (p>0.05). Larvae predators showed high correlations with white mango scale. The numbers of most of white mango scale were higher at Poly than at Peda and Woramit. Maximum numbers of white mango scale were recorded on upper and middle portion of trees than the lower. Direction of branches did not affect the distribution and number of white mango scales. The population dynamics of predatory larvae was high and significant at (F=8.3, p=0.001) in October at Peda than other months. In contrast, adult predators were statistically significant (F=1.7, p=0.05) in April, March and February than other months. This research addressed the population flactuations of white mange scale and its natural enemies across months and correlations with weather variables. A total of six different natural enemies of white mango scale were found. Five of them were predators and the rest were parasitoids. Five predators were *Chilocorus bipustulatus*, *Chilocorus stigma*, *Cryptolaemus montrouzieri*, *Crysoperla carnea* and *Lindorus lophanthea*. The rest were parasitic wasps (parasitoids). The infestation level of white mango scale in Bahir Dar area is very high. Any concerned bodies including government, researchers, mango growers and other bodies should participate on management of the scale insect.

Keywords: Mango (*Mangifera indica)*, Natural enemies, Population fluctuation, White mango scale

TABLE OF CONTENTS

Contents……………………………..…..………………..…………………………….Page

List of figures ....Pages

List of tables ....Pages

List of appendices...Pages

1. INTRODUCTION

1.1. Background

Mango (*Mangifera indica* L.) is a fruit crop originating in tropical Asia and distributed to other tropical and sub-tropical areas of the world, following human distribution (Dirou, 2004; Crane *et al*., 2013 and 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 taste, and high nutritional value. Mango is widely consumed as a fresh fruit and various forms of preparations. It is known for its high content of sugar, protein, fats, salts and all known vitamins (Nabil *et al*., 2012). Pertaining to its global demand, mango could play significant role in foreign currency generation, and accordingly, its production is increasing from time to time (UNCTAD, 2016).

The world production of mango is estimated at over 45.22 million tones, with a production area of 5.64 million hectares. The average yield per hectare is 8 tones (FAOSTAT, 2014). Overall, 80% of mango is produced and 90% is consumed by nine countries including India followed by China, Indonesia, Mexico, Thailand, Pakistan, Brazil, Philippines and Nigeria (Sauco, 2010). Major mango exporters in the world include Peru (10.3%), India (9.7%) and Mexico (3.2%). The largest importing regions include European communities (34%), Asia (27%), USA (20%) and Arabian Peninsula (14%) (Gerbaud, 2009). Mango is also grown in many parts of Ethiopia, mainly in the Rift Valley, in Western and South Western Ethiopia (Takele Honja, 2014). Mango production is constrained by white mango scale, *Aulacaspis tubercularis* Newstead, a pest insect common in countries such as Mexico, India, Pakistan, Italy, Ghana, Kenya, Madagascar, Mauritius, Tanzania, Uganda and Zimbabwe, among others (Salem *et al*., 2015; Hodges and Harmon, 2016).

White mango scale is one of agriculturally important insect pest belonging to order Hemiptera, which is characterized by piercing and sucking mouth part and hence, it severely injures mango trees by feeding on the plant sap through leaves, branches and fruits. Recently, it became a serious pest of mango in all mango orchards in many countries. White mango scale is a significant problem on mango in Egypt (Abo Shanab, 2012).

The year of first report of infestation of white mango scale markedly varies among African countries. White mango scale was first recorded on one cultivar of mango in South Africa in 1947 (Waafa *et al*., 2014). In Ethiopia, white mango scale was first recorded in 2010 in Western Ethiopia, East Wollega Zone of Oromia region in Green focus Ethiopia private farm at loko places in Guto Gida district (Mohammed Dawd *et al*., 2012).

A severe white scale infestation may retard mango growth in the nursery. Young trees infested by white mango scale are most vulnerable to excessive leaf loss and twig death, especially during the dry season (drought) (Daneel and Joubert, 2009 and Rehmat *et al*., 2011). Infestations on fruits cause external lesions and pink spots, which decrease their quality and make them unacceptable for export (Daneel and Joubert, 2009).

1.2. **Statement of the problem**

Mango trees were grown in different parts of north western Ethiopia. In Bahir Dar area, it was extensively grown, in individual households and orchards (such as Woramit Kebele, Bahir Dar University Main Campus and Poly campus). Unfortunately, white mango scale arrived here in 2017 and has now destroyed mango trees completely. These scales were newly introduced, an alien invasive species, which could not be stopped even by commercial pesticides due to its waxy covering. Therefore, commonly used contact insecticides can't penetrate into the body of the scale from its cuticle. In general, pesticides are less effective against scales; they rather promote them by destroying natural enemies. The reduction of the quality and quantity of marketable mango fruit due to white mango scale infestation impacts negatively on farmers through revenue losses. The population flactuation of white mango scale and its natural enemies in months and with weather variables is not studied in Bahir Dar area. This was due to recent introduction of this pest on this area. As a result the food and income generated from mango is decreasing from time to time. In addition mango growers have no information on the way of management practice of white mango scale. This pest can be managed by biological, chemical and cultural methods. But before that studying the population dynamics of white mango scale and their natural enemies across the season and in relation to weather conditions and other contributing factors is necessary. Therefore, this study elucidates the population dynamics of white mango scale and its natural enemies across the seasons, weather variables and other sources of variations in Bahir Dar area.

1.3. **Significance of the Study**

This study gives information about the seasonal variation of white mango scale and its natural enemies and about the effect of weather factors on the dynamics of white mango scale in the study area. Assessing the population dynamics and its natural enemies of white mango scale contributed for the management of this pest by determining the seasonal and geographical occurrence of the pest on mango leaves and fruits. Researchers and development experts would be benefited for the information gained. In addition, it provides feedback to mango owners and mango value chain workers, such as input suppliers, traders, processors and consumers.

1.4. **Research questions**

1. What does the population dynamics of mango scale look like across the season?
2. What is the level of infestation of white mango scale on the study area?
3. What is the abundance of white mango scale in the study area?
4. What are the natural enemies associated with white mango scale?

1.5. **Objectives**

1.5.1. **General objective**

- ❖ To determine the population dynamics and distributions of white mango scale and its natural enemies in Bahir Dar area

1.5.2. **Specific objectives**

- ➢ To determine the seasonal variation of white mango scale and their natural enemies on mango tree
- ➢ To identify natural enemies of white mango scale
- ➢ To determine the infleunce of weather factors on WMS and its natural enemies dynamics
- ➢ To determine the role of other sources of variation (such as canopy of trees, direction of branches, etc.) on WMS
- ➢ To assess cultural management practice of white mango scale

2. **REVIEW LITERATURE**

2.1. **Origin and distribution of mango**

Mango (*Mangifera indica* L.) is classified under the family Anacardiaceae, and genus Mangifera which consistsof 69 species (Sawangchote *et al*., 2009). Mango (*Mangifera indica* L.) (Anacardiaceae) is originated in Southeast Asia (Ubwa *et al.*, 2014). Genus *Mangifera* consists of 69 species in the tropical Asia. Some of these; *Mangifera caesia*, *Mangifera foetida*, *Mangifera odorata* and *Mangifera sylvatica* are among some of edible fruits found under this genus, of which *Mangifera indica* L is the only species grown commercially on large scale (Nagina, 2015).

The total production of mango among the top 100 mango producing countries in tropical and subtropical areas exceeds 34.3 million tons per annum (Sauco, 2010). Asia is the largest producer continent of mango with (26 million tones) followed by Africa (3.4 million tones), north and Central America (2.9 milliontones) and South America (2.0 million tones) in descending order (Sauco, 2010). The production of mango firstly ranked in the world is India. India produces 65% of the world's mango crop 10,800 (70% of its fruit-growing area) followed by China (3673 mt), Thailand (1800 mt), Mexico (1679 mt), Pakistan (1674 mt), Indonesia (1478 mt), Brazil (1000 mt) and Philippines (985 mt) (Evans, 2005). In 2010, Kenya was the largest producer in Africa with (553,710 mt) followed by Egypt (505,741 mt) (FAOSTAT, 2010a). Until 2005, Mexico was the leading global exporter of mango. Recently, it is overtaken by India. Total exports from Mexico amounted to 232, 643 mt as compared to 286,775 mt from India in the 2009. Other important exporting countries in the world include the Philippines, Thailand and Ecuador (FAOSTAT, 2009b).

Mango crop is also cultivated in Ethiopia. In southwest Ethiopia, mango is the first fruit crop grown. The area of mango production in different regions is about Oromia (3789.47 ha) followed by SNNPR (3375.89 ha), Benishangul Gumz (652.56 ha), Harari (367.24 ha), Amahara (246.85 ha), Gambella (180.41 ha), Tigray (118.20 ha), Dire Dawa (44.5 ha) and Somali (33.52). The total area allotted for mango is about 8,808.64 ha and the country annual production of mango from all mango grower regions is about 697,507 quintals (Edossa *et al*., 2006).

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 and 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).

Mango production and trade at all levels (local, domestic and international) generate sizeable benefits and externalities for producers, manufacturers and traders, as well as for rural societies in the producing countries. On top of this its benefits for worldwide consumers in health and dietary terms; of particular importance is the fact that mango is one of the main sources of fresh fruit in many poorer areas, adding dietary benefits to the local populations. The 35 million metric tons of mango produced world wide generate income for farmers which are highly variable from one country to another, depending on the country's levels of development and technology, wage costs, and farm structure, and the level of integration of farmers into the handling and marketing chain (FAOSTAT, 2009a).

In traditional medicine the different parts of the mango tree (fruit pulp, extracts of fruit kernel, leaves, and stem bark) are used for their health properties (Guevara *et al,* 2004). Decoction of mango kernel is used, for example, in the treatment of diarrhea, haemorrhages, and bleeding haemorrhoids for its vermifuge and astringent properties (Sairam *et al*, 2003), extracts of unripe fruit, bark and leaves are used for their antibiotic activity (Thambi *et al*, 2016), while an aqueous stem bark extract from mango is used in Cuba as a remedy for diarrhoea, fever, gastritis, and ulcers (Masibo and He, 2009).

2.3. **Mango production in Ethiopia**

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, where as very few large farms produce mango for local and export markets (Alemayehu Chala *et al*., 2014). 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 mango with about 12.61%. In Ethiopia, a total of 716447 private farmers holding 6051 hectares of cultivated mango land could produce 441582 quintals of mango in 2008/2009 production season. The yield was about 73 quintals per hectare (CSA, 2008). 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 south west 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). 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 Emana, 2010 and Yigzaw Desalegn *et al*., 2014). Due to small scale and scattered production of indigenous mango varieties which are unfit for further processing, Ethiopia can hardly compete for international mango export market (Wiersinga and Jager, 2009).

Mango trees in most parts of Ethiopia are developed from seedlings and are inferior in productivity and in fruit quality. To alleviate these problems improved varieties named Kent, Keit and Tommy Atkins were introduced from Israel in 1983 and are being commercially produced by the Upper Awash Agro Industry Enterprise (UAAIE). These varieties are widely distributed to different parts of Ethiopia by UAAIE. In 2001/2002 E.C, a private farm called Green Focus Ethiopia introduced a new mango cultivar called Alphanso from India and planted in its farm at Loko in Guto Gida district of East Wollega zone of Oromia, western Ethiopia. Many farmers are growing mango trees used as a source of income and for shading purpose. (Mohammed Dawd *et al,* 2012).

The practice of mango production in Ethiopia is traditional (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). Mango crop is distributed in the world due to its purposes. However, this crop is attacked by white mango scale.

2.4. **Some pests and pathogens on Mango production**

Mango production is constrained by a variety of pests and pathogens. Over 492 species of insects, 17 species of mites and 26 species of nematodes are reported to have been damaging mango trees (Medina and García, 2002). 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. 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). Powdery mildew and anthracnose are among disease causing pathogens that severely affect mango production in different countries. 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). There have been frequent complaints from mango growing communities in western Ethiopia regarding the damage caused by *Aulacaspis tubercularis* (Tesfaye Hailu *et al*., 2014). White mango scale is among insect pests inflicting damage to mango in Ethiopia. The threats are reported to have caused damages ranging from significant vegetative damage to total mango yield losses (Seid Hussen and Zeru Yimer, 2013 and Alemayehu Chala *et al*., 2014).

2.5. **Overview of scale insects**

Scale insects get their name because of the females secrete a waxy covering that gives them the appearance of a fish scale. They are tiny insects varying in colour. Scale insects are a diverse group of insects in the order Hemiptera, superfamily coccoidea. Scale insects can be broadly divided into two groups: armoured scales (Diapididae) and soft scales (Coccidae). Armoured scales secrete a protective cover over their bodies. The soft scales are usually half round rubbery and are usually larger, lack the protective cover, but protect themselves with waxy secretions. Scale insects are sucking insects laying their eggs underneath. The hard scale covering or in an ovisac covered with filamentous secretion, making them difficult to get killed with conventional chemicals (Mani and Krishnamoorthy, 2001).

Scales (Hemiptera: Coccoidea) are diverse group of insects consisting of eight thousand species in 30 families (Gullan and Cook, 2007). The superfamily Coccoidea includes family Diaspididae with 2369 species (32%), Pseudococcidae 2048 (28%), Coccidae 1129 (15%) and 1179 species (16%) are in all other families (Ben-Dovo *et al*., 2003). Many species of scale insects are extraordinarily invasive due to the adaptation of both the individual and the population to varying environmental conditions (Ben-Dov, 1994). However, the impact of infestation depends on the species, the host, environmental factors and natural enemies (Moiler, 1996). Scale insects have a wide host range including mango (Germain *et al*., 2010), tomato (Culik and Gullan, 2005), and cotton (Wu and Zhang, 2009 and Nagrare *et al*., 2009). Scale insects reproduce both sexually and parthenogenetically with some species have sexual diamorphism (Moharum, 2006). Life cycle and biological activities of scale insects vary in their natural environment (Vennila *et al*., 2010). White mango scale is among the scale insect that damage mango crop in different parts of the world.

2.6. **Distribution and infestation of white mango scale**

White mango scales are distributed in a wide range of climates (Ben-Dovo *et al*., 2006). It is a tropical species that may have originated in Asia (Borchsenius, 1966). It has been spread by the transport of infested plant material and it is now widespread in many mango growing countries, including the United State of America (Florida), northern part of South America (Brazil, Colombia, Jamaica, the Caribbean) the east and west coasts of Africa (Egypt, Ghana, South Africa, Kenya), Asia (India, China, Iraq, Indonesia, Japan, Pakistani), Italy and Australia (Suit, 2006).

The year of first report of infestation of white mango scale on its host markedly varied in different parts of the world. White mango scale has been firstly reported in India on mango tree (Ben-Dov *et al*., 2006). This pest was introduced in Florida and Australia with the importation of mango fruit from India (Suit, 2006). White mango scale was first recorded on one cultivar of mango in South Africa in 1947 (Waafa *et al*., 2014). In Benin, it was recorded from mango during 2005-2007 (Germain *et al*., 2010).

In Ethiopia new pest (white mango scale) inflicting damage to mango trees was reported in 2010 in an orchard of the Indian company Green Focus Ethiopia in western Ethiopia (Temesgen Fita, 2014). The pest was identified in April 2011 by Gillian Watson (California Department of agriculture, USA) as White mango scale, *Aulacaspis tubercularis* Newstead, 1906 (Hemiptera: Diaspididae) (Mohammed Dawd *et al*., 2012). The pest could have been most likely introduced to Ethiopia accidentally from abroad with mango seedlings imported by the aforementioned company. Following its initial record, infestation was reported in other mango farms in western Ethiopia, as far as 100 km away from the site of the first record within one year (Temesgen Fita, 2014). Currently, White mango scale has spread to northern and central Ethiopia, with the infested area in the north being about 1500 km away from the place of initial infestation (Gashaw Beza *et al*., 2015). The pest has been transported most likely with fruits. When an exotic pest is introduced to a new region, where there are no natural enemies, its population can increase if left untreated; to the level when it becomes invasive to the host plant (Satti, 2011).

2.7. **Biolology of white mango scale**

White mango scale, *Aulacaspis tubercularis* is one of agriculturally important insect pest belongs to order Hemiptera, Super family Coccoidea and Family Diaspididae. It is known by its accepted scientific name *Aulacaspis tubercularis* Newstead, 1906 (Varshney *et al*., 2002). 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 and Moharum, 2012). 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. Unlike the female, male mango scale possesses one pair of wings. Adult female has neither wing nor appendage for locomotion. It glues itself to the plant part by the use of its armor and remains sucking sap from the plant tissues. They occur in groups gathering around the female, while the female usually occurs singly (Tagaki, 2010 and Ben-Dov, 2012). 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 (Borchsenius, 1966). The naked adult female's body is wrinkled, with quadrate and enlarged prosoma. The body of fully-grown adult female is rosae type, as its prosoma (the fused head, prothorax and mesothorax) is swollen and wider than the postsoma (the fused metathorax and abdomen) (Tagaki, 2010).

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). 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). 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. 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 (Gyeltshen and Hodges, 2006).

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 (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).

2.8. **Damage symptoms of white mango scale**

White mango scale is a polyphagous pest which feeds on plants belonging to 18 families, even though it is a serious pest of mangos (Malumphy, 2014). White mango scale attacks four plant families such as *Palmae*, *Lauraceae*, *Rutaceae*, and *Anacardiaceae* particularly mango and cinnamon (Borchsenius, 1966).

White mango scale inserts its stylets and feeds on sap from fruit, leaf, twigs and other young parts of mango plant by sucking. According to feeding habit of this pest, it results yellowing of leaves, development of conspicuous pink blemish on mature and ripe fruit and dieback on mango plantation (El-Metwally *et al*., 2011 and 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 and Ofgaa *et al*., 2016).

2.9. **Management practices of white mango scale**

White mango scale is an insect that is covered by hard armour, which protects them from many attackers including chemicals. That is why its name is called scale insects. This pest can be managed by two ways. These are artificail method and natural methods. Artificial methods include area clearing and chemical spray. Biological management mehod means white mango scale is eaten by other natural enemies that do not damage the environment in contrast to chemicals. Biological controlling mechanisms include predators and parasitoids that are used to controll white mango scale by natural means.

2.9.1. **Cultural control method**

Cultural method is one of artifial managemen method of white mango scale. This method is easier than the other management practices; it did not ask money for management, it can be done by easily available materials including chainsaw, cutter, chopping ax and other cutting materials. 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). 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).

2.9.2. **Chemical control method**

Pesticides are chemicals or mixture of different chemicals used for the purpose of killing, repelling, mitigating or reducing pest damages (Pal and Gupta, 1994). Mealy bugs and scales are serious pests of agriculture and ornamental gardens, reducing the vigor of perennial crops by removing plant sap, secreting toxic en-zymes, or transmitting plant diseases (Khoo, 1974). In addition, these insects are important quarantine pests that impede international trade of fruits, vegetables, and ornamental plants. They are notoriously dificult to control with conventional insecticides (Schread, 1970 and Hamlen, 1977). Mealy bugs and scales are protected from sprays by their sedentary habits (making them less likely to contact pesticides), sheltered feeding locations (under leaves, at plant nodes, or on roots within the soil) and the water-repellent waxes that cover their bodies (Donahue and Brewer, 1998). Mineral oil emulsions or solutions of insecticidal soap (potassium salts of fatty acids) are commonly recommended at 1-2% active ingredient, alone or in combination with other insecticides, for control of scale insects and mealy bugs on actively growing plants (Donahue and Brewer 1998). The oil or soap helps the mixture“wet” (penetrate) the waxy exterior of these insects. Chimicals can be made artificially in laboratory and from plant extracts. 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).

2.9.3. **Natural control method**

There are many natural enemies of white mango scale. The most known natural enemies used as bio-control agents include parasitoids (parasitic wasps and flies), predators (some insects, spiders and predatory mites) and pathogens (fungi, protozoa, bacteria and virus) (Mills and Daane, 2005).

Aphytis species and *Encarsia* speceies (Aphelinidae), *Habrolepis diaspidi* (Risbec) (Encyrtidae) are parasitoids. Among *Aphytis* species and *Encarsia* species (Aphelinidae), *Aphytis mytilaspidis* (Le Baron) and *Encarsia citrina* (Craw) respectively are parasitoids (Nabil *et al*., 2012). On the other hand, the ectoparasitoid *Aphytis chionaspis* Ren (Hymenoptera: Aphelinidae) which is introduced from Thailand is known to have been established and made valuable control in South Africa (Daneel and Joubert, 2009). Parasitoid *Encarsia citrina* (Craw) is also recorded as natural enemies of white mango scale in South Africa (Labuschagne *et al*., 1995).

Predatory beetle, *Scymnus syriacus* Marseul and *Cybocephalus micans* Reitter are used as predator of white mango scale in Egypt (Nabil *et al*., 2012). The predatory thrips, *Aleurodothrips fasciapennis* (Franklin) is also a predator (Labuschagne *et al*., 1995). Moreover, *Chilocorus bipustulatus* L and *Chilocorus nigritus* (Fabricius) are predators on white mango scale in Egypt and South Africa, respectively (Labuschagne *et al*., 1995 and Abo-Shanab, 2012). Product of *Chilocorus nigritus* is also being used as biological control agent against armored scales (Entocare, 2015).

3. **MATERIALS AND METHODS**

3.1. **Description of the study area**

The study was conducted in Bahir Dar town, the capital of Amhara National Regional State of Ethiopia. The town is situated at 576 km northwest of Addis Ababa, the capital city of Ethiopia. Bahir Dar is located at 11°36" North latitudes and 37°23" East longitudes (Kassie Koyachew, 2016). The town lies at the shore of Lake Tana and Blue Nile River (Fenta Biruk, 2017). It has a total population of 221,991 of whom 108,456 are men and 113,535 are women (CSA, 2007). The land scape is flat with some small hills to the east and west. The average elevation in the town is about 1801(m.a.s.l) (Haregeweyn *et al*., 2012). According to the recently revised master plan, the town covers an area of about 16,000 hectares. The foundation of Bahir Dar dates back to the 14th century associated with the establishment of Kidane Mehretchurch near Lake Tana (Seltene Seyoum, 1988). Bahir Dar receives an average annual rainfall ranging between 850mm to 1250mm with the minimum and maximum average daily temperatures of 10℃ and 32℃, respectively (BoARD, 2006).

Study on population dynamics of white mango scale was conducted in three selected sites of Bahir Dar city; Peda, Poly and Woramit. These study areas were selected on the basis of infestations observed. This was due to mango trees found densely and near each other that result high distribution by wind and other external forces. Both these study areas received unimodal rainfall and similar daily temperature (BoARD, 2006). The extended location of this study area is 11°34"' to 11°36"N and 37°21" to 37°23"E. Trees on the study area were homogenous in size, height and vegetative.

Peda (Bahir Dar University Main Campus), which is located 11°38" North and 37°10" East (BDU, 2003). It is located south-east of the town where the former Bahir Dar Teachers College was situated. It is situated at about 1800 meters above the sea level (m.a.s.l). On this campus there were a lot of plant species and animals. Plants were a source of food for monkey and other organisms. *Carica papaya, Psidium gujava* and *Mangifera indica* were some of the plant species that were used as a source of food. Mango trees were 4 meter tall and spaced at 5 meter distance from each other, on average and its age was 4 years old. The sampled area in Peda was landed on 0.57 ha on average. Almost all of the mangos in this site belonged to indigenous variety. But mango trees on this campus were attacked by insect pest called white mango scale. This pest voraciously attacks the leaf, twig and the fruit of mango. There had been management practices such as pruning and area clearing in some extent but no application of insecticide for pest control prior to this study. Some mango leaves were dried due tothis pest infestation.

The second study area was Woramit, which was found in Shimbt kebele on the western part of Bahir Dar city and it is situated at about 1789 mean sea level. On this study area, there were agricultural activities including farm and different fruit productions. Mango (*Mangifera indica* L) and avocado (*Persea americana*) were the dominant fruits produced. Similarly *Psidium gujava* and *Carica papaya* were grown. But except mango (*Mangifera indica* L), other plant types were not attacked by white mango scale, this condition need further study. Mango trees on this study area were 6 meter tall and spaced at 5 meter distances from each other on average. The ages of trees were 5 years old and the study area was landed on 1.15 ha on average. Both lately introduced mango variety and recently introduced mango varieties were grown, but all of these mango varieties were attacked by white mango scale. Prior to the study periods, there were no management activities such as pruning and application of pesticides.

The third study area was poly (Bahir Dar Institutes of Technology) which was found on the western part of the Bahir Dar city in belay Zeleke district and on the north direction to Bahir Dar University Main Campus. Like Woramit and Peda, this study area contained different types of plants that were grown on it. Mango (*M.indica*) trees were among the plants that were grown. Mango trees were planted 2 meter distance from each other and their height was 6 meters and their ages were 5 years old on average and this site was landed on 2.22 ha on average. Some mango trees were touched each other over their canopy. Mango trees on this site were also highly attacked by white mango scale which was exotic and invasive species that introduced suddenly. Leaves and fruits were the dominant tree parts that were damaged by this pest. White mango scale was not managed by any means of management activities including leaf cutting and application of chemicals.

Weather data including rainfall, maximum and minimum temperatures, humidity, wind and sunshine of all the three sites were obtained from Bahir Dar Meteorological agency, 2019

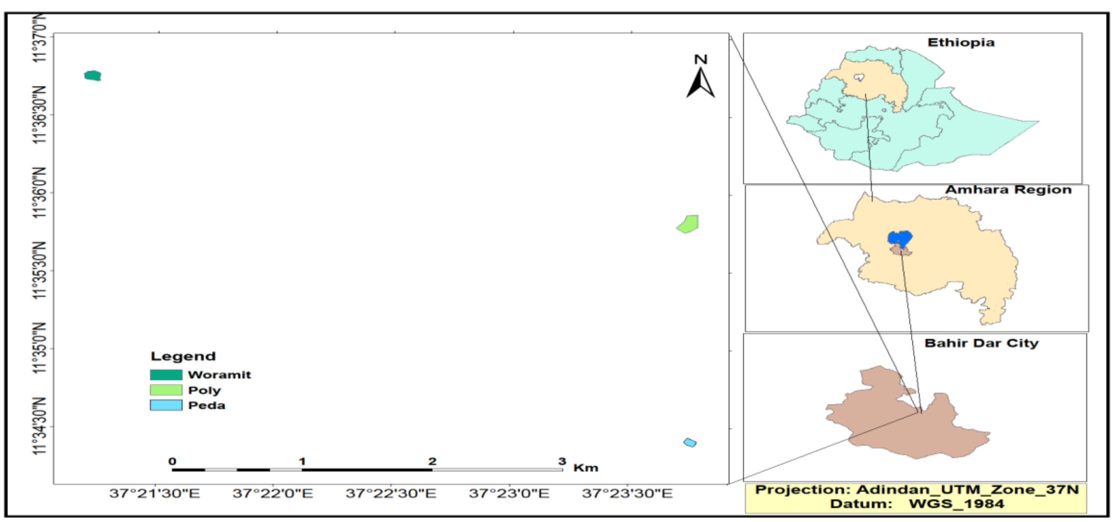


Figure 1. Map of the study sites in Bahir Dar area

3.3. **Research design and sampling procedures**

Survey of white mango scale insect, *A. tubercularis* and their natural enemies associated with mango trees, *M. indica* L was conducted during the period from October 2011 till May 2011 in Bahir Dar area, North Western Ethiopia.

A random sample of mango trees was selected in Woramit, Peda and Poly areas. Three for each site and from which 24 leaves were plucked (two at the bottom, two at the middle and two at the upper portion) at each of the four directions of the tree (East, West, North and South). From nine trees a total of 216 leaves were taken once a month. Because leaves were the dominant mango tree part that was attacked by this pest than other body parts of mango trees. Generally, a total of 1728 leaves were taken from nine trees in eight consecutive months. Once physical inspection was done, from each leaf, the number of male colonies, number of males, number of females, number of predators, parasitic wasps, number of eggs and the percent of leaf coverage was recorded. Dissecting needle was used to open up the armour of the female white mango scale for ease of counting the eggs underneath.

Assessing the population dynamics of white mango scale onsite was very difficult; samples were taken to the laboratory for better assessment. The leaves collected from each tree were placed in a plastic bag, labeled and taken to Bahir Dar University, Zoology laboratory. The leaves were observed under dissecting microscope and the number of white mango scales was recorded (Figure 2). Much of the sampled trees were inspected for the presence of predatory lady beetles and parasitoids. Many larval and adult predatory lady beetles were trapped and put in glass vials and brought to the laboratory for identification to genus and species level (Figure 2). The researcher identified natural enemies by their morphology, basically by color patterns (Lompe, 2012) and coccinelidea family identification guides was used for identification.

a)  b) 

c) 

Figure 2. Observation of white mango scale and their natural enemies under microscopes (a) natural enemies in glass vials (b and c)

The level of leaf infestation was determined by visual estimation of the proportion of leaves infested, i.e., each leaf was inspected for signs of damage and it was grouped qualitatively into no infestation, mild, high and very high infestation (depending on the scale of leaf area coverage and burned parts). Grouping of these infestation levels was supported by equation adopted from Kataria and Kumar (2012). This value was used to define severity index from which severity status at each location was determined, as follows:

$$Relative\ frequency\ of\ WMS\ occurence = \frac{number\ of\ WMS\ scale\ per\ mango\ farm}{\text{Total number of WMS recorded from survey area}} * 100$$

Relative frequency of mango scale occurrences	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

3.4. **Data collection**

Data collection of white mango scale was conducted from October, 2018 to May, 2019 for eight consecutive months in Bahir Dar area. Infested mango leaves were cut inserted and put in plastic bags and taken to the laboratory for observation. In addition to observation, mango growers were asked to get information related with white mango scale. Data including age, variety, time of occurrence, damageon nutritive value and financial income were collected (Appendix 3).

Generally 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. The interview was executed while the respondents were in their respective mango fields. Therefore, face-to face survey method was conducted. Agricultural experts were also interviewed about the management activities and on the time occurrence of white mango scale on the study area.

3.5. **Data analysis**

Data on months, weather variables and locations of white mango scale and its natural enemies were analyzed by using descriptive and inferential statistics. Descriptive statistics such as mean, standard deviation, and sum, maximum and minimum number of white mango scale infestation was summarized by using Microsoft Excel and SAS softwares. Variations in white mango scale (males, females, colonies, natural enemies of white mango scale), population between months, locations, and branch directions were analyzed using ANOVA. Correlation analysis was used to determine relationship between white mango scale numbers and weather variables and the relationships between white mango scale and its natural enemies. Tukey was used at 5% confidence interval level.

4. **RESULTS AND DISCUSSION**

4.1. **RESULTS**

4.1.1. **Seasonal population fluctuations of white mango scale in the study areas**

Population fluctuations of white mango scale varied greatly from month to month. Statistically significant number of male colonies (F=6.7, p=0.001), live males (F=12.4, p=0.001), live females (F=34.4, p=0.001) and number of eggs (F=25.1, p=0.001) were recorded in October than the other months (Table 1). The number of eggs were also sinificant (F=7.9, p=0.001) in November. The numbers of male colonies were very high as compared with live female during October. After that the numbers of those white mango scales steadily declined from October to May (Table 1).

Table 1. Seasonal population flactuations of WMS

Month	Colony	Live male	Live female	Dead female	Eggs	Leaf area coverage
October	20.20 ^{a}	19.18^{a}	14.32 ^{a}	59.04 ^{bc}	18.31 ^{a}	35.61 ^{c}
November	14.76 ^{b}	4.21b^{c}	12.16 ^{ab}	33.22 ^{e}	16.54 ^{a}	42.63 ^{ab}
December	15.35 ^{b}	3.26 ^{bc}	10.56 ^{b}	30.32 ^{e}	6.66 ^{b}	42.32 ^{ab}
January	14.78 ^{b}	3.89 ^{bc}	5.75 ^{cd}	35.06 ^{de}	4.21 ^{bcd}	37.79 ^{bc}
February	15.69 ^{b}	9.19 ^{b}	7.22 ^{c}	36.02 ^{de}	5.05 ^{bc}	39.9 ^{bc}
March	16.03 ^{b}	4.16 ^{bc}	2.97 ^{de}	47.16 ^{cd}	1.78 ^{cd}	37.79 ^{bc}
April	14.55 ^{b}	0.43 ^{c}	0.19 ^{e}	59.88 ^{b}	0.13 ^{d}	37.69 ^{bc}
May	15.72 ^{b}	0.00 ^{c}	0.30 ^{e}	90.64 ^{a}	0.12 ^{d}	45.46 ^{a}

Note: Means followed by the same letter (s) within a column are not significantly different (p<0.05).

On the other hand, statistically significant number of dead females (F=28.5, p=0.001) and leaf area coverage of white mango scale (F=7.9, p=0.001) was recorded in May. Maximum number of dead females recorded was 90.64 (Table 1). Most of other months did not show significance differences on it.

4.1.2. **Correlations of weather variables on population dynamics of white mango scale and its natural enemies**

Rainfall and humidity were high in October and May (Figure 3). According to the results of bivariate correlation, the number of dead female white mango scale did not show correlations with humidity (r=0.026, p=0.903) and sunshine intensity (r=0.326, p=0.12). The rest of other weather variables showed significant differences and positive correlation with dead females (Appendix 2). The number of live females and eggs were positively correlated with humidity and negatively correlated with maximum temperature and wind. Eggs also showed negative correlation with sunshine. Rainfall and minimum temperature were not significant and correlated with live females and eggs (Appendix 2). The number of male colonies, predatory larvae, adult predators and leaf area coverage of white mango scale did not show significant correlations with most of other weather variables. But number of live males were negatively correlated with wind (r= -0.40, p = 0.05) (Appendix 2).

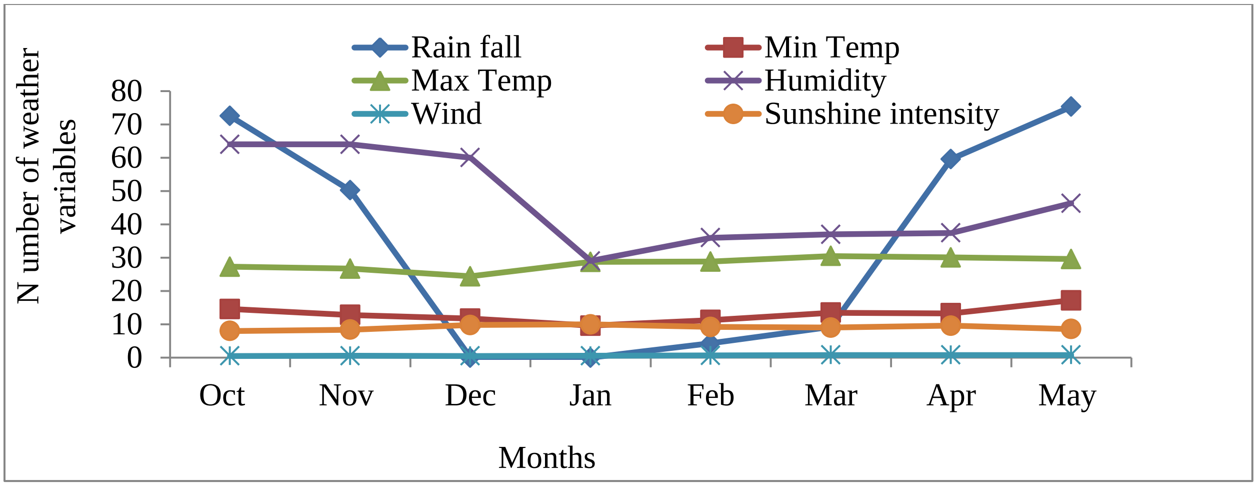


Figure 3. Weather variables in Bahir Dar area

Except the number of leaf area coverage of white mango scale (r=0.67, p=0.755), the number of predatory larvae were positively correlated with most of white mango scales. Very high correlation was found with male colonies and live males (Table 2). Leaf area coverage of WMS was significant and positively correlated with adult predators. But the numbers of other WMS were not significant with adult predators. Parasitic wasps were not significant with any of WMS (Table 2).

Table 2. Correlations between white mango scale and its natural enemies

WMS	Correlations	Predatory larvae	Adult predators	Parasitic wasp
Male colonies	r	0.633**	0.044	-0.011
Live males	r	0.615**	0.003	0.032
Live females	r	0.577*	-0.037	0.005
Dead females	r	0.446*	0.063	0.007
Eggs	r	0.538*	-0.029	0.033
Leaf area coverage of WMS	r	0.067	0.072*	-0.005

Note: **. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

4.1.3. **Population fluctuations of white mango scale at tree location, canopy, branch direction**

Population fluctuations of male colonies, live males, and leaf area coverage of white mango scale were significantly different among the study areas. Numbers of male colonies and leaf area coverage were significantly higher (F=6.7, p=0.001) at Poly (Table 3). In Poly mango trees were found near each other and densely than Peda and Woramit. The number of live males was significant in Woramit. But the rest other mango scales were not significant at all sites (Table 3).

The number white mango scales were significantly higher at the upper and middle portion of the trees than the lower (Table 3). The number of dead females was maximum as compared with live males on middle canopy and its number was 53.28 (Table 3). The population fluctuation of white mango scales was not significantly different in four branch directions (Table 3).

Statistically significant number of predatory larvae was recorded in October (F=8.3, p=0.0001) which was 1.2. After this month its number was steadily declined and insignificant (Table 4).

The population fluctuation of adult predators was significant in April (Table 4). Maximum number recorded was 0.09. Its number was not significant in the other months (Table 4)

Table 3. Abundance of WMS numbers across locations, tree canopies, and branch directions

Variable	Location			Canopy			Branch direction^{NS}			
	Poly	Peda	Woramit	Upper	Middle	Lower	East	West	North	South
Colony	17.21 ^{a}	15.85 ^{ab}	14.59 ^{b}	16.7 ^{a}	16.84 ^{a}	14.11 ^{b}	15.03	16.5	16.74	15.25
Live male	2.17 ^{b}	3.61 ^{b}	10.83 ^{a}	7.49 ^{a}	6.51 ^{a}	2.61 ^{b}	4.56	5.44	5.6	5.56
Live female	6.11 ^{a}	6.72 ^{a}	7.21 ^{a}	7.39 ^{a}	7.37 ^{a}	5.30 ^{b}	5.89	6.95	6.88	7.01
Dead female	50.89 ^{a}	49.77 ^{a}	46.01 ^{a}	51.22 ^{a}	53.28 ^{a}	42.25 ^{b}	46.14	51	50.55	47.98
Eggs	5.75^{a}	7.81^{a}	6.24^{a}	7.44 ^{a}	7.53 ^{a}	4.82 ^{b}	5.5	6.89	7.57	6.43
Leaf coverage	43.50 ^{a}	38.66 ^{b}	37.54 ^{b}	39.97 ^{ab}	41.74 ^{a}	37.99 ^{b}	39.5	39.9	40.59	39.6

Means followed by the same letter(s) within a row are not significantly different from each other ($p<0.05$)
Where NS stands for “not significant”

Table 4. Seasonal population fluctuations of natural enemies of white mango scale

Month	Predatory larvae	Adult predators
October	1.19 [a]	0.00 [b]
November	0.14 [b]	0.00 [b]
December	0.13 [b]	0.00 [b]
January	0.13 [b]	0.02 [ab]
February	0.13 [b]	0.04 [ab]
March	0.16 [b]	0.04 [ab]
April	0.13 [b]	0.09 [a]
May	0.10 [b]	0.02 [ab]

Note: Means followed by the similar letter(s) within column are not significantly different from each other ($p<0.05$)

Significantly high number of predatory larvae were found at Peda ($F=8.3$, $p=0.001$) (Table 5). On the other sites its number was not statistically significant. Tree canopies and branch directions did not show significant differences (Table 5). Similarly, the number of adult predators were not significant ($p>0.05$) in locations, tree canopies and branch directions (Table 5).

Table 5. Population fluctuations of natural enemies of WMS numbers across locations, tree canopy, and branch directions

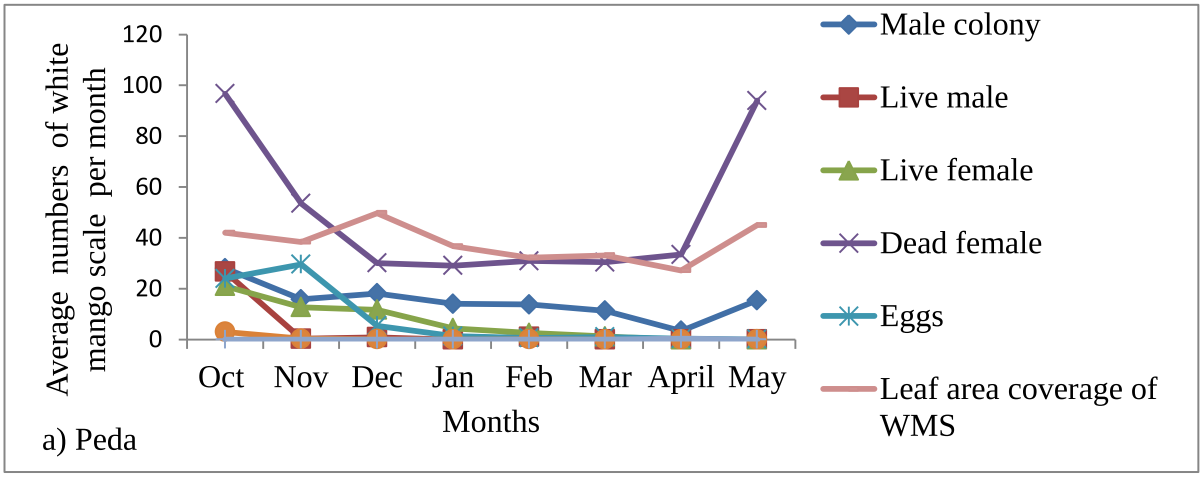
Natural enemies	Location			Canopy			Branch direction			
	Poly	Peda	Woramit	Upper	Middle	Lower	East	West	North	South
P. larvae□	0.16 [b]	0.44 [a]	0.18 [b]	0.32 [a]	0.32 [a]	0.15 [a]	0.21 [a]	0.36 [a]	0.22 [a]	0.26 [a]
A. predators□ □	0.02 [a]	0.02 [a]	0.05 [a]	0.02 [a]	0.03 [a]	0.03 [a]	0.04 [a]	0.04 [a]	0.02 [a]	0.02 [a]

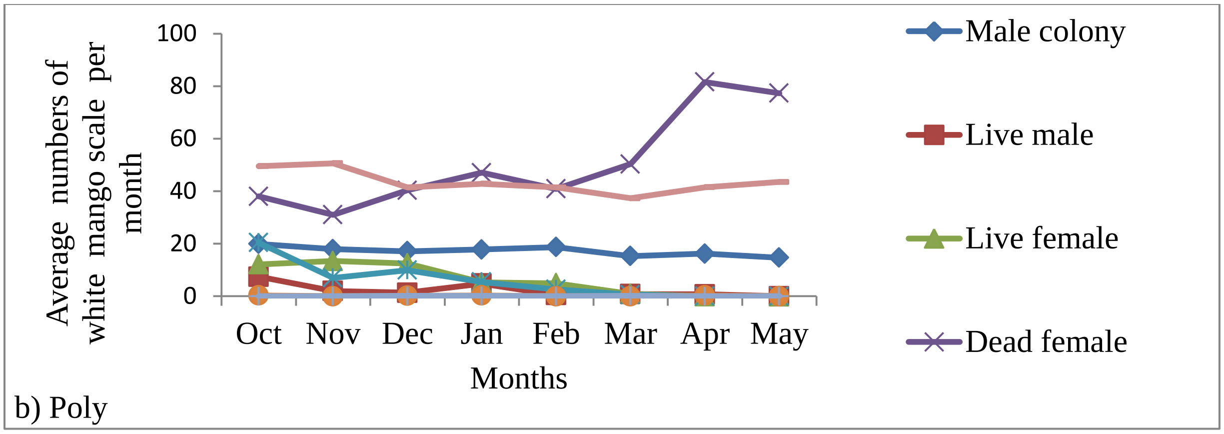
Means followed by the same letter(s) within a rows are not significantly different from each other ($p<0.05$).
□P. larvae stand for "Predatory larvae";
□ □A.predators stands for "Adult predators"

4.1.5. **Abundances of white mango scale population in Bahir Dar area**

In Bahir Dar area, the number of dead females was higher as compared with the number of live males in eight consecutive months. Its number was 37,480 times greater than live male from white mango scale and 42260 times greater than parasitic wasps. On the other hand, medium numbers of male colonies were recorded on this area (Appendix 1).

The average numbers of white mango scale varied across sites and months. In Peda, Poly and Woramit, the average numbers of dead females and leaf area coverage of mango scale were relatively higher than the other forms of white mango scales. At both sites, maximum average numbers of dead females and leaf area coverage were recorded in October and May where as minimum numbers were recorded in between November and April. The numbers of live male, live females, male colonies and eggs showed little difference between months and most of its numbers were less than 20. But in Woramit, the numbers of live males and eggs increased a little bit in February. At the beginning of the study periods, most of white mango scales showed little increament. After that its number declined steadily across the study periods (Figure 4).





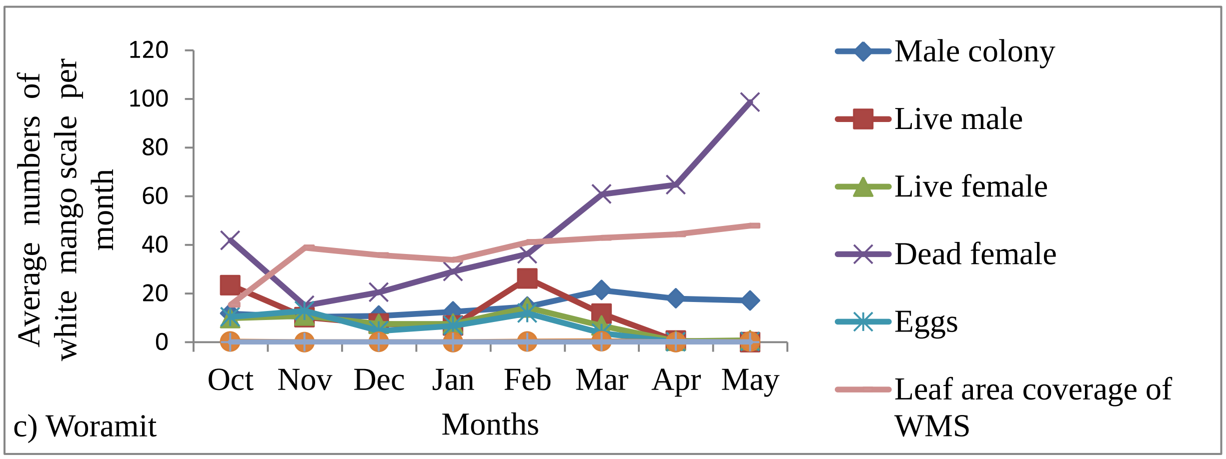


Figure 4. Population dynamics of white mango scale across the season in (a) Peda, (b) Poly and (c) Woramit

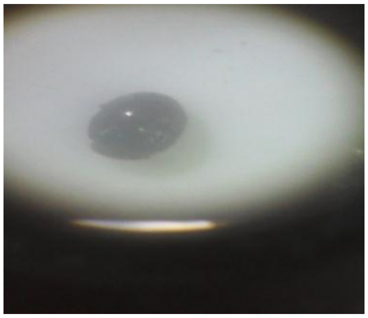
4.1.6. **Seasonal population dynamics of natural enemies of white mango scale**

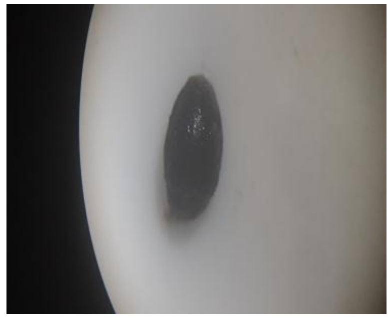
White mango scale was attacked by different natural enemies in Bahir Dar area. A total of 248 predators and five parasitoids were recorded (Figure 5). From 248 predators, 226 were predatory larvae and 22 adult predators. The parasitoids found were parasitic wasps and its number was five (Table 6). All of these natural enmies were fed on white mango scale. These natural enemies were identified by their external morphology. Basically by color patterns and shapes (Lompe, 2012).

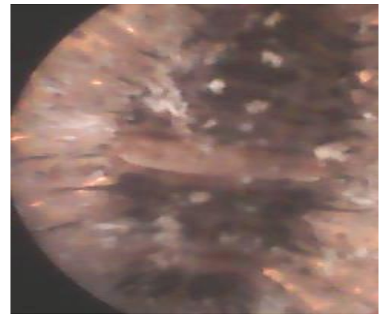
Table 6. List of identified natural enemies of white mango scale in Bahir Dar area

Scientific name	Common name	No recorded	Developmental stage	Family	Order
Lindorus lophanthea	Scale insect eater	179	Larvae	Coccinellidae	Coleoptera
Chrysoperla carnea Stephens	Green lacewing	9	Larvae	Crsopidae	Neuroptera
Chilocorus bipustulatus L	Heather lady beetle	38	Larvae	Coccinellidae	Coleoptera
Chilocorus stigma Say	Twice-stabbed ladybeetle	17	Adult	Coccinellidae	Coleoptera
Cryptolaemus montrouzieri Mulsant	Orange headed lady beetle	5	Adult	Coccinellidae	Coleoptera
Aphtis species	Parasitic wasps	5	Adult	Aphelinidae	Hymnoptera

Most of these natural enemies were feeding on both male and female white mango scales. When feeding, the larvae easily destroyed the coat of the male mango scale and reached the insect underneath, while they forcefully pushed their heads inward and partly opened up the cover of the female, captured and chewed it. The feeding mechanism of these natural enemies was observed on microscope during observation and there are many litratures that show these insects are natural enemies of white mango scale.







a) *Cryptolaemus montrouzieri* b) *Chilocorus stigma* c) *Chilocorus bipustulatus*

d) *Chrysoperla carnea* e) *Lindorus lophanthea*

Figure 5. Types of natural enemies of WMS identified in Bahir Dar area (a, b, c, d and e)

Like that of white mango scales, the average number of natural enemies varied from study site to study site. High numbers of *Lindorus lophanthea* and *C. bipustulatus* were found at Peda than Poly (Figure 6) but *Cryptolaemus montrouzieri* was not found. Similarly parasitic wasps were not recorded in Woramit. More number of parasitic wasps was recorded in Poly. The rest other natural enemies were found in both sites and then numbers were below 15 (Figure 6).

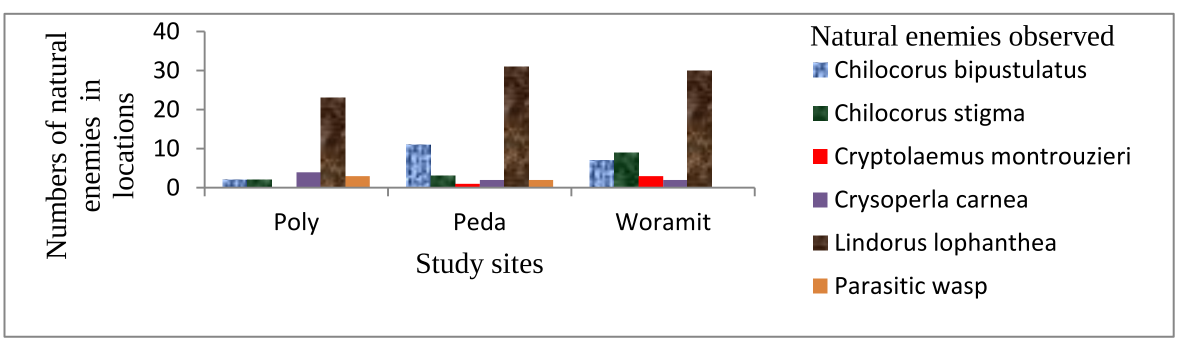


Figure 6. Population distribution of natural enemies of white mango scale across the locations

The average number of *Lindorus lophanthea* was high as compared with *Chrysoperla carnea* in October. Similarly, the average number of *C.bipustulatus* was high in October. The average numbers of the rest of other natural enemies were less than five from October to May. Parasitic wasps were recorded in November and December. The time of occurences of these natural enmies were not similar in all the months. As a result, all of them were not found in each month (Figure 7).

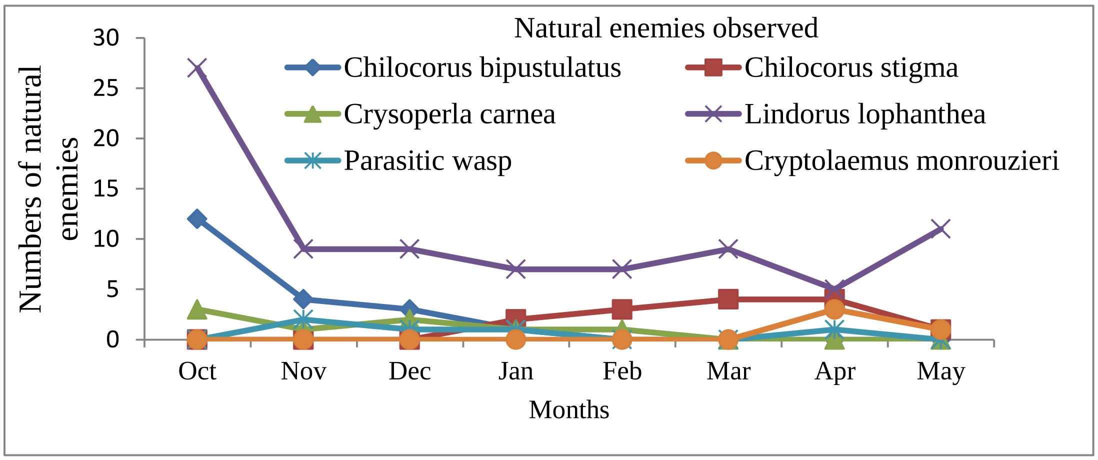


Figure 7. Population dynamics of natural enemies of white mango scale across the season in Bahir Dar area

4.1.7. **Severity status of white mango scale**

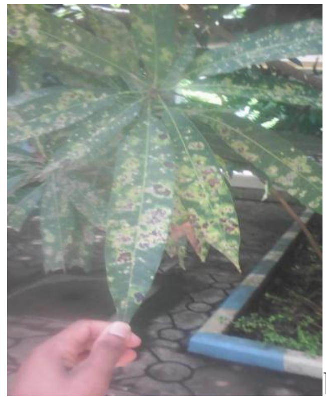
The severity status of white mango scale in Bahir Dar area was very high. The level of infestation was calculated using the formula adopted by Kataria and Kumar (2012). The formula stated that if the relative of occurences of white mango scale is greater than 11, its level of infestation is very high and if it is lessthan 11. Then in Woramit, Peda and Poly the levels of infestation of white mango scale was very high because the relative frequency of mango scale was greater than 11 (Table 6). There were no high, mild and no infestations levels observed in Bahir Dar areas, the level of infestation of all sites were very high.

Table 7. Level of severity status of white mango scale in study areas

Location	Relative frequency of mango scale occurrences	Severity index	Severity status
Woramit	35	3	Very high
Peda	33	3	Very high
Poly	32.5	3	Very high

The damage infestation symptoms of white mango scale were clearly observed on mango trees. First, black spots appeared on the leaf and completely covered by the scale, particularly the upper surface. Then after some times later leaves were dry. The barks of mango trees were also completely covered by the scale (Figure 8).

a)



b)

c)

Figure 8. Status of infestations of white mango scale on leaves (a and b), twigs (c) in Bahir Dar area

(Photo by the researcher, 2019)

4.1.8. **Survey of indigenous knowledge on white mango scale and its management**

4.1.8.1. **Demographiccharacterstics of respondents**

The age and education levels of respondents were not similar on study sites. From a total of nine participants, 66.6% were above 30 years old whereas 33.4% were below 30 years. 55.6% were male and 45.4% were female. For education level, 55.6% of them were 9-12 grades, 22.2% were 1-8 grades and 22.2% did not attend schooling. Most mango trees grown were late introduced varieties while some were recently introduced variety from abroad. Both varieties of trees were attacked by white mango scale and all mango growers did not know it. But they understood that the trees were damaged, which they assumed was fungal attack. According to them, in Bahir Dar area, the problem started for the first time in 2018, but as the agricultural expert in Woramit said that it first appeared in 2017. The incomes they used to get sharply declined ever since and did not know anything do to fight back. In Peda, some small trees were pruned (Figure 8). Many of them were ready to prune the trees in the future and they did not practice any chemical spray treatment against the pest. Most of respondants believed that pruning of infested mango trees would decrease the infestation of white mango scale.

a)  b) 

Figure 9. Cultural control of white mango scale in Peda (Bahir Dar University Main Campus) (a and b)

(Photo by researcher in Peda, 2019)

4.2. **DISCUSSION**

The number of white mango scale varied from month to month. Most white mango scales were high in October. These include number of male colonies, live males, live females and eggs. This idea is not in agreement with Ofgaa Djirata (2017) who reported that the maximum population peaks were high in April and May. In another case, the number of dead females and leaf area coverage of white mango scale were high in May which agrees with (Ofgaa Djirata, 2017).

The number of live females and eggs showed positive relationships with humidity and negatively correlated with maximum temperature and wind. Rainfall and minimum temperature did not correlate with live female and eggs. This finding is not in agreement with the report of El-Metwally *et al.* (2011) who concluded that population dynamics of white mango scale was affected by temperature and rainfall. On the other hand, the number of dead females was positively correlated with rainfall, maximum and minimum temperatures and with wind. The positive correlation of dead females with rainfall and temperature is in agreement with the work of (El-Metwally *et al*., 2011).

Incase of maximum and minimum temperature, the number of dead females agrees with the findings of Miller and Davidson (2005) who reported that white mango scale can produce five to six generations per year, at a maximum temperature of 26°C and minimum of 13°C. The number of most white mango scales did not correlate with any of weather variables. This idea disagree with the findings of Abo-Shanab (2012) who reported that white mango scale population was affected by weather variables such as rainfall, temperature and humidity but which agrees with Ben-Dov (1994) who concluded that many species of scale insects are extra ordinarily invasive due to the adaptation of both the individual and the population to varying environmental conditions. In some cases, live males were negatively correlated with wind. This finding disagrees with the report of Greathead (1990 and 1997) who reported that many of white mango scale were dispersed by wind.

Maximum numbers of white mango scale were recorded in Poly than other sites. This was might be due to branches of neighbouring mango trees were interlocked in this site than that of the rest. Such shady environment might provide more suitable over wintering and prefered habitat for the scales.

The population dynamics of white mango scale were high at upper portion of trees than lower canopies. 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. Similar findings of Beardsley and Gonzalez (1975) as cited from Priesner (1931) reported that most white mango scales preferred middle and upper portion of the tree than the lower in positive responses to light.

In addition to abiotic factors the population dynamics of white mango scale were influenced by biotic factors. Predatory larvae were positively correlated with the number of male colonies, live males, live females and numbers of eggs. The reason for increament of white mango was due to presence of imbalance between white mango scale and its natural enemies. The numbers of predatory larvae were very small as compared with its host. This is in agreement with the work of Ofgaa Djirata *et al.* (2017) who reported that the numbers of white mango scale was positively correlated with its natural enemies and natural enemies did not decrease the number of white mango scale due to imbalance between numbers each other.

There were a lot of natural enemies that fed on scale insects. In Ethiopia, there were some studies related to white mango population dynamics but due to being introduced recently (Mohammad Dawd *et al*., 2012; Temesgen Fita, 2014; Tesfaye Hailu *et al*., 2014 and Gashaw Beza *et al*. 2015), there was no report of natural enemies and its population dynamics in Ethiopia. But in Bahir Dar area a total of six different natural enemies of white mango scale were found. Five of them were predators and the rest were parasitoid. Adult *Chilocorus stigma* and *Chilocorus bipustulatus* larva were the two *Chilocorus* spescies, adult *Cryptolaemus montrouzieri; Chrysoperla carnea* larva and many *Lindorus lophanthea* larva were recorded. All of these natural enemies fed white mango scale. This finding agree with Mendel *et al*. (1985), Erkiling and Uygun(1995) and Lambdin (1995) depicted that various *Chilocorus* species preyed on armoured scale insects such as *Chilocorus bipustulatus* and *Chilocorus nigritus.* The occurrence of *Lindorus lophanthea* larvae also agreed with Ofgaa Djirata (2017) who described that some *Lindorus lophanthea* larvae was feeding white mango scale in Bako and Arjo orchards in Oromia region. Therefore, identifying of natural enemies of white mango scale was probably for the first time in Ethiopia.

The population dynamics of natural enemies varied in month. Maximum average numbers of predatory larvae were recorded in October than the rest. This is not in agreement with Ofgaa Djirata *et al*. (2017) who depicted that maximum numbers of *Chilocorus* species were recorded in April and May.

The infestation level of white mango scale was very high in Bahir Dar area. This idea agrees with Ofgaa Djirata, (2017) who reported that very high infestation level of white mango scale was recorded in Oromia region.

Most mango growers did not do anything to stop white mango scale infestation what so ever, which contributed for high severity. Only in Peda some mango trees were cut to control scale insects. This idea is in agreement with Bautista-Rosales *et al.* (2013) who revealed that mango tree pruning significantly decreased the number of female white mango scale. Similarly Saeed *et al*. (2012) who reported that the presence of infected trees and improper management practices would ultimately lead to the collapse of the whole mango orchard. As a result, the food and income generated from mango fruit was decreased. But the level of damage on food and money was not well known in study sites.

In Bahir Dar area, white mango scale was introduced in 2017/18. But in Ethiopia its introduction was as far as these years. This finding disagrees with the findings of Mohammed Dawd *et al*. (2012) who reported that white mango scale was introduced in Ethiopa in 2010.

5. **CONCLUSION**

The present study addressed that the population dynamics of white mango scale and its natural enemies showed great variations in months. Maximum population dynamics of most white mango scale and its naural enemies were recorded in October than in other months. Parasitic wasps were recorded in November and December. But the number of adult predators, number of dead females and leaf area coverage of white mango scale was high in April. In addition, the numbers of these scales and its natural enemies were high in Poly than Peda and Woramit. This condition might be happened due to location differences and distances between trees. But the numbers of male colony and leaf area coverage of white mango scale was high in Peda and the number of live male white mango scale was high in Woramit. This condition might be happened due location and distance differences between trees.

In the present research, six different types of natural enemies were found. Two of them were belonged to *Chilocorus* species (*Chilocorus bipustulatus* and *Chilocorus stigma)*. The rest of them were *Lindorus lophanthea*, *Cryptolaemus montrouzieri*, *Chrysoperla carnea* and parasitic wasps. This finding was probably the first time in Ethiopia that provides directions for management of white mango scale biologically if the number of natural enemies and white mango scale is balanced in number. But due less numbers natural enemies did not decrease the numbers of white mango scale population

The population dynamics of white mango scale and its natural enemies were influenced by weather variables. Temperature, rainfall, wind, humidity and sunshine intensity influenced the dynamics of white mango scale positively and negatively. The numbers of live male and live female white mango scales were negatively influenced by wind. Due to this phenomenon, the numbers of live white mango scales increased as wind decreased and vice versa.

The rest other weather variables did not influence the number of live white mango scales. On the other hand, the number of dead females was influenced positively by rainfall, maximum and minimum temperature and wind. This indicates that, as these weather variables increased, the number of dead females increased and vice versa. Generally, most of white mango scale and its natural enemies were not influenced by weather variables. The numbers of natural enemies were positively correlated with white mango scales. This was happened due to imbalace between the number of white mango scale and its natural enemies. The numbers of natural enemies were smaller than white mango scale that is why the number of white mango scales was not decreased by natural enemies. But, if the number of white mango scale and its natural enemies were balanced in number, natural enemies can decrease the number of white mango scale.

The number of mango scales was higher at upper and middle portion of the tree than lower. Most leaves on lower portion were old and due to presence of shadow, scale insects prefere middle and upper potion of the tree for food and positive responses of light. Tree directions did not affect the number of white mango scale and its natural enemies.

The infestation level of white mango scale in Bahir Dar area was very high. Most mango leaves were completely covered and burned as a result of infestation. As a result of high infestation, some mango trees were dried. White mango scale introduced in Bahir Dar area in 2017/18. Most mango growers have no more information on white mango scale and its management.

6. RECOMMENDATIONS

- ❖ Any concerned bodies including government, researchers, mango growers and any other bodies should participate in management of white mango scale.
- ❖ Mango growers on the study site have no more information about white mango scale management. So, the agricultural experts should be creating awareness on its management.
- ❖ The population fluctuation of white mango scale and its natural enemies were not studied in year round. So, further research is expected from concerned body to know its generation per year and to implment management strategies.
- ❖ In the present study identification of natural enemies was difficult. Future efforts should target sending specimens abroad for confirmation (which may require foreign currency).
- ❖ The idenfication of many natural enemies (predators as well as parasioids) are good indicators of biological control agents of white mango scale if the natural enemies are multilpied in laboratory and its numbers equalize with white mango scale.
- ❖ Environmentally sound pest control options such as white oil may be used in white mango scale management

7. **REFERENCES**

Abo-Shanab, A.S.H. (2012). Suppression of white mango scale, *Aulacaspis tubercularis* (Hemiptera: Diaspididae) on mango trees in El-Beheira Governorate, Egypt. *Egyptian Acad. J. Biol. Sci* **5(3**):43-50.

Alemayehu Chala, Muluken Getahun, Samuel Alemayehu and Mekuria Tadesse (2014). Survey of mango anthracnose in southern Ethiopia and in-vitro screening of some essential oils against *Colletotrichum gloeosporioides*. *International Journal of Fruit Science* **14**:157-173.

Ayantu Tucho, Fikre Lamessa and Gezahegn Berecha (2014). Distribution and occurrence of mango anthracnose, (*Colletotrichum gloiesporioides* Penz and Sacc) in humid agro-ecology of south west Ethiopia. *Plant Pathology Journal* **13**(4): 268-277.

Ben-Dov, Y. (1994). **Asystematic catalogue of the mealy bugs of the world**. Intercept Limited, Andover, UK pp. 686.

Ben Dov, Y., and V. German. (2003). **A systematic catalogue of the Diaspididae (armoured scale insects) of the world, subfamilies Aspidiotinae, Comstockiellinae and Odonaspidinae**. Intercept, Andover, United Kingdom.

Ben-Dov Y., Miller, DR. and Gibson, GAP. (2006). Scale Net. Available online at: http://www. sel.barc.usda.gov/scalenet/scalenet.htm (accessed April 2007).

Ben-Dov, Y. (2012). The scale insects (Hemiptera: Coccoidea) of Israel-checklist, host plants, Zoogeographical considerations and annotations on species. *Israel Journal of Entomology* **41**:21-48.

Bezabih Emana (2010). **Market Assessment and Value Chain Analysis in Benishangul Gumuz Regional State, Ethiopia**. SID Consult Support Integrated Development, Addis Ababa.pp 95.

Bahir Dar University (BDU). (2003). Survey of woody flora and fauna of Bahir Dar Univerisity main campus: a showcase for the need of conservation. http://www.bdu.telecom.net.et. Accessed August 2005.

Bautista-Rosales, P.U., Ragazzo-Sánchez, J.A., Calderón-Santoyo, M., Cortéz Mondaca, E. and Servín-Villegas, R. (2013). *Aulacaspis tubercularis* Newstead in mango orchards of Nayarit, Mexico, and relationship with environmental and agronomic factors. *South western Entomologist* **38**(2):221-230.

Beardsley Jr, J.W. and Gonzalez, H. (1975). The biology and ecology of armoured scales. *Annual Review of Entomology* **20**:47-73

Bureau of Agriculture and Rural Development (BoARD) (2006). **Amhara region statistics section**, Bahir Dar, Ethiopia.

Borchsenius, N. S. (1966). **A catalogue of the armoured scale insects (Diaspidoidea) of the World**. In Russian.) Nauka, Moscow, Leningrad, Russia. 449 pp.

Buss, E.A. and Turner, J.C. (2006). **Scale Insects and Mealy bugs on Ornamental Plants**. University of Florida, Arrington.6pp.

Crane, J.H, Balerdi, C.F. and Maguire, I. (2013). **Mango growing in the Florida home landscape**. University of Florida, IFAS Extension, http://www.edis.ifas.ufl.edu (accessed: 12January 2015).

Central Statistical Agency, Federal Democratic Republic of Ethiopia (2008). **Agricultural Sample Survey 2008/2009: Report on Area and Production of Crops, (Private Peasant Holdings Meher Season), Volume I.** Statistical Bulletin, Addis Ababa. 128pp.

CSA (2007). Population and housing census report. Statistical Summary Report at National Level. Addis Ababa: Central Statistical Agency

Culik, M. P. and Gullan, P. J (2005). A new pest of tomato and other records of mealy bugs (Hemiptera: *Pseudococcidae*) from Espirito Santo, Brazil. *Zootaxa* **964**: 1–8.

Daneel, M.S., and Joubert, P. H. (2009). Biological control of the mango scale *Aulacaspis tubercularis* Newstead (Coccidea: Diaspididae) by a parasitoid *Aphytis chionaspis* Ren (Hymenoptera: Aphelinidae*). Acta Hort* **820**: 567-574.

Donahue, J. D., and M. J. Brewer. (1998). Scales and mealy-bugs. Univ. Wyom. Coop. Ext. Serv. B-1050.1.

Dirou, J.F. (2004). **Mango Growing**. NSW Centre for Tropical Horticulture, Alstonville.6pp.

Edossa Etisa, Lemma Ayele and Dereje Tadesse (2006). Review on the status of some tropical fruits in Ethiopia. **Proceeding of the inaugural and first Ethiopian Horticultural Society** conference. Addis Ababa, Ethiopia. Pp39-44.

El-Metwally, M. M., Moussa, S.F.M. and Ghanim, N.M. (2011). Studies on the population fluctuations and distribution of the white mango scale insect, *Aulacaspis tubercularis* Newstead within the canopy of the mango trees in eastern of Delta region at the north of Egypt. *Egyptian Academic Journal of Biological Sciences* **4**:123-130.

Entocare, C. (2015). Natural enemies armoured scales. Chilocorus, http://www.entocare. nl/english/products_armoured_scales.htm#Chilocorus (accessed 20 February 2017).

ErkiligL. and Uygun N. (1995). Distribution, population fluctuations and natural enemies of the white peach scale, *Pseudaulacaspis pentagona* (*Targioni Tozzetti*) (Homoptera: Diaspididae) in the East Mediterranean region of Turkey. *Israel Journal of Entomology* **29**:191-198.

Evans. (2005). **Recent Trends in World and U.S. Mango Production, Trade, and Consumption.** University of Florida, United state of America. Pp 4.

FAOSTAT. (2009a). Rural Income Generating Activities database (available at www.fao.org/es/ESA/riga/english/index_en.htm).

FAOSTAT (Food and Agriculture Organization statistics) (2014). Agricultural database. /http://faostat.fao.org./ (accessed on February 25, 2017).

FAOSTAT. (2010a). **World mango production**. www.novagrim.com.pages/2000-2001.Mango-statistics-EN.aspx.

FAOSTAT. (2009b). **World mango exports**. www. novagrim. com.pages/2000-2001.Mango-statistics-EN.aspx.

Fenta Biruk (2017). Waste management in the case of Bahir Dar City near Lake Tana shore in North western Ethiopia: A review. *African Journal of Environmental Science and Technology* **11**: 393-412.

Gashaw Beza, Abiy Fekadu and Birhanu Sisay (2015). Appearance and chemical control of white mango scale (*Aulacaspis tubercularis*) in Central Rift Valley. *Science, Technology and Arts Research Journal* **4**:59-63.

Gerbaud, P. (2009). The European mango market: a supply puzzle. *Fruitrop* **164**:35-37

Germain, J. F., Vayssieres J. F and Matile-Ferrero G. (2010). Preliminary inventory of scale insects on mango trees in Benin. *Entomologia Hellenica* **19**:124–131.

Gyeltshen, J. and Hodges, A.C. (2006). **Field Key to Identification of Scale Insects on Holly (Ilex spp**.).IFAS Extension, University of Florida.7pp.

Greathead, D.J. (1990). **Crawler behaviour and dispersal**, In: D. Rosen [ed.], **Armored scale insects, their biology, natural enemies and control**. World Crop Pests. Elsevie Scientific Publishers, Amsterdam. pp 305-308.

Greathead, D.J. (1997). **Ecology: Crawler behaviour and dispersal**, In: Ben- Dov Y. and Hodgson, C.J. [eds.], Soft **scale insects: their biology, natural enemies and control**. Elsevier Scientific Publishers, Amsterdam. pp. 339-342

Griesbach, J. (2003). **Mango production in Kenya. World Agroforestry Centre**, Nairobi.122pp.

Gullan, P. J. and Cook L. G. (2007). Phylogeny and higher classification of the scale insects (Hemiptera: Sternorrhyncha: Coccoidea). *Zootaxa* **1168**: 413– 425.

Guevara Garcia, M.; Gonzalez Laime, S.; Alvarez Leon, A.; Riano Montalvo, A.; Garrido, G.G.; Nunez Selles, A.J. (2004). Ethno medical uses of *Mangifera indica* L stem bark extraction Cuba (spanish). *Rev. Cuba Plant Med* **9**:27–32.

Ha, S., Mahmoud, Y. and Ebadah, I. (2015). Seasonal abundance, number of generations and associated injuries of the white mango scale, *Aulacaspis tubercularis* (Mangifera) (newstead) (Homoptera: *Diaspididae*) attacking mango orchards. *Research Journal of Pharmaceutical, Biological and Chemical Sciences* **6**: 1373–1379.

Halteren, P.V. (1970). Notes on the biology of the scale insect *Aulacaspis mangiferae* Newstead. (*Diaspididae*, Hemiptera) on mango. *Ghana Journal of Agricultural Sciences***3**:83-85.

Haregeweyn, N., Fikadu, G., Tsunekawa, A., Tsubo, M., and Meshesha, D. T. (2012). The dynamics of urban expansion and its impacts on land use/land cover change and small-scale farmers living near the urban fringe: A case study of Bahir Dar, Ethiopia. Land scape and urban planning. Pp 149–157.

Hodges, G., and Harmon A. (2016). **White Mango Scale, *Aulacaspis tubercularis* Newstead (Coccoidea: *Diaspididae*).** Pest Alert, Florida Department of Agriculture and Consumer Services, Pest Alert Division of Plant Industry, Pest Alert 2 pp.

Kassie Koyachew (2016). The problem of solid waste management and people awareness on appropriate solid waste disposal in Bahir Dar City: Amhara region, Ethiopia. *Journal of Health and Environmental Sciences* **3***:1*-8.

Kataria, R. and Kumar, D. (2012). Occurrence and infestation level of sucking pests: aphids on various host plants in agricultural fields of Vadodara, Gujurat (India). *International Journal of Scientific and Research Publications* ***2*** (7):1-6.

Kayode, R.M.O. and Sani, A. (2008). Physicochemical and proximate composition of mango (*Mangifera indica*) kernel cake fermented with mono-culture of fungal isolates obtained from naturally decomposed mango kernel. *Life Science Journal* **5**:*1*-9.

Khoo, S. G. (1974). Scale insects and mealybugs: their biologyand control. Malay. *Nat. J*. **27**: 124-130.

Labuschagne, T.I., Hamburg, H.V. and Froneman, I.J. (1995). Population dynamics of the mango scale, *Aulacaspis tubercularis* (Newstead) (Coccoidea: Diaspididae), in South Africa. *Israel Journal of Entomology* **29**: 207-217.

Lambdin, P.L. (1995). Release, development and establishment of *Chilocorus kuwanae* Silvestri for control of *Unaspis euonymi* (Comstock) in Tennessee. *Israel Journal of Entomology* **29**:327-330.

Lompe, A. (2012). **Family Coccinellidae identification**. (available from www. Coleopterist. org.uk/checklist.htm)

Louw, E. C. Labuschagne, T.I and Swart, SH. (2008). Developing a mango programme for optimum mango yield and quality. *South African Mango Growers' Association Research Journal* **28**:1-11.

Magsig-Castillo, J., Morse, J.G., Walker, G.P., Bi, J.L., Rugman-Jones, P.F.and Stouthamer, R. (2010). Phoretic dispersal of armoured scale crawlers (Hemiptera: Diaspididae). *Journal of Economic Entomology* **103** (4):1172-1179.

Malumphy, C. (2014). An annotated checklist of scale insects (Hemiptera: Coccoidea) of Saint Lucia, Lesser Antilles. *Zootaxa* **3846** (1):69-86.

Mani, M. and Krishnamoorthy A. (2001). Managing scale insects on fruit crops. *Indian Hort* **46**(3): 4-7.

Masibo, M.; and He, Q. (2009). Mango Bioactive Compounds and Related Nutraceutical Properties—A Review. *Food Rev. Int*. **25**: 346–370.

Medina, J.D.L.C., and García, H.S. (2002). **Mango: Post-harvest operations**. http://www.fao. org/3/a-av008e.pdf (assessed 27June 2016).

Mendel, Z., Podoler, H. and Rosen, D. (1985). A study of the diet of *Chilocorus bipustulatus* (Coleoptera: Coccinellidae) as evident from its midgut contents. *Israel Journal of Entomology* **19**:141-146.

Miller, D.R., and Davidson, J.A. (2005). Armourd Scale Insect Pests of Trees and Shrubs. Cornell Univ. Press, Ithaca, USA. 442 pp.

Mills, N. J. and Daane, K.M. (2005). Biological and cultural controls: non-pesticide alternatives can suppress crop pests. *California agriculture* **59**:23-28.

Moiler, H. (1996). Lessons for invasion theory from social insects. *Biol. Control* **78**:125–42

Mohammed Dawd., Belay H/Gabriel., Lemma Ayele, Konjit Feleke., Seyoum Hailemariam., and Teshome Burka (2012). White mango Scale: A new Insect Pest of Mango in Western Ethiopia. pp 257-267 In Eshetu Derso (eds.) **Proceedings of the 3rd Biennial Conference of Ethiopian Horticultural Science Society**, 4-5 Feb 2011, Addis Ababa, Ethiopia.

Moharum, F. A. (2006). Ecological and morphological studies of white peach scale *Pseudaulacaspis pentagona* (*Targioni–Tozzetti*) and its natural enemies. Ph.D Thesis, Fac. of Agric., Moshtohor Benha University. 192 pp.

Nabil, H. A., Shahein, A. A., Hammad, K.A.A., and Hassan, A.S. (2012). Ecological studies of *Aulacaspis tubercularis* (Diaspididae: Hemiptera) and its natural enemies infesting mango trees in Sharkia Governorate, Egypt. *Acad. J. Biolog. Sci* **5**: 9-17.

Nagina, P.S. (2015). Diversity in genus *Mangifera* L. and varietal variation and improvement in mango (*Mangifera indica* L.): A review. *Progressive Horticulture* **47**(1):20-38.

Nagrare, V. S., Kranthi, S. Biradar, V. K., Zade, N. N., Sangode, V., Kakde, G., Shukla, R. M Shivare, D., Khadi, B. M and Kranthi K. R. (2009). Wide spread infestation of the 147 exotic mealybug species, *Phenacoccus solenopsis* Tinsley (Hemiptera: *Pseudococcidae*), on cotton in India. *Bull Entomol. Res* **99**: 537–541.

Ofgaa Djirata (2017). Bionomics and Management of White Mango Scale, *Aulacaspis tubercularis* Newstead (Hemiptera: Diaspididae) on Mango in Western Ethiopia, and Central and Eastern Kenya, PhD thesis, Addis Ababa University, Ethiopia. pp 27-30

Ofgaa Djirata, Emana Getu and Kahuthia-Gathu R. (2016). Trend in mango production and potential threat from emerging white mango scale, *Aulacaspis tubercularis* (Homoptera: Diaspididae) in central and eastern Kenya. *Journal of Natural Sciences Research* **6**(7): 87-94.

Ofgaa Djirata, Emana Getu and Kahuthia-Gathu (2017). Association of a native predator *Chilocorus* sp. (Coleoptera: Coccinelidae) with a new exotic mango pest, *Aulacaspis tubercularis* Newstead (Hemiptera: Diaspididae) in Ethiopia. *Israel Journal of entomology* **47**:1–8

Pal, S.K. and Gupta, S.K.D. (1994**). Pest Control: Skill Development Series no. 15**. International Crops Research Institute for the Semi-Arid Tropics, Patancheru.56pp.

Rehmat, T., Anis, S. B., Khan, M. T., Fatma, J., and Begum, S. (2011). Aphelinid parasitoids (Hymenoptera: Chalcidoidea) of armoured scale insects (Homoptera: Diaspididae) from India. *Biol. Med* **3**(2): 270-281.

Ross, L., Shuker, D.M., Normark, B.B. and Pen, I. (2012). The role of endosymbionts in the evolution of haploid-male genetic systems in scale insects (Coccoidea). *Ecology and Evolution* **2**(5): 1071-1081.

Saeed, S., Masood, A. & Khan, S. M. (2012). Diseased Plants as a Source of Dissemination of Mango Sudden Death Disease in Healthy Mango Plants. Pak. *J. Phytopathol* **24**(1), 21-25.

Sairam, K.; Hemalatha, S.; Kumar, A.; Srinivasan, T.; Ganesh, J.; Sarkar, M.; Venkataraman, S. (2003). Evaluation of anti-diarrhoeal activity in seed extracts of *Mangifera indica*. J. *Ethnopharmacol* **84**: 11–15.

Salem, H.A., Mahmoud Y, and Ebadah, I. (2015). Seasonal abundance, number of generations and associated injuries of the white mango scale, *Aulacaspis tubercularis* (Newstead) (Homoptera: Diaspididae) attacking mango orchards. *Research Journal of Pharmaceutical, Biological and Chemical Sciences* **6**:1373-1379.

Satti, A.A. (2011). Alien insect species affecting agriculture and natural resources in Sudan. *Agriculture and Biology Journal of North America* **2**:1208-1221.

Sawangchote, P., Grote, P.J. and Dilcher, D.L. (2009). Tertiary leaf fossils of Mangifera (Anacardiaceae) from Li Basin, Thailand as examples of the utility of leaf marginal venation characters. *American Journal of Botany* **96** (11):2048-2061.

Saúco, V. (2010). World wide mango production and market. Current situation and future prospects. **In**: international mango symposium, 9, 2010. Sanya, Proceeding. Sanya: **International Soc. for Horticultural Science**. Pp 107-116

Sayed, A. M. (2012). Influence of certain bioagents and climatic changes on the population density of the white mango scale insect, *Aulacaspis tubercularis* Newstead, and http://www. researchgate.net/publication/275891568 (assessed 12 January 2016).

Seid Hussen and Zeru Yimer (2013). Assessment of production potentials and constraints of mango *(Mangifera indica*) at Bati, Oromia Zone, Ethiopia. *International Journal of Sciences: Basic and Applied Research* **11**(1):1-9.

Seltene Seyoum (1988). A History of BahirDar Town (1936-1974), MSc. Thesis Addis Ababa University, Ethiopia, Pp 73-94

Schread, J. C. (1970). Control of scale insects and mealy bugs on ornamentals. Conn. Agric. Exp. Sta. Bull No. 710.

Suit. (2006). Importation of Fresh Mango Fruit (*Mangifera Indica L.*) from India into the continental United State. United States Department of Agriculture, USA. Pp 101-113

Takagi, S. (2010). The *Tubercularis* species group of *Aulacaspis* of (*Sternorrhyncha*: Coccoidae: Diaspididae). *Insecta Matsumurana Series Entomology* **66**:57-114.

Takele Honja (2014). Review of mango value chain in Ethiopia. *Journal of Biology, Agriculture and Health care* **4**(25):230-239.

Thambi, P.A., John, S., Lydia, E. I., Yer, P., Sarah Jane Monica, S.J. (2016). Antimicrobial efficacy of mango peel powder and formulation of recipes using mango peel powder (*Mangifera indica* L.). *Int. J. Home Sci* **2**:155–161.

Temesgen Fita (2014). White mango scale, *Aulacaspis tubercularis*, distribution and severity status in east and West Wollega Zones, western Ethiopia. *Science, Technology and Arts research Journal* **3**: 1–10.

Tesfaye Hailu, Solomon Tsegaye and Tadele Wakuma (2014). White mango scale insect's infestations and its implications in Guto Gida and Diga Distrcts of East Wellega Zone. *ABC Research Alert* **2**:1-33.

Tewodros Bezu, Kebede Woldetsadik and Tamado Tana (2014). Production scenarios of mango (*Mangifera indica* L.) in Harari Regional State, Eastern Ethiopia. *Science*, *Technology and Arts Research Journal* **3**:59-63.

Ubwa, S. T., Ishu, M. O., Offem, J. O., Tyohemba, R. L. and Igbum, G. O. (2014). Proximate composition and some physical attribute of three mangos (*Mangifera indica* L.) fruit varieties. *International Journal of Agronomy and Agricultural Research* **4**:21-29.

UNCTAD, United Nations Conference on Trade and Development. (2016). Mango: an INFOCOMM commodity profile, http://unctad.org/en/ Publications Library/ INFOCOMM_cp07_Mango/ (assessed 30January 2017).

USDA, United States Department of Agriculture. (2006). **Importation of Fresh Mango Fruit (*Mangifera indica* L.) from India into the Continental United States: a Qualitative, Pathway-Initiated Pest Risk Assessment**. Center for Plant Health Science and Technology, Plant Epidemiology and Risk Analysis Laboratory, Raleigh.90pp.

Varshney, R.K., Jadhav, M.J. and Sharma, R.M. (2002). **Scale Insects and Mealy Bugs (Insecta: Homoptera: Coccoidea**). Zoological Survey of India, Pune. 49pp.

Vennila, S., Deshmukh, A. J., Pinjarkar, D., Agarwal, M., Ramamurthy, V. V., Joshi, S., Kranthi, K. R and Bambawale, O. M. (2010). Biology of the mealybug, *Phenacoccus solenopsis* on cotton in the laboratory. *J. of Insect Science* **10**: 115

Wafaa, H.M., Shabaan A.M., Nasr, A.K. and Abd El-Salam, A.M.E. (2014). Integrated pest management for sustainable mango production. *International Journal of Pharmaceutical Sciences and Research*. **29** (2):276-282.

Waskom, R.M. (1995). Best Management Practices for Crop Pests. Colorado State University Publications and Creative Services.14pp.

Wauthoz, N., Balde, A., Balde, E.S., Damme, M.V. and Duez, P. (2007). Ethnopharmacology of *Mangifera indica* L. bark and pharmacological studies of its main C-Glucosylxanthone, mangiferin. *International Journal of Biomedical and Pharmaceutical Sciences***1**:112-119.

Wiersinga, R.C. and Jager, A.D. (2009). **Business Opportunities in the Ethiopian Fruit and Vegetable Sector, Report 2008 075**.LEI, Wageningen. 51pp.

Wu, S. A. and Zhang R. Z. (2009). A new invasive pest, *Phenacoccus solenopsis* threatening seriously to cotton production. *Chinese Bull Entomol* **46** (1): 159–162.

Yigzaw Dessalegn, Habtemariam Assefa, Teshome Derso and Mesfin Tefera (2014). Mango production knowledge and technological gaps of smallholder farmers in Amhara region, Ethiopia. *American Scientific Research Journal for Engineering, Technology, and Sciences* **10**(1):28-39.

Yilma Tewodros (2009). **United Nations Conference on Trade and Development Expert Meeting of LDCs in preparation for the 4th United Nations Conference on the Least Developed Countries:** Case Study on Ethiopia.United Nations Conference on Trade and Development.51pp.

APPENDICES

Appendix 1. Descriptive statistics on the abundances of white mango scale and its natural enemies

Descriptive Statistics						
WMS and its natural enemies	N	Minimum	Maximum	Sum	Mean	Std. Deviation
Colonies	864	2	66	13725	15.89	7.887
Live male	864	0	218	4785	5.54	17.646
Livefemale	864	0	54	5774	6.68	8.572
Dead females	864	5	250	42265	48.92	35.213
Eggs	864	0	125	5701	6.60	12.654
Larva predators	864	0	17	226	.26	1.107
Adult predators	864	0	2	22	.03	0.185
Parasitic wasps	5	1	1	5	1.00	0.000
Leaf area coverage	864	3	100	34473	39.90	12.791

Appendix 2. Correlations of white mango scale and its natural enemies with weather variables

Weather variables	Corre	Male colony	Live males	Live females	Dead females	Eggs	P. larvae	A.predators	Leaf coverage
Rainfall	r	0.089	0.097	-0.048	0.601**	0.205	0.257	0.020	0.075
T min	r	0.127	-0.004	-0.223	0.695**	-0.035	0.155	-0.055	0.160
T max	r	-0.097	-0.16	-0.683	0.397	-0.494*	-0.127	0.296	-0.109
Humidity	r	0.198	0.271	0.644**	-0.026	0.640**	0.303	-0.296	0.124
Wind	r	-0.191	-0.404	-0.793	0.472*	-0.648**	-0.288	0.377	0.069
Sunshine intensity	r	-0.277	-0.374	-0.330	-0.326	-0.502*	-0.365	0.344	-0.033

Note : **. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Where Corre- correlations

T min - minimum temperature

T max - maximum temperature

P. larvae – Predatory larvae

A.predators- Adult predators

Appendix. 3. Questionnaire used to gather baseline information on WMS in Bahir dar area

This questionnaire has been designed to gather baseline information from mango farmers in Bahir dar area regarding their knowledge about white mango scale, its impact on mango production, management methods of the pest and related aspects.

I. Demographic data

1. Sex: A) Male _____ B) Female_____

2. Age: A) below 30 B) above 30

3. Level of Education: A) Never attended school B) Grade 1-8 C) Grade 9-12

II. Information about WMS and its impact on mango production

4. Age of trees. --

5. Variety of mango you produce. A. Late introduced B. Recently introduced

6. Did you experience from your mango farm (already knew) White Mango Scale (white insect pest attached to mango fruits, leaves & sometimes to twigs) that result in reddish (pink) spots on fruits and yellowish/brown spots on leaves of mango? A. Yes B. No

7. Do you remember when this pest appeared? A) 2008 B) 2009 C) 2010 E.C

8. Did the damage of White Mango Scale to mango plantation affect the food and income you may get from mango? A) Yes _____ B) No _____

9. What method(s) have you been using to control White Mango Scale? A) Cultural (traditional) methods ____ B) Insecticides (Chemicals)_______C) Other (please, specify):____

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