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SURVEY AND MANAGEMENT OF WHITE MANGO SCALE (Aulacaspis tubercularis) ON MANGO (Mangifera indica) PRODUCTION AT ASSOSA AND BAMBASI DISTRICTS, IN BENISHANGUL GUMUZ REGION, WESTERN

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M.Sc. Thesis

By

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October, 2019

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By

Bizuayehu Jemaneh Woldesenbet

SUBMITTED IN PARTIAL FULFILLMENT OF THE R
DEGREE OF MASTER OF SCIENCE (M.Sc.) IN PLANT PROTECTION

Major Supervisor: Dr. Merkuz Abera
Co-Supervisor: Dr. Adane Tesfaye

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THESIS APPROVAL SHEET

As member of the Board of Examiners of the Master of Sciences (M.Sc.) thesis open defence examination, we have read and evaluated this thesis prepared by Mr. Bizuayehu Jemaneh Woldesenbet entitled SURVEY AND MANAGEMENT OF WHITE MANGO SCALE (*Aulacaspis tubercularis*) ON MANGO (*Mangifera indica*) PRODUCTION AT ASSOSA AND BAMBASI DISTRICTS, IN BENISHANGUL GUMUZ REGION, WESTERN ETHIOPIA. We hereby certify that, the thesis is accepted for fulfilling the requirements for the award of the degree of Master of Sciences (M.Sc.) in Plant Protection.

Board of Examiners

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DECLARATION

This is to certify that this thesis entitled "SURVEY AND MANAGEMENT OF WHITE MANGO SCALE (*Aulacaspis tubercularis*) ON MANGO (*Mangifera indica*) PRODUCTION AT ASSOSA AND BAMBASI DISTRICTS, IN BENISHANGUL GUMUZ REGION, WESTERN ETHIOPIA." submitted in partial fulfilment of the requirements for the award of the degree of Master of Science in "Plant Protection" to the Graduate Program Department of Plant science College of Agriculture and Environmental Sciences, Bahir Dar University by Mr.Bizuayehu Jemenah Woldesenbet (ID.No.BDU1018408PR) is an authentic work carried out by him under our guidance. The matter embodied in this project work has not been submitted earlier for award of any degree or diploma to the best of our knowledge and belief.

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Wishing all Holy blessings from Jesus Christ and be considered in His eternal Government.

DEDICATION

To my wife Hana Kelifa Elias for her dedicated partnership in the success of my life and my son Elnathan Bizuayehu for his affection.

ABBREVIATIONS AND ACRONYMS

BGR	Benshungul-Gumuz Region
BoA	Bureau of Agriculture
CIMMYT	Centro Internacional De Mejoramiento De Maiz Y Trigo International Maize And Wheat Improvement Centre
CSA	Central Statistical Agency
FYM	Farm Yard Manure
GLM	General Linear Model
GPS	Global Positioning System
IPM	Integrated Pest Managemet
Ltd	Limited
MoA	Ministry of Agriculture
MRR	Marginal Rate Of Return
NMA	National Meteorological Agency
QGIS	Quantum Geographical Information System
SAS	Statistical Analysis System
SNNPR	Southern Nations, Nationalities, And People's Region
SPSS	Statistical Package for The Social Sciences
SRA	Small Research Activity Report
UAAIE	Upper Awash Agro Industry Enterprise
WMS	White Mango Scale

SURVEY AND MANAGEMENT OF WHITE MANGO SCALE (*Aulacaspis tubercularis*) ON MANGO (*Mangifera indica*) PRODUCTION AT ASSOSA AND BAMBASI DISTRICTS, IN BENISHANGUL GUMUZ REGION, WESTERN ETHIOPIA

ABSTRACT

Mango (*Mangifera indica* L.) is grown commercially on a large scale across all tropical and subtropical lowland areas throughout the world. It is a good source of vitamin A and C, and is rich in carbohydrates, potassium and phosphorus. It is the major fruit crop grown in Benshangul Gumuz Region of western Ethiopia for family consumption and markets. The production in the region is currently constrainted by infestation of white mango scale, *Aulacaspis tubercularis* Newstead. This research was conducted to assess damage status and evaluation of management options in Assosa and Bambasi from August 2018 to April 2019. Survey data of white mango scale infestation status and growers assessment collected from randomly selected of 7 kebele administrates of Amba_14, Amba_5, Amba_8 and Megele_32 from Assosa district and Mender_47, Mender_48 and Sonika from Bambasi district and 35 household with their respective mango orchards 5 per kebele administrates within 5 – 10 km interval. A well-structured questionnaire and face-to-face survey approach were used for assessment. Stratified sampling method was used for selecting 10 leaves per tree for 9 consecutive months, hence 90 leaves from each tree and 3150 sample leaves from 35 mango trees for counting the clusters of white mango scale insect pest for the study of infestation. Randomized complete block design (RCBD) was used for evaluation of Imidacloprid 20SL, Dimethoate 40%EC, White oil extract, Pruning, Imidacloprid 20SL + Pruning, Dimethoate 40%EC + Pruning and White oil extract + Pruning. The survey result showed that growers' perceived that there was a heavy infestation of white mango scale insect pest which is a new pest and mainly dispersed by planting material, due to unmanageable mango size nature and backyard farm production made management difficult which results a significant yield reduction. White mango scale insect pest infestation was significantly higher at Assosa than at Bambasi orchards and more abundant on upper leaf than on lower leaf surface. Infestation status was significantly varied among study months; lowest and highest record during December and April respectively. Temperature influence the infestation positively; a maximum record during maximum temperature of the study month April. High amount and continued rain fall and relative humidity influence infestation negatively. Optimum rain fall and relative humidity and also unmanaged mango orchards condition made the infestation serious. Experiment against white mango scale infested mango trees using Dimethoate 40%EC, white oil + pruning, Imidacloprid 20SL, and Dimethoate 40%EC + pruning treatments gave higher yield and statistically significant different from pruning and white oil treatments but their costs were such that they did not provide an acceptable rate of return. Imidacloprid 20 SL + pruning treatment was the most significantly effective which also provide a promising alternative cost to producers against white mango scale insect pest than other treatments. Therefore it is recommended to regular inspection and monitoring, develop a strong domestic quarantine, investigate resistance mango varieties and further screening of IPM compatible insecticide for providing sustainable management approach of white mango scales insect pest.

Keywords: White mango scale, Mango orchard, Distribution, Abundance, Severity status

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Chapter 1. INTRODUCTION

1.1 Background and Justification

Mango is a member of the family *Anacardiaceae* within the genus *Mangifera* which consists of over 25 species. Among the several species of mango, *Mangifera indica* (Linnaeus) is the only species grown commercially on large scale (Griesbach, 2003). Mango (*Mangifera indica* L.) originated in tropical Asia and is currently distributed across all tropical and subtropical lowland areas throughout the world (Diro, 2004; Okoth *et al*., 2013; Ubwa *et al*., 2014 and Crane *et al*., 2017). Mango is one of the most cherished fruits, not only for its flavour and taste, but also for its nutritional value. Mango is a good source of vitamin A and C, and is rich in carbohydrates, potassium and phosphorus (Griesbach, 2003 and Nabil *et al*., 2012). Mango serves as a fruit crop and as a subsistence crop for family farms. As it ripens at the end of the dry season and at the start of the rainy season, the mango is a fundamental source of nutrition for rural populations (Vayssières *et al*., 2012).

Mango is traditionally grown in Ethiopia primarily for family consumption and local markets, but some emerging modern farms have started to produce mango for both local and export markets (Alemayehu Chala *et al*. 2014). Ethiopia exports mango to Djibouti, Saudi Arabia, Yemen, Sudan and the United Arab Emirates (Tewodros Bezu *et al*., 2014). Total world mango production is more than 40 million tons, with only 3% of the crop traded around the globe (Evans and Mendoza, 2009; Gallo, 2015; Galán Saúco, 2015; Balyan *et al*., 2015 and Mitra, 2016).

In Ethiopia mango is one of the second potential fruit crop next to banana which is the first fruit crop produced in large quantity and produced mainly in west and east of Oromia, SNNPR (Southern Nations, Nationalities, And People's Region), BGRS (Benshungul Gumuz Region) and Amhara National Regional State (Takele Honja, 2014). According to CSA (Central Statistical Agency) (2017) report 15,413.76 ha total area allotted for mango and 1,046,461.25 quintals annual production. Similarly in BGR (Benshungul_Gumuz Region) area cultivated and production were 1,191.68 ha and 79511.96 quintals respectively.

Different literature showed that mango is attacked by a variety of insect pests such as stone weevil (*Sternochetus* spp.), mealy bugs, fruit flies, scales, and mites, and various diseases of which fungal diseases are the common (Griesbach, 2003 and FAO, 2010). In Ethiopia

Mango production is constrained by insect pests such as fruit flies, mango seed weevil, mites, thrips, mealybugs and scale insects (Seid Hussen and Zeru Yimer, 2013 and Alemayehu Chala et al. 2014). Among these insect pests of mango, white mango scale (*Aulacaspis tubercularis* Newstead) is the most important of hard scale insects which is reported to have damaged mango in various parts of the world (SRA, 2006; Germain et al., 2010 and Abo-Shanab, 2012).

The mango white scale insect pest morphological description is opaque white female armour which is circular, flat, thin and often wrinkled and Exuviae is near the margin, and is yellowish-brown, with a median black ridge, forming a dark distinct median line; Male armours are small, white, sides nearly parallel and distinctly tricarinate and crawlers are deep bright brick red (Hamon, 2016). The pest reproduces during both dry and wet seasons (Halteren, 1970). White Mango Scale is a sucking insect that poses severe threat to mango plantations in various mango growing countries (Labuschagne et al. 1995; Pena et al. 1998; Nabil et al. 2012 and Juárez-Hernández et al. 2014). The damage caused by White Mango Scale includes yellowing of leaves, appearance of conspicuous pink blemishes on mature and ripe fruits, and dieback of the plant (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 population density of white mango scale was formerly recorded on mango trees in few parts of the world. However, it has been spread by the transport of infested plant materials and widened its scope and has become an important mango pest in many mango growing countries such as Mexico, India, Pakistan, Italy, Ghana, Kenya, Madagascar, Mauritius, Tanzania, Uganda and Zimbabwe, among others (Labuschagne et al., 1995; Pena et al., 1998; El-Metwally et al., 2011; Salem et al., 2015 and Hodges and Hamon, 2016). Infestation of mango by white mango scale insect pest in Ethiopia was first reported in 2010 in a mango orchard owned by Green Focus Ethiopia Ltd. (Mohammed Dawd et al., 2012) which used to import mango seedlings from India and hence it is deduced that the insect pest probably entered Ethiopia accidently on imported seedlings. Within one year of first record, white mango scale was reported to have dispersed 100 km and west northern and central Ethiopia, with the infested area in the north being about 1500 km away from the place of initial infestation (Temesgen Fita, 2014 and Gashawbeza Ayalew et al. 2015).

Different literatures were indicated for management of white mango scale such as a recommendation of applaud and white oil by Ambo Plant Protection Research Centre (Tesfaye Hailu et al., 2014). Mineral oils such as Diver®, CAPL2® and super masrona® and insecticide such as Deltametrine and pyrethrin in Kenya, chloropyrifos, methidathion, Dimethoate 40%EC, Movento, Folimat 500SL, D-C-Tron and Closer insecticides showed different effectiveness in reducing the insect number (Howard, 1989; Findlay, 2003; Abo-Shanab, 2012; Gashawbeza Ayalew et al. 2015 and Ofgaa Djirata, 2017).

1.2 Statement of the problem

Mango production in western Ethiopia is highly constrained by white mango scale. The damage of white mango scale induced panic and frustration in Western Ethiopia for the loss in crop production and indirect sociological consequences, since mango plantation serves as shade for animals and conference hall for the people, in addition to generating income and serving as food in the region. The insect has become a growing concern among various government organizations and civil societies and communities. The problem is no more regarded as economic one as it has social, environmental, and other repercussions (Tesfaye Hailu et al., 2014 and Ofgaa Djirata and Emana Getu, 2015).

The development of conspicuous blemishes on mango fruit skin which was infested by white mango scale markedly damages mango fruit export potential and eventually to lead economic loss (USDA, 2006 and 2007). According to the information obtained from farmers, they used to harvest up to 10 quintal of fruits per tree before the occurrence of this new insect pest. But the fruit yield reduced to 2-3 quintal per tree or may not be obtained at all due to the heavy infestation of white mango scale (Mohammed Dawd et al., 2012).

For control of white mango scale pest in Ethiopia no single insecticide has been registered. Insecticides currently in use against white mango scale in the infested mango orchards are insecticides recommended for the control of armoured scales such as the red scale (Aonidiella auranti) on citrus in the early 1980s (Tsedeke Abate, 1994 and Ferdu Azerefegne et al., 2009). Ofgaa Djirata (2017) reported that limited report of experiments performed regarding insecticide screening against white mango scale insect pest in Ethiopia since the insect introduced in the country has been less than a decade. There fore there is limited information on effective management option for the control of white mango scale in BGR (Benshungul-Gumuz Region). Besides to this, regular assessment of the pest will tell us the severity of infestation and distribution over time and across location of the pest and also farmers, knowledge and management practices of the pest.

1.3 Objectives of the Study

1.3.1 General objective

To assess the white mango scale damage status and evaluation of management options on mango scale at Assosa and Bambasi districts in Benshungul-Gumuz Region

1.3.2 Specific objectives

- ð§ To develop spatial and seasonal map of white mango scale distribution
- ð§ To determine the main and alternative hosts of white mango scale
- ð§ To determine the infestation level, incidence and damage status of white mango scale
- ð§ To evaluate the effective management method on white mango scale

1.4 Research questions

The research question of the survey and management of mango white scale in the study area are listed as the following:

- ð§ What are the spatial and temporal distribution of white mango scale?
- ð§ What are the main and alternate hosts of white mango scale?
- ð§ How are the infestation level, incidence and damage status of white mango scale in the study area?
- ð§ What are the effective management options to manage mango white scale?

Chapter 2. LITERATURE REVIEW

2.1 Mango Origin, Biology, Ecology and Production

2.1.1 Mango origin and taxonomy

Mango (*Mangifera indica*) is a member of the family *Anacardiaceae* from Asia and has been cultivated for at least 4000 years (Crane, 2008). It is one of the most important members of this family (Normand *et al*., 2015). The main center of origin for mango is within the region between north-east India and Myanmar (Crane, 2008; Bompard, 2009; Dinesh *et al*., 2015; Sherman *et al*., 2015; Krishnapillai and Wijeratnam, 2016 and Sahu *et al*., 2016). Many of the cultivars grown in India are at least 400 years old (Mukherjee *et al*., 1968). There are more than 100 different cultivars in some parts of India, including West Bengal (Mitra *et al*., 2015). All mango cultivars belong to the species *Mangifera indica*. The taxonomy of mango is described as: Kingdom, Plantae; Class, Mangoliopsida; Phylum, Mangoliophyta; Order, Sapindales; Family, Anacardiaceae; Genus, Mangifera and Species, Indica (Litz, 2003).

2.1.2 Mango biology

The tree is a deep-rooted, evergreen plant which can develop into huge trees, especially on deep soils. The height and shape varies considerably among seedlings and cultivars. Under optimum climatic conditions, the trees are erect and fast growing and the canopy can either be broad and rounded or more upright. Seedling trees can reach more than 20 m in height while grafted ones are usually half that size (Iyer and Schnell, 2009). In deep soil the taproot descends to a depth of 20 feet, and the profuse, wide-spreading feeder roots also send down many anchor roots which penetrate for several feet (Matsuoka, 2000).

The tree is long-lived with some specimens known to be over 150 years old and still producing fruits. The mature leaves are simple, entire, leathery, dark green and glossy; they are usually pale green or red while young. They are short-pointed, oblong and lanceolate in shape and relatively long and narrow, often measuring more than 30 cm in length and up to 13 cm in width (Salim *et al*., 2002). The mango inflorescence is a branched terminal panicle, 4–24 in. long, bearing what has been variously estimated to range from 500 to 10,000 (McGregor, 1976), 200 to 6000 (Free, 1993), and 1000 to 6000 (Mukherjee, 1953) individual flowers per panicle. The number of panicles range from 200 to 3000 per tree depending on tree size and extent of branching (McGregor, 1976). Individual flowers are borne collectively on panicles or thyrses (Weberling, 1989). Individual mango flowers are small, ranging in size from five to ten mm in diameter (McGregor, 1976; Scholefield, 1982; Mukherjee and Litz, 2009 and Ding and Darduri, 2013)

The fruits can be oval, egg shaped and round depending on the variety with smooth and soft skin. When ripe, the skin is usually a combination of green, red, and yellow depending on the variety (Matsuoka, 2000). The interior flesh is bright orange and with a large, flat pit in the middle in all ripe varieties. The fruit has a rich luscious, aromatic flavor and a taste in which sweetness and acidity are pleasantly blended (Hobson and Grierson, 1993). Mango trees are often irregular in their cropping habit, with no clear pattern across different years. Plantings can also suffer from alternate or biennial bearing, where a tree or an orchard produces a large crop in an on-year followed by a small crop in the following off-year (Souza et al., 2004). There can be periods of irregular bearing and periods of alternate bearing in the same orchard (Fitchett et al., 2016).

2.1.3 Mango ecology

Mango grow well from sea level up to 1,200 m above sea level, however, fruit production decreases at higher altitudes. Mangoes are naturally adapted to tropical lowland between 25° N and 25°S of the equator and up to 915 meters above sea level (Johnson et al., 1997). Mango is successfully cultivated under conditions which vary from very-hot humid to cool and dry or arid areas; its mean annual rainfall is between 400mm and 3600mm (Bally, 2006). The average temperature must be at least 21°C with an optimum of 25°C (Samson, 1986). Well drained soil with pH ranging from 5.5 to 7.5 is suitable for mango. Mango is drought tolerant and survives on as little as 300 mm of rainfall per year (Johnson et al., 1997).

Sarwar (2015) recorded nearly, 200 known insect and non-insect pests in mango. The foremost insect pests of mango recorded as hopper, mealy bug, inflorescence midge, fruit fly, scale, shoot borer, leaf Webber and stone weevil. Among these, homopterans and coleopterans were principal insect pests considered for integrated pest management. Also Chowdhury (2015) recorded various insect pests on mango viz. hopper, mealy bug, inflorescence midge, fruit fly, scale, shoot borer, leaf Webber and stone weevil. Sahoo and Jha (2008) reported 26 insect species in nursery bed and orchard of mango. These are fruit borer, hopper, hairy caterpillar, nest forming caterpillar, slug caterpillar, shoot borer, bag worm, hopper, painted bug, aphid, mealy bug, leaf eating weevil, grey weevil, fruit fly and gall insect. These insects infesting the crop during flowering and fruiting periods and cause severe damage.

Srivastava (1997) observed spiders, coccinelids, black ant, red ant, *Chlrysoperala carnea*, praying mantid, predatory bug as a predator on different insects of mango orchard. Peng and Christian (2005) observed survey of natural enemies in mango orchards in Australia and observed that common beneficial predators and parasitoids like lady bird beetles (its feed on aphids, leaf hoppers, scales, mealy bug and Lepidoptera eggs), lace wing (its larvae very important role in controlling thrips, mango hopper, aphids, mites, immature scales, mealy bug and small caterpillar), Hoverflies (its larvae feed on mealy bugs, aphids, and thrips), Spiders (its prey on the mango hoppers, mango tip borers, thrips, plant hoppers, moth, bug and flower caterpillars, leaf hoppers, pest bugs, aphids, and insect eggs), Praying mantids (its feed on grasshoppers, leaf hoppers, plant hoppers, fruit spotting bug, tea mosquito bug and moth etc.), Ants (these are effective predators of a range of arthopods including the major insect pests) and other predators like dragon fly, damsel fly, ground beetle, rove beetle, insectivorous birds. Also observed parasitoids, like many species of parasitic wasp that parasitizes eggs, pupa and larvae of insect pests. They play important role in the northern territory of mango orchards in controlling the mango hoppers, mango tip borers, fruit spotting bug, scale insect and flower caterpillars.

2.1.4 Mango production practice

The number of trees per household varies from 10-50, depending on size of the farm land and preference of farmers. However, majority of growers have less than 20 trees while few have more than 40 trees (Tewodros Bezu *et al*., 2014). Similar holdings by peasant growers have also been reported by Semwal *et al*. (2008), in Assosa (western Ethiopia) and Seid and Zeru (2013) in Bati (northern Ethiopia). Tewodros Bezu *et al*. (2014) reported mango production has a long history in eastern Ethiopia particularly in eastern Hararghe. This also supported by Salim *et al*. (2002), Griesbach (2003) and Merkuz Abera (2017) as mango tree is long-lived with some specimens known to be over 150 years old and still producing fruit.

Most of the time Ethiopian farmers did not give attention to spacing. Orchards growth were not well spaced, according to the oldness of the trees age most of the farmers had no knowledge about spacing. Space plays significant role for all activities, absence of proper spacing create difficulties for production (Seid Hussen and Zeru Yimer, 2013). Olaniyan (2004) reported that mango tree spacing appears to be an important consideration in production. Mango orchards are normally planted at fairly wide spacing because the trees can grow into large specimens (Khan et al., 2015). Mango fruits grown under high density planting show a progressive decline in crop yield after 14/15 years, due to overcrowding of canopies, which suggested regular canopy management was necessary (Sharma et al., 2006 and Merkuz Abera, 2017). Overcrowding results in the production of fewer fruits which are apt to be poorly colored and infected with pests. Tall trees also present a harvesting problem and create difficulties during spraying and pruning (Griesbach, 2003). In general, well managed orchard trees require regular annual pruning to maintain an open canopy of manageable size. This allows air and sunlight to penetrate, which reduces pests and diseases and improve fruit color (Bally, 2006).

Significant numbers of mango producers in Ethiopia use river water and a small portion of smallholders use pound water. The yield is greater in river water irrigation than pond water irrigated crops. The quantity and quality of water available is on factors that determine the yield. Frequency and amount of irrigation need depends on soil type, property, climate and others (Seid Hussen and Zeru Yimer, 2013). The same study showed that fertilizer application, irrigation, pest and disease control, wind break and pruning are the mango production practices adopted by the smallholder farmers in the area. However, use of organic and inorganic fertilizers for the mango production purpose is rare except some innovative farmers that use organic fertilizer. Similar study conducted by Ayelech Tadesse (2011) indicated that FYM (Farm Yard Manure) principally transported from homestead to the field mostly during the dry season and spread in the bottom of each tree in circular form. The assessment report highlighted that chemical inputs entirely evaded neither for fertilization nor for pest treatment. The same study indicated that smallholder farmers in the area intercrop mango with maize, taro, ginger, chat, cabbage and banana at early stage.

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, Keitt 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. Green Focus Ethiopia Limited private farm introduced a new mango cultivar Alphanso (2001/2002) from India and planted in its farm at Loko in Guto Gida district of East Wollega zone of Oromia, western Ethiopia

(Mohammed Dawd et.al 2012). The farm cultivates Keitt, Kent, Tommy Atkins, Apple, Dodo and Alphanso (Temesgen Fita, 2014).

Knight (1997) reported that mango fruit matures in 100 to 150 days after flowering and the fruit will have the best flavor if allowed to ripen on the tree. Griesbach (1992) reported that commercial marketability requires 13% dissolved solids or sugars and the fruit ripens best if placed stem end down in trays to prevent the sap from spreading to other parts of the fruit and also to encourage even ripening at room temperature (21-25°C) and covered with a dampened cloth to avoid shriveling. Rosals (2005) found that loss of fruit increases dramatically after harvest as the fruit maturity increased. Methods of harvesting adopted by the smallholder farmers in Ethiopia are hand picking, cut by scissor and using stick. Hand picking method of harvesting produce can maintain good quality of fruit and protect the fruit from mechanical damage. Hand picking can produce the fruit with stem and reduce fruit bruising and damage but stick structure result in fruit dropping and leave the fruit without stem which facilitate fruit bruise and mechanical damage (Seid Hussen and Zeru Yimer, 2013). Ayelech Tadesse (2011) showed that harvesting usually start after fruit dropping which is principal maturity index. FAO (2005) which indicated cuts, punctures and/or bruises has increased ethylene production and hastened fruit softening and ultimately caused mechanical injuries and decay.

2.2 Production Constraints of Mango

Mango production constrainted by different biotic and abiotic factors. Among the biotic factors that mango trees damaged were different insects and diseases such as Anthracnose, Bacterial Black spot, stone weevil (*Sternochetus* spp.) fruit fly, mango gall flies, Mango leaf coating, Mites, Mango seed weevil, Mealy bug, Powdery mildew, Scale, Spider mites, Mango tip borer, Stem end rot, Termite, Thrips and White flies (Borchsenius, 1966; Balock and Kozuma, 1963; Halteren, 1970; Griesbach, 2003 and FAO, 2010). Among these insect pests of mango, white mango scale is the most important of hard scale insects which is reported to have damaged mango in various parts of the world (Cunningham, 1989; SIRA, 2006; Germain et al., 2010 and Abo-Shanab, 2012).

In Ethiopia mango production is constrained by insect pests such as fruit flies, mango seed weevil, mites, thrips, mealybugs and scale insects and 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). Also Tewodros Bezu et al. (2014) reported thrips, fruit flies, termites, and various fungal diseases constrain mango production in Ethiopia, in the absence of proper management practices. Mango anthracnose, caused by Colletotrichum gloeosporioides was reported to be 100% prevalent in the humid-agro ecology of southwest Ethiopia, and found causing severe damage to the fruit crop (Ayantu Tucho et al., 2014). White mango scale is among insect pests inflicting damage to mango trees in BGR (Benishangul-Gumuz Region).

The study in the East and West Wollega Administrative Zones by Temesgen Fita (2014) who reported that survey in the infested districts mango yield obtained before white mango scale emergence was significantly higher than after white mango scale emergence. Mohammed Dawd (2012) also reported that farmers responded that fruit harvest up to 10 quintal before the occurrence of white mango scale had been decreased to 2 to 3 quintal or not at all after the occurrence of mango white scale. Hodges and Harmon (2016) reported that in 2001, losses caused by fruit rejection from Nayarit due to white mango scale infestation were ranged from 50 to 100%.

2.3 White Mango Scale Origin, Taxonomy and Biology

2.3.1 Origin and taxonomy

White Mango scale is a tropical species that may have originated in Asia (Borchsenius, 1966) and has been firstly reported in India on mangoes (Ben-Dov et al., 2006). The taxonomy of white mango scale is described as domain: Eukaryota; kingdom: Metazoa; phylum: Arthropoda; sub phylum: Uniramia; class: Insecta; order: Hemiptera; sub order: Sternorhyncha; Unknown: Coccoidea; family: Diaspididae; Genus: Aulacaspis and Species: Aulacaspis tubercularis (CABI, 2018).

White mango scale is known by its accepted name Aulacaspis tubercularis Newstead, 1906 (Varshney et al., 2002). However, there were times when it was known by several different names, namely, Aulacaspis cinnamomi Newstead, 1908, Aulacaspis cinnamomi mangiferae Sasscer, 1912, Aulacaspis mangiferae MacGillivray, 1921, Aulacaspis sinnamomi Kuwana, 1926, Aulacaspis tubercularis Sanders, 1909, Diaspis cinnamomi Hall, 1928, Diaspis cinnamomi mangiferae Newstead, 1911, among others (CABI, 2018 and Halteren, 1970).

2.3.2 White mango scale biology

White mango scale differs from false mango scale mainly by females which are described as being red with scale coverage that is flat, white and circular with a black oval shaped caste skin and males white and rectangular in shape with two or three distinct ridges usually clustered round a single female (Northern Territory Government Department of Resources, 2010). White mango scale is hard scales or armored scale which do not produce honeydew (Mark et al., 2019). 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).

As cited by Abo-Shanab (2012) and shown in Figure 2.1 by Hamon (2016) white mango scale shows sexual dimorphism. Adult female is larger in size than the male; with thin and nearly circular body shape and white armour that possesses dark and oval terminal exuviae. The naked adult female's body is wrinkled, with quadrate and enlarged prosoma. Takagi (2010) described the body of fully-grown adult female rosae type, as its prosoma (the fused head, prothorax and mesothorax) is swollen and wider than the postsoma (the fused metathorax and abdomen). Adult female has neither wing nor appendage for locomotion. It glues itself to the plant part by the use of its armour and remains sucking sap from the plant tissues. Like most species of armoured scale insects, adult male white mango scale is smaller in size than the female; its body is elongated and nearly rectangular in shape with three raised parallel dorsal ridges on its cover (Takagi, 2010 and El-Dein, 2012).

Figure 2.1 Image of white mango scale
Source: (Hamon, 2016)

Unlike the female, male mango scale possesses one pair of wings. They occur in groups gathering around the female, while the female usually occurs singly. The reproductive biology of scale insects in general exhibits marked diversity. A variety of sexual and asexual modes of reproductions are present in scale insects (Ross et al., 2012). Hermaphroditism is among the sexual modes of reproduction in this group of insects. Adult female of some scale insects may lay eggs or give birth directly to live first instars (Gyeltshen and Hodges, 2006). In the course of development, female scale insects undergo incomplete metamorphosis with a total of three to four instars; whereas the male passes through five instars exhibiting a metamorphosis which resembles the complete one. However, it is evident that members of the order Homoptera normally undergo incomplete metamorphosis. The life cycle of white mango scale begins when the female lays fertilized eggs under its cover, which may be about 80-200 depending on variations in temperature (Sayed, 2012).

The newly hatched nymph is very small, elongate, oval, and totally bare of any wax secretion. After an incubation period of 7-8 days, the first instars hatch and move out of their mother‚s cover and the crawlers moves about until it discovers a suitable place to settle on. After settling, fine threads of wax which appears cottony; begin to exude from the body and this secretion continues until the insect is completely covered with the white filament. Hence the common name is ……white cap‚‚ (Halteren, 1970). Momarum (2012) described the external morphology of first instar white mango scale. Accordingly, the newly hatched nymph is small in size, elongate-oval and totally bare of wax secretion. It has well developed functional legs, antennae and eyes. Claws and tarsus on the legs have setae. The presence of such structures may help the nymph to attach itself to body of other animals to disperse phoretically. It was reported that crawlers of armored scale insects could remain attached to flying insects for certain periods of time, which may be an indication that phoresy might help them disperse (Magsig-Castillo et al., 2010).

In scale insects first instars of both sexes usually look alike, but sexual dimorphism becomes evident as of second instar (Gyeltshen and Hodges, 2006). Earlier study by Great head (1990 and 1997) also confirmed that white mango scale can move with the help of external forces like wind, birds and insect pests. Also Haggag et al. (2014) cited that only the crawler stage can move to a new host (adult males can fly but cannot establish a colony), but scale insects can move to new hosts as a result of wind, birds, and insects. Crawlers are capable of moving distances of tens of kilometres on wind currents to infect clean crops. The crawlers move about until they get suitable feeding site on the plant where they settle and continue molting. 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 molting until fully develops. The male crawlers settle in groups, while the females settle randomly (Lou et al., 2008). The wax develops into tricarinate puparia in the male. The settlement clearly described by Halteren (1970) as male crawlers settle in groups of 10-80, often near females; these groups are conspicuous due to the white scale covers they produce.

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). As showed in Figure 2.2 the scale have a joined life cycle where, from eggs to first moult, the sex is not defined however roughly 80% of crawlers will become males and follow one path of the life cycle, while the remaining 20% will be become females and follow a different lifestyle path (Owens, 2016 and Holmes, 2016)

Figure 2.2. Life cycle of mango white scale

Source: (Holmes, 2016)

In bi-parental species of scale insects, like white mango scale, the male insect does not have functional mouth part to feed and hence lives for only few hours after begins flying, while the female normally feeds and lives longer (Beardsley and Gonzales, 1975 and 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).

2.3.3 Ecological adaptation

White mango scale can produce five to six generations per year, at a maximum day time temperature of 26°C and night time minimum temperature of 13°C (Miller and Davidson, 2005). White mango scale has been spread by the transport of infested plant material and it is now widespread in many mango growing countries. The scale was introduced to Florida and Australia with the importation of mango fruit from India (Suit, 2006). Various reports indicate that white mango scale is distributed throughout the world wherever mango is grown (USDA, 2007, El-Metwally et al., 2011 and Han et al., 2015). These include northern part of South America, the Caribbean, the east and west coasts of Africa, Asia, and Italy, among others. In Africa alone, the pest is reported to have infested mango in about 21 countries (Abo-Shanab, 2012 cited from Borchsenius, 1966). These include Ghana, Kenya, Madagascar, Mauritius, Tanzania, Uganda, Zimbabwe, and Zanzibar, among others (Hodges and Harmon, 2016).

The year of first report of infestation of white mango scale on its host markedly varied among African countries. White mango scale was first recorded on one cultivar of mango in South Africa in 1947 (Waafa et al., 2014), but it was reported to have been recorded infesting mangos in Ethiopia in 2010 (Mohammed Dawd et al., 2012). In Benin, white mango scale was recorded from mango during 2005-2007 (Germain et al., 2010). This pest is currently posing sever threat to mango plantations in various mango growing countries (Labuschagne et al., 1995; Pena et al., 1998; Nabil et al., 2012; Tesfaye Hailu et al., 2014 and Ofgaa Djirata and Emana Getu, 2015).

2.3.4 White mango scale infestation and damage

Infestation fluctuation Field infestation assessment in Guto Gida and Diga Districts of East Wellega Zone showed that during rain fall male and female were less but crawlers and eggs were high. After the rain stop the crawlers changed to adult which indicates that the presence of mango scale with the mango tress all year round, with overlapping generations throughout. Peak population observed during the flowering time of spring and harvesting period (Tesfaye Hailu *et al.*, 2014). The study in the East and West Wollega Zones by Temesgen Fita (2014) reported that there was infestation variation among the study sites. Tsegaye Babege *et al.* (2017) reported that the study in Bench Maji Zone South West Ethiopia majority of respondents replied that white mango scale infestation varied among the study districts and season high level of pest prevalence was occurred in winter however field survey result at Kuja kebele indicated the rate of pest infestation was sever in spring while the majority of mango trees in the study area were severely damaged.

In contrary to these results Abo-Shanab (2012) reported the lowest population density was observed in the beginning of spring season during the two study years. Study in western Ethiopia by Ofgaa Djirata and Emana Getu (2015) reported that Infestation of white mango scale on mango fruits at different stages of fruit development study revealed that white mango scale has become a devastating pest to mango fruit in western Ethiopia. The study in Central and Eastern Kenya by Ofgaa Djirata *et al.* (2016) also reported that considerable percentage of respondents said that level of the damage showed variation over time since first recognized and also the infestation was varied spatially among the study site.

The study by Nabil *et al.* (2012) on mango in Egypt who recorded that white mango scale Newstead preferred the upper leaf surface compared to the lower one. The studies by Mawa *et al.* (2017) also strengthen the above that mango upper leaf surfaces were heavier infestation compared with the lower surface. In Ethiopia study in Arjo and Bako by Ofgaa Djirata *et al.* (2018) proved that all developmental stages of mango white scale were found to be more abundant on the upper leaf surfaces.

Population of white mango scale remained at an extremely low level when average monthly rainfall was below 10 mm which implying that white mango scale is highly affected by drought (Ofgaa Djirata *et al.*, 2018). Ofgaa Djirata and Emana Getu (2015) reported that maturation and ripening of mango fruit begin during the first months of rainy season, that is, in March to April and continues for few months, vis-à-vis significant infestation of mango fruits by white mango scale, in Western Ethiopia. Ofgaa Djirata et al. (2018) also strengthen the above report that the build-up of mango scale population is affected by rainfall, a minimum average monthly rainfall of about 50 mm is required to initiate build-up of the scale population. The optimum rainfall for the insect to reach its peak population may vary spatially and temporally, as it was found to be 110 mm in April at Arjo and 140 mm in May at Bako. The build-up of the scale population coincides with the physiological maturity of mango fruit, both happening at the beginning of the rainy season in the study area. Also in his study stated that a swift population decline of mango scale followed prolonged heavy rain probably because the rain washes the scale off mango leaves. This finding agrees with study result of other countries such as Salem et al. (2015) who stated that low population density of white mango scale from the end of rainy season in Egypt. El-Metwally et al. (2011) also recorded low population of white mango scale during the rainy season. This condition was also supported by earlier study Moran et al. (1987) as it is evident that strong rain can kill small or immobile stages of insects.

The study by Ofgaa Djirata et al. (2018) in Arjo and Bako identified three phases of mango scale population fluctuation. In Arjo, the first phase was from February to July, when the population began to build up towards its peak; the second phase, in August, September and October was characterized by sharp decline of the population and the last one was from November to January during which the population remained low and inconspicuous. In Bako, the first phase began in February as in Arjo but continued to May only. In June, July and August, the population declined abruptly, denoting the second phase. The last phase in which population remained low to undetectable was between September and January in Bako.

Different studies in different countries were reported that different population fluctuations of mango white scale, some of these are study by Kwaiz and Fayza (2009) who stated that white mango scale had three peaks of seasonal abundance on mango trees in Egypt. These peaks were occurred on March, June and November, while the lowest population was occurred on mid-July. And also Abo-Shanab (2012) recorded four annual peaks of seasonal abundance for white mango scale on mango trees in Egypt. These peaks were occurred on April, August, October and December, 2008, while these peaks were occurred on March, July, September and December, 2009.

Temperature variation also affect the mango white scale populations, as stated by Ofgaa Djirata et al. (2018) peak populations were recorded in the months with maximum monthly temperatures of 35 and 31°C at Arjo and Bako of western Ethiopia, respectively, indicating that white mango scale tolerates higher temperatures. But this contradicted with the earlier finding of Labuschagne et al. (1995) that white mango scale had a low tolerance to high temperature, and as a result its population declined in temperatures above 30°C. The study by Bautista-Rosales et al. (2013) stated that males were mostly in the lower canopy of the trees, while females were distributed more homogenously. But as the temperature warmed, females moved toward the lower canopy, which is the coolest area of the tree

Labuschagne et al. (1995) stated that white mango scale stays as crawler for shorter period of time compared to sessile stages. This finding also supported by latest study Ofgaa Djirata et al. (2018) who stated that crawler-stage population of mango scale was much smaller than any of the other developmental stages throughout observation; because crawlers move to different parts of the host plant in search of suitable settling sites and may also be dispersed away from the plant by various factors all of which would reduce their numbers on the sampled leaves.

Damage symptoms: the study in Bench-Maji Zone of south west Ethiopia by Tsegaye Babege et al. (2017) reported that farmers identified the pest by colors and symptoms observed such as yellowing, defoliation, die back and white colors. The study in east Wollega by Tesfaye Hailu et al. (2014) also reported that the discussants of mango growers described the symptoms of the pest infestation on leaves whitish materials, spots and drop down from the tree, attack the stems basement of the leave, fruit with conveying its original color with varies spot, change color of the leaf after penetrate inside, fix on the root of the tree along by covering of white small fibers and increasingly substantial infested to poor growth and finally drying out the tree. The study in Central and Eastern Kenya by Ofgaa Djirata et al. (2016) also reported that the damages that the respondents believed to have been caused by the pest to mango plantation were spots on fruits, yellow spots on leaves, drying and falling off of leaves, and drying of young twigs.

The study in Western Ethiopia by Ofgaa Djirata and Emana Getu (2015) reported that the heavily infested premature fruits dropping and the mature fruits became small in size with lacking of juice. Mango white scale attacked the fruit leaving pinkish blemish on skin of matured and ripe fruits. White mango scale insect pest feeding style is by inserting its stylets in the soft parts of mango tree and sucks saps. As a result it causes yellowing of leaves, development of conspicuous pink blemish on mature and ripe fruit and dieback to mango plantation (El-Metwally et al., 2011 and Abo-Shanab, 2012). Juárez-Hernández et al. (2014) described high level of nutrient exploring potential of white mango scale by stating that it can pierce cell walls, even the lignified secondary walls of xylem by the use of its stylet bundles, resulting in severe damage to the crop. They described that the stylet bundles of the female insect is about 3 millimeters, which may be 3x the length of the insect body. Infestation in young trees may lead to excessive fall off leaves, retarded growth and death of the whole plant (Nabil et al., 2012).

The study in Mango Orchards of Nayarit in Mexico by Hodges and Harmon (2016) also reported that white mango scale does not cause direct internal damage to mango fruit but produces chlorotic spots. The discoloration 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). Haggag et al. (2014) reported that white mango scale attacks mango leaves, branches and fruit, where it causes superficial pink or yellow blemishes to develop, making the fruit unmarketable. In line with this, United States entered white mango scale in the list of pests that were of quarantine significance and underlined that further analysis should be put in to effect when mango and fresh longan fruits are imported in to the nation from India and Taiwan, respectively (USDA, 2006 and 2007).

Farmers, perception study by Tesfaye Hailu et al. (2014) reported that farmers, observation was taken as the pest is not selective for one or another type of mango varieties. Both improved grafted and local orchards were invariably attacked by the pest. Also Study by Ofgaa Djirata et al. (2016) that the respondents reported that all the mango varieties were affected by white mango scale but some stressed that the damage to Apple mango was more serious than other varieties. However it is reported that damage by the pest is not limited to mango plantation. However Erichsen and Schoeman (1992) reported that white mango scale was found feeding on avocado in South Africa. According to Borchsenius (1966) cited in Abo-Shanab (2012) stated that the pest has been recorded mainly from four plant families such as *Palmae*, *Lauraceae*, *Rutaceae*, and *Anacardiaceae* particularly from mangos and cinnamon. Malumphy (2014) white mango scale is a polyphagous pest which feeds on plants belonging to 18 families, even though it is a serious pest of mangos. The latest pest alert reported by Hamon (2016) stated that hosts of white mango scale are: Aceraceae: *Acer kawakamii*; Anacardiaceae: *Mangifera indica*, *Mangifera* sp. Arecaceae: *Cocos nucifera*; Iridaceae: *Dietes prolongata*; Lauraceae: *Cinnamomum camphora*, *Cinnamomum ceylanicum*, *Laurus nobilis*, *Litsea laurifolia*, *Litsea polyantha*, *Litsea pungens*, *Litsea sebifera*, *Machilus* sp., *Phoebe* sp. Pittosporaceae: *Pittosporum glabratum* and Rutaceae: *Citrus* sp. Sapindaceae: *Dimocarpus longan*.

2.4 Introduction of White Mango Scale in Ethiopia

In 2001 and 2002, a private farm called Green Focus Ethiopia Ltd introduced a new cultivar called Alphanso from India and was planted at Lako in Guto Gida Woreda of East Wollega zone of Oromia region, western Ethiopia. A study made in western Ethiopia confirmed that the variety introduced was highly infested with a new insect pest called white mango scale (Mohammed Dawd *et al*., 2012). Temesgen Fita (2014) also confirmed that farmers in the neighborhood of Green Focus mango farm land witnessed, for first time this insect pest on Green Focus mango plant and after a while it spreads to adjacent old cultivar mango plantations of the local farmers through seedling distribution. Accordingly, Mizan plant protection laboratory has reported the occurrences of this pest in Bench-Maji Zone in 2014. The pest was first observed in Guraferda district where commercial mango farm Seka is located (Tsegaye Babege *et al*., 2017).

Tsegaye Babege *et al*. (2017) reported that natural outbreak and spread of most scale insects are very minimal but survey from Bench-Maji zone indicated that the outbreak and spread of the pest is likely to be with planting materials that are hosts to this pest. Similar arguments were made by Gashawbeza Ayalew *et al*. (2015) reported that the pest introduction to the country is likely to be with planting materials or fruits that are hosts to white mango scale.

The study in Bench-Maji Zone of south west Ethiopia by Tsegaye Babege *et al*. (2017) reported that Majority of the respondent indicated that the pest is new for the locality. Tesfaye Hailu *et al*. (2014) reported that farmers had never ever seen such kind of problem in their mango farm and considered it as new experience for the people of east Wollega. The study in East and West Wollega Zones by Temesgen Fita (2014) also reported that majority of the respondents did not know the name and type of the mentioned insect pest. In Ethiopia white mango scale dispersed 100 km west of the original site, Green Focus Ethiopia Ltd. (Temesgen Fita, 2014) and 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 (Gashawbeza Ayalew et al. 2015).

2.5 Management of White Mango Scale

2.5.1 Management practice in Ethiopia for white mango scale

The study in Guto Gida and Diga Distrcts indicated that Grower farmers were opted to use variety of cultural practices to mitigate the effect of the pest in mango production. Cultural practices that growers, used such as smoking of mango tree for chess out the pest from the tree, washing with soluble ash and soap, thinning for spacing among the planted trees through removing the trees, adding the urination of goat over attacked mango tree, pruning to inhibit the transmission of the pest, removing the infected tress not to contaminate other normal tree or part of the tree, burning and keeping the sanitary of soil under the tree. However the farmer responded that the whole range of efforts made to combat the pest was only gave a temporarily relief (Tesfaye Hailu et al., 2014). Also Temesgen Fita (2014) reported that mango growers were undertaken cultural control methods like pruning, smoking and site clearing in wollega area.

Tsegaye Babege et al. (2017) reported that few farmers undertook control measure like pruning of heavily infested twigs and dense branches to eliminate infestations when infestations are on limited parts of the plant. After the occurrence of mango white scale in the commercial farm of Seka located in Bench-Maji Zone Gurafereda administrative districts in 2014 the farm sprays two broad spectrum synthetic chemicals such as Diazinon and Dimethoate to reduce pest damage. The farm also undertook cultural practice such as pruning of heavily infested branches and leaves. Meanwhile, field inspection made by the expertise team from Mizan-Tepi University had been realized that such managements were unable to avoid the pest in the entire farm and in fact in some tree the infestation even got worsen (Tsegaye Babege et al., 2017). It has been reported that commercial farms and government offices use a variety of broad spectrum insecticides to reduce the pest's damage in western Ethiopia (Mohammed Dawd et al., 2012 and Temesgen Fita, 2014).

The study by Temesgen Fita (2014) indicated that white mango scale management practices of Green Focus Ethiopia Ltd which is found at Loko Adminstrative kebele, Guto Gida district since the infestation observed in the early 2008 the farm started application of broad spectrum synthetic chemical insecticides (organo phosphates) by using tractor mounted sprayers and manual spray methods. The farm sprays Diaznon and Dimethoate chemicals two times a year before flower setting and after harvest. Additionally the farm practice opening of mango canopies (pruning) and mulching with savannah grass. With such continuous management practices the pest distribution and severity status was reduced when compared to small growers, farms, but still the farm does have the problem of the insect pest due to the spraying was carried throughout day time and the type of spray practiced by the daily workers did not completely cover the infested plants. However the farm is situated at hot and low land area having an average altitude of 1384 m.a.s.l and average minimum temperature of 26-34 ^{0}C. As a result chemicals sprayed at mid_day can simply evaporate and this condition can create pest resistance. So that it is suggested that complete spray coverage of infested plants (such as the underside of leaves) and knowing time of spray is needed to have good control. Thorough spray coverage is especially critical when treating species of armored scales like white mango scale, as these scales are generally less susceptible to pesticides than soft scales.

However the use of old broad spectrum insecticides for controlling WMS should be discouraged as they are ineffective in most cases and negatively affect the natural enemy population that aid in the natural control of the pest (Gashawbeza Ayalew et al., 2015). Bench-Maji Zone had been taken to resolve the problem of white mango scale infestation using destruction of infected seedlings and restriction in transfer of planting material. However, such measures were unable to reduce the prevalence and in fact in some district the pest infestation even got worse and worse over time (Tesegaye Babege et al., 2017). There was no proper control method practiced by the farmers. The main reason for this may be due to the unmanageable size of local cultivars (Tsegaye Babege et al., 2017).

2.5.2 Different management approach for white mango scale

Cultural control: Cultural pest control is a practice of manipulation of a crop's planting, growing and cultivation with the purpose of reducing pest number and its damage to the crop under consideration (Waskom, 1995). Tesfaye Hailu, et al. (2014) from expertise point of view recommends clearing of different weed species from the surrounding and other plant residue and cutting of the all infected canopy of the tree and good management practice for newly emerging coppice can be used for the control of white mango scale. Only propagate from clean mother stock plants; remove crop debris and disinfest the growing area since scale may survive for weeks on crop debris and in egg masses that have fallen off plants;

avoid movement of infested plant material within the growing area; avoid staff movement in areas known to be infested with scale insects; If necessary, disinfest clothing and equipment after working in such areas; Provide an optimal growing environment, including appropriate nutrition, water, growing media and other conditions; weak plants are more susceptible to damage at lower populations of pests; control ants as they spread crawlers and protect scale insects from natural enemies; keep the growing area and surrounds free of weeds; ensure adequate plant spacing which allows greater air movement and increases pesticide coverage and also reduces ideal environments for scale insects to develop and increases the ease of detection (Andrew, 2016).

Post-harvest pruning is an effective control measure and also helps the penetration of chemical sprays through the tree canopy (Cunningham, 1989). The study of Bautista-Rosales et al. (2013) stated that pruning significantly reduced the number of females per leaf in both kinds of conventional and organic management of mango plantations, but was most evident in organic plantations where females per leaf decreased significantly and the increase in abundance of males per leaf was not significant. Pest control measure using pruning is recommended before the flower induction and right after harvest, it can be done by removal of undesirable vegetative parts, crowded branches, insect-infested and diseased branches, leaves, flowers and other plant parts. Small branches were cut first followed by large branches and all debris will be removed to clean the surroundings (William, 2009).

Pruning is an important cultural operation for obtaining quality yield from the fruiting trees, which involves judicious removal of vegetative parts. An unpruned tree becomes very large, which inhibits light penetration inside the canopy. As a result, leaf spread decreased, photosynthetic activity remains low and high incidence of pests and disease occurs due to high relative humidity (Lal and Mishra, 2007). Sunlight not only influences the flowering and fruit set, but also enhances quality and colour development of fruits (Hampson et al., 2002). For this reason, fruits in the top of the tree always have better quality than fruits in the lower shaded part of the canopy (Crisosto et al., 1997). Several studies have been conducted on pruning in the mango tree in relation to better light penetration, fruit set and yield in pruned trees (Shaban, 2009 and Sharma and Singh, 2006). Lal et al. (2000) reported poor mango fruit yield during the first year after pruning, which kept increasing in the successive years. Fruit yield of pruned trees was found to decrease during the first year compared with the fruit yield of unpruned trees; later on, it become increased during the second year. Pruning resulted in significantly higher fruit weight, fruit firmness, total carotenoids, antioxidant capacity and total phenolic content (Ram et al., 2013)

The study by Bautista-Rosales et al. (2013) recommends that agronomic practices used in the conventional plantation to combat the white scale did not offer better results than those used in organic plantations against white mango scale. However, these seemed to be more efficient than excessive fertilizer use. A proposal for management of white mango scale is rational use of the compounds and appropriate pruning. These can be done after the season when white scales are least abundant.

Mechanical Control: Mechanical methods bring about reduction or suppression of insect populations. Minor scale infestations on small houseplants can be removed using cotton balls or swabs to brush rubbing alcohol onto the plant (Mark et al., 2019). Tesfaye Hailu, et al. (2014) from expertise point of view recommend that kill white scales by rubbing then off with fingers and if possible; dislodge scales by hosing down plants frequently and use a high pressure stream of water to dislodge scales. Double-sided sticky tape to a stem above a scale infestation. Crawlers that are moving to new locations will become caught on the tape. Crawlers move toward light. Placing the tape above the scale infestation will increase monitoring of scale crawlers (Mark et al., 2019). Andrew (2016) reported that when only a small number of plants are present with a low rate of infection, squash scale insects and egg batches using rubber gloves. The presence of a small number individuals should prompt regular and rigorous inspections of the consignment.

Physical Control: Physical control methods in crop protection comprise techniques that limit pest access to the crop, induce behavioural changes, or cause direct pest damage or death. The primary action is attained through stress responses or reduce pest populations by affecting pest physically or alter their physical environment, viz. application of heat, application of cold, and manipulation of moisture (Charles and Guy, 2009). Tesfaye Hailu, et al. (2014) from expertise point of view recommends that mulching improve natural enemies and soil fertility for checking white mango scale population.

Biological control: Mango white scale insect pest is under good biological control in most other mango producing countries and therefore it was decided to introduce an exotic biological control agent and try to establish it in different mango producing areas. Both the parasite and predators were successfully augmented, released into mango orchards and became well established (Labuschagne and Pasques, 1994 and Daneel and Dreyer, 1998). The predatory thrips (Auleurodothrips fasciapennis Franklin) and the parasitoid (Aspidiotiphagus citrinus) were reported as the most important biocontrol agents of white mango scale in South Africa (Labuschagne and Pasques, 1994). It has been demonstrated that some Chilocorus species are important biological agents for the control of armoured scales (Greathead and Pope 1977; Charles et al. 1995; Boothe and Ponsonby 2006; Ponsonby 2009 and Entocare and Wageningen, 2015). However study by Ofgaa Djirata et al. (2017) reported that Chilocorus species larvae preying on A. tubercularis in Ethiopia were recorded for the first time. The density of the predatory larvae population recorded in the study area was very low, probably due to recent introduction of A. tubercularis to Ethiopia and consequently a very recent association of the predator with the pest. Therefore, population of Chilocorus species may gradually build up in the future.

Nabil et al. (2012) recorded Aphytis and Encarsia species (Aphelinidae), Habrolepis diaspidi Risbec (Encyrtidae) as parasitoids and Cybocephalus micans Reitter as predator of white mango scale in Egypt. Similarly, Abo-Shanab (2012) recorded little numbers of natural enemies which included parasitoids such as Aphytis mytilaspidis Le Baron and Encarsia citrina Craw, and a predatory beetle, Scymnus syriacus Marseul in the same country. The predatory thrips, Aleurodothrips fasciapennis Franklin and parasitoid Encarsia citrina Craw were also recorded as natural enemies of white mango scale in South Africa (Labuschagne et al., 1995).

Botanical Control: Botanical insecticides can be recommended as an Eco chemical and sustainable strategy in the management of insect pests. Because of their biodegradable nature, systemicity after application, capacity to alter the behaviour of target pests and favourable safety profile (Prasannath, 2016). Scale insects were suffocated by oils and dried out by insecticidal soaps disrupt the waxy cuticle or €skin• of the insect, which eventually causes the insect to dry out or desiccate and die (Mark et al., 2019). White oil is recommended for control of white mango scale by Ambo Plant Protection Research Center (Tesfaye Hailu, et al., 2014). White oil extract can be prepared by taking an empty jar or plastic bottle, ordinary cooking oil is poured in a cup (approximately 250ml) and mixed with ¼ cup of dishwashing liquid and shaked well finally turned to white. The sprayer tank is first half filled and then one tablespoon or approximately 10ml per 1 liter of water will be added and mixed well. Dosage rate of white oil should be taken as care because too much oil will cause leaf burn and the spraying time should be taken place after 11 hours to avoid using it in very hot weather (over 25°C) because it can also burn foliage (https:// www. organicgardener.com.au/ blogs/home-made-pest-remedies, retrieved on 01 June 2018). Tesfaye Hailu, et al. (2014) from expertise point of view recommends that botanical insecticide like pyrethrums and rotenone can be used for the control of white mango scale. Pyrethrums are effective against many sucking insect pests which kill insects by interrupting their nerve impulses. Rotenone is a powerful inhibitor of cellular respiration, the process of converting cell nutrients into energy. It acts primarily in insects, nerve and muscle cells, causing them to stop feeding quickly (David, 2019)

Using of Pesticide: Chemical control using insecticides was the most efficient method to minimize sucking pest damages to crop production, although such practice is hazardous to water, soil, environment and human health. That may be due to the misuse of chemical insecticides. On the other hand, the increasing incidence of resistance to many conventional insecticides has led to the development of large number of new active compounds such as the neonicotinoides which were introduced as an alternative to the organophosphate, carbamate and pyrethroid insecticides. Neonicotinoides have been the fastest growing class of insecticides in modern crop protection with wide spectrum effect against sucking and certain chewing insect pests (Jeschke and Nauen, 2008). Organophosphates insecticides like chloropyrifos, methidathion, dimethoate 40% EC, to control white mango scale on mango tree match with many earlier studies (Howard, 1989). USAID Kenya Business Development Services Program recommended deltametrine and pyrethrin to be used for the control of white mango scale in Kenya (Findlay, 2003).

Ofgaa Djirata (2017) reported that limited experiments performed regarding insecticide screening against white mango scale in Ethiopia since the insect introduced in Ethiopia has been less than a decade. Gashawbeza Ayalew et al. (2015) tested movento and methidathion, and reported they had equal efficacy in reducing white mango scale infestation on mango in Central Rift Valley of central Ethiopia. Study by Ofgaa Djirata (2017) reported Folimat 500SL was found to be the most effective compared with D-D-Tron and Closer insecticides. It was reported that mango farmers in central and eastern Kenya were using this product to have controlled white mango scale. In general, pertaining to its waxy covering, the commonly used contact insecticides cannot penetrate into the body of white mango scale from its cuticle (Buss and Turner, 2006). Therefore systemic insecticides and horticultural oils that may suffocate the pest are the most used formulations for the control of white mango scale. Applaud is recommended for control of white mango scale by Ambo Plant Protection Research Centre (Tesfaye Hailu, et al., 2014). Insect growth regulators like azadirachtin and pyriproxyfen interfere with an immature scale insect,s ability to molt (shed its outer skin to allow for growth); in some cases, insect growth regulators suppress egg development. Although these insecticides often act more slowly than contact insecticides, they can effectively control scales (Mark et al., 2019). Andrew (2016) reported that imidaclopride and Dimethoate active ingredients are registered for scale control for fruit and citrus crop in Australian agriculture.

Imidacloprid, a new class of neonicotinoid insecticides, is potently replaced with different toxic and hazardous insecticides due to their unique mode of action (nicotinic acetylcholine receptor agonist or acetylcholine mimic) and comparatively less toxicity to human and environment. Imidacloprid is a new class of insecticide and its potency against sucking insect is well reported in different countries of the world (Hegde and Nidagundi, 2009 and Patil et al., 2009). Some recent studies show that imidacloprid gives an outstanding result against sucking insects (Kerraddai and Balikai, 2012 and Joshi and Sharma, 2009). Qureshi et al. (2011) reported that the populations of nymphs and adults of mango leaf hoppers and scale insects were significantly reduced by thiamethoxam and imidacloprid. It is comparatively safer than other conventional insecticides and once it is applied, the action continued for a longer period. On the other hand, the action of imidacloprid persisted at least up to day 10 which raises the possibility that once it enters into the plant system, the imidacloprid remains comparatively for a longer period of time (Robson et al., 2007 and Shi et al., 2011). Varghese (2000) conducted experiments on mango varieties, Alphanso and Bangampalli showed that imidacloprid recommendation dosage between 0.2 to 0.8 ml/liter was found effective. Imidacloprid 20SL is registered for the control of aphids (Macrosiphum euphorbiae) on potatoes in Ethiopia (MoA, 2016).

Swaminathan et al. (2010) reported that dimethoate was effective in reducing the effect of sucking insect pest. Earlier study by Howard (1989) showed that Dimethoate 40%EC was used for control of white mango scale. Dimethoate 40% EC which is registered for the control of beanfly (Ophiomiya phaseoli); Bean aphid (Aphis fabae); Thrips (Taenothrips spp.) ABW (Helicoverpa armigera) on 26 French beans; for the control of aphids (Myzus persicae) and ABW (Helicoverpa armigera) on tomato and for the control of cabbage Aphid and various aphids on cabbage and potato, respectively (MoA, 2016).

Mineral oils against homopterous insects is encouraged. Mineral oils are valuable insecticide materials because they have little residual toxicity for beneficial insects as mentioned by (Abo-Shanab, 2005 and Helmy et al., 2006). Abo-Shanab (2012) describes that a series of field test of three mineral oils against white mango scale showed effectiveness by the following descending order of efficacy : Diver® > CAPL2® > super masrona®, the first two being statistically not different from each other. The timing of oil sprays is important, as adverse effects such as reduced flowering, oil burns and fruit drop may occur if timing is incorrect (Brooks, 1992).

Integrated pest management: Integrated pest management is a pest management philosophy that utilizes all suitable pest management techniques and methods to keep pest populations below economically injurious levels. An integrated pest management alternative could be applied that would consist of a combination of pesticides, cultural practices and the use of biological control agents (Dale, 2002). Monitoring of mango white scale monthly throughout the year helps to prevent severe problems from occurring as the mango scale is present all year round become peak during flowering and harvest (Tsegaye Babege et al., 2017). Population peaks of scale crawlers is an essential finding for control of the pest through targeting the crawler stage, which is sensitive to both systemic and contact insecticides (Buss and Turner, 2006).

Pesticide application in mango orchards resulted in high mortality of endemic parasitoid (Labuschagne and Pasques, 1994, Labuschagne and Froneman, 1992). The study by Bautista-Rosales et al. (2013) recommends biological control by conservation can be implemented using natural enemies of the insect pest, combined with products such as soap and citroline that have low toxicity and less environmental impact than insecticides such as Malathion. Suresh et al. (2007) reported that efficacy of insecticides on sucking insect increased when applied in combination with soaps and oils. Implementation of integrated pest management based on organic inputs and biological control would more safely produce mango with added value. Scales infesting houseplants can be controlled using a commercially available insecticidal soap or make your own soap solution by diluting a mild dishwashing detergent. If possible, dip the entire plant into the soap solution, otherwise thoroughly cover all plant parts using a hand-held sprayer (Mark et al., 2019). Management of mango white scale requires strict inspection of planting materials transfer and destroying any planting materials after proof of WMS presence and provide farmers with high quality planting material, and multiply the local cultivar in large number by grafting technique using desirable characters of which may shorter in height which facilitate various cultural operations and chemical spraying (Tsegaye Babege *et al*., 2017).

3 MATERIALS AND METHODS

3.1 Survey of White Mango Scale

3.1.1 Description of survey area

The study area is located in the Benishangul-Gumuz Regional State. The region has three zones and one special district. Benishangul-Gumuz Regional State is found at 687 km away from the capital city of the country, Addis Ababa, in the west. It is located at 9°30′ - 11°30′ latitude and 34°20′ - 36°30′ longitude. The region is bordered with the Sudan in the west, Amhara Regional state in the east and north, Oromiya Regional state in the East and south east and Gambella Regional state in the South. It covers a total area of about 50,380 km². Plain undulating slopes and mountains characterize the topography of the region. The altitude of the region ranges mainly between 580 and 2731 meter above sea level. The average annual rainfall is 800-1600mm and the annual ambient temperature varies from 17-29°C (NMA, 2015).The agro climatic zonation of the region can be categorized as 75% Kola, 24% Woina Dega, and 1% Dega. Major crops grown include: Maize, sorghum, soya bean, Mango, Banana, Lemon, Orange and others (BGRS BoA, 2017). Major mango growing zones in the region are Assosa and Metekel Zones and mango is produced by 87,230 smallholders and covered an estimated area of 1,191.68 ha and almost half of the growers are from Assosa zone (CSA, 2017).

Bambasi is one of the district in Assosa Administrative Zone in the Region situated 45 km in North East part of the Assosa town and located at a distance of 610 Km from Addis Ababa and 45 Km from administrative city of the Region Assosa. The district geographically lies between 9‡45′ latitude and 34 45′ longitude. The total area is about 120 km² of land (BGRS BoA, 2017). It is located in 1100-1450 meter above sea level. The average annual rainfall is 1350-1450mm and the annual ambient temperature varies from 21-35°C (NMA, 2015). The major crop grown in the area are Maize, sorghum, soya bean, Mango, Banana, Lemon, Orange and others (BGRS BoA, 2017).

Assosa is the district in western Ethiopia and capital of the Benishangul Gumuz regional state located in Assosa Administrative zone. The district is geographically lies between 10°04′ - 10.067° latitude and 34°31′ - 34.517° longitude. It is 687 km away from Addis Ababa. The total size of the area is about 2317 km² (BGRS BoA, 2017). It is located in 1401-1544 meter above sea level. The average annual rainfall is 900-1200 mm and the annual ambient temperature varies from 21-31°C (NMA, 2015). The major crop grown in the area are sorghum, maize, soya been, ground nut, sweet potato, banana, mango and others (BGRS BoA, 2017). Figure 3.1 showed the study Location map of both Bambasi and Assosa districts.

Figure 3.1. Location map of the study site

3.1.2 Assessment of mango orchards for scale

White mango scale infestation assessment was conducted from August 2018 to April 2019 for nine consecutive months. Multi stage sampling procedure was adopted in the choice of sample mango orchards and household heads for this study. At first stage Assosa zone was selected purposively on the basis of being a prominent mango producing and white mango scale infestation areas. In The second stage the study districts of Assosa and Bambasi were selected by purposive sampling technique based on major mango farm production and white mango scale infestation problem in the Zone. In the third stage the study Kebele administrates were selected by proportional sampling technique based on area coverage of mango production in two areas that means more number of Kebele administrates were selected in the highest production areas and less number of Kebele administrates in low production areas. Mango producing kebele administrates 10% from each district four in Assosa district such as: Amba_14, Amba_5, Amba_8 and Megele_32 and three in Bambasi district such as: Mender_47, Mender_48 and Sonika a total of seven kebele administrates were selected by using a commonly accepted approach known as the rule of the thumb (Mulat Demeke, 2000). In the fourth stage a total of 35 mango producing households holding a minimum of ten mango trees per orchard in the two mango producing districts, five mango orchards from each Kebele administrate within 5-10km interval along the main and accessible road side were selected by systematic sampling method. Within each orchard of assessments, one mango tree was selected and tagged from more or less the most central point of the orchard. Hence, 20 (57.15%) and 15 (42.85%) of the sampled mango orchards and households were from Assosa and Bambasi districts respectively.

Even though the leaves, twigs and fruits of mango were attacked by white mango scale for easy count rating had been done by counting the clusters they form on the leaves to study the infestation status of white mango scale. The sample leaves were selected from the top, middle and bottom mango canopy horizon by stratified sampling method. So that ten leaves were randomly picked three at the top, four at the middle and three at the bottom parts from each tree once within a month for nine consecutive months for counting the clusters of white mango scale formed on leaves. Hence, 90 leaves from each tree and a total of 3150 sample leaves, 1800 and 1350 sample leaves were selected from Assosa and Bambasi respectively. These samples leaves were kept in polyethylene bags and transferred to the laboratory for counting procedures as the method used by Temesgen Fita (2014); Tsegaye Babege et al. (2017) and Ofgaa Djirata et al. (2016 and 2018). The presence or absence of cluster was observed by hand lenses observation on both upper and lower surfaces using identification key (Appendix Table 3). When present, the number of the cluster on every leaf was recorded.

The infestation and the degree of damage was recorded by using a scoring method from 0 to 5 scale as, free = <5% of the panicle destroyed, minimal damage = 5 to 24% of the panicle destroyed, moderate = 25 to 50% damage, severe = 51 to 70% damage and very severe = 71 to 100% damage (Williams et al., 2009). So severity status of the infestation as used by Temesgen Fita (2014) was rated and categorized based on cluster number per leaf can be related to each other as: <1 = < 5% (Free or Zero for less than one cluster formation), >1.0 - 2.0 = 5 to 24% (Minimal for greater than one and less than two clusters formation per leaf), >2.0 - 4.0 = 25 to 50% (Moderate for greater than two and less than four clusters formation per leaf) >4.0 - 5.0 = 51 to 70% (Severe for greater than four and less than five clusters formation per leaf) and >5 = 71 to 100% (Very Severe for greater than 5 clusters formation) of leaves damaged as seen in Appendix Figure 1.

During the assessment, the coordinates of each assessed site was recorded by the use of GPS and metrological data like rain fall, relative humidity and temperature was taken from Assosa metrological station for both Assosa and Bambasi districts. However relative humidity was obtained from the station for only Assosa district.

3.1.3 Mango growers, assessment

The farmers, assessment was done from September 20 to October 5, 2018. Mango growers, of 20 (57.15%) and 15 (42.85%) from Assosa and Bambasi districts respectively which were used for field assessment of white mango scale survey were in turn used for farmers, assessement. Assessment of farmers, view about white mango scale damage to mango tree, questionnaires were distributed to 35 mango orchard owner and interviewed. A well-structured questionnaire and face-to-face survey approach methods were conducted to gather information from the respondents while they were in their respective mango fields.

The characteristics of mango growers, used for the assessment were described in Table 3.1. The gender composition was 32 male and 2 female. The age range of 27 and 8 mango growers, were 21 ƒ 50 and above 51 years respectively. The mango growers, holding household sizes of 5 ƒ 10, less than 5 and above 10 were 22, 11 and 2 household number respectively. The education status who joined standard, informal and secondary education was 24, 6 and 5 mango growers, number respectively. Mango trees holding of 10 ƒ 20, 20 ƒ 40 and greater than 40 were possessed by 29, 3 and 3 mango growers, number respectively. Age of mango trees possessed by growers, above 20 years, between 10 ƒ 20 years and below 10 years were 17, 10 and 8 mango growers, number respectively. The growers, mango trees majorly attacked by white mango scale insect pest.

Table 3.1. Mango growers' characteristics and mango tree possession

Variable	Frequency	Percent
Gender		
ð§ Male	32	91.4
ð§ Female	3	8.6
Age of Respondent		
ð§ 21 ƒ 30	8	22.9
ð§ 31 ƒ 40	9	25.7
ð§ 41 ƒ 50	10	28.6
ð§ 51 ƒ 60	5	14.3
ð§ 61 ƒ 70	3	8.6
Education		
ð§ No Formal Education (0 Grade)	6	17.1
ð§ Standard Education (1-7 Grades)	24	68.6
ð§ Secondary Education (8-12 Grades)	5	14.3
Household Size		
ð§ <5	11	31.4
ð§ 5_10	22	62.9
ð§ >10	2	5.7
Age of Mango Plantation		
ð§ Below 10 Years	8	22.9
ð§ 10 - 20 Years	10	28.6
ð§ Above 20 Years	17	48.6
Number of Mango		
ð§ 10_20	29	82.9
ð§ 20 - 40	3	8.6
ð§ >40	3	8.6
Major Pest		
ð§ White mango scale	25	71.4
ð§ Fruit Fly	13	37.1
ð§ Anthracnose	20	57.1
ð§ Powdery Mildew	18	51.4
ð§ not aware	10	28.6
Total	35	100

3.1.4 Collected survey data

The qualitative and quantitative data were collected during mango tree assessment with their respective farmers' interview. Data collected for white mango scale infestation status from the assessed mango trees were (1) sampling date (2) Mango orchards characteristics/age, height, canopy size, planting pattern, weed, intercropping condition (3) Mango varieties (4) mean number of white mango scale cluster per leaf (5) Spatial data like Altitude, latitude, longitude (6) Severity of infestation (free, minimal, moderate, severe, very severe) and (7) metrological data like Rain fall, Relative humidity and Temperature

Mango growers, assessment data collected were (1) white mango scale insect pest introduction periods (2) Knowledge of the pest (3) Yield loss estimation (4) Dispersal mechanism (5) Pest trend over time (6) Seasonal and farm site infestation variability of white mango scale insect pest infestation (7) Management practices and (8) Extension service condition.

3.1.5 Statistical analysis of the survey data

The data from the survey questionnaires were analysed by descriptive statistics with SPSS software, version 20. The severity of the pest and its distribution in the study areas were tested by counting white mango scale cluster formed on mango leaves and analysed using a general linear model (PROC GLM). Whenever the F-test was significant, significant means were separated by Fisher‚s Least Significant Difference (LSD) at 5% or 1% error level. For two different groups, t-test was used for comparison using PROC TTEST at 5% or 1% error level. Count data of white mango scale was subjected to square root transformation ($\sqrt{(+ 0.5)}$) before analysis to stabilize the variance. Homogeneity of variance of the sample was tested using levene‚s test before and after data transformation ($p > 0.05$) (Gomez and Gomez, 1984 and SAS Institute, 2009). The data were reported in the text using the back transformed values.

The effect of explanatory variable of mango orchard characteristic factors which determined the severity status of the responsive variable of white mango scale categorical data were analysed by odds ratio to measure the strength of the association and Chi Square (X^2) test for the significance at 5% error level using cumulative logit model of PROC LOGISTIC PROCEDURE (Gomez and Gomez, 1984 and SAS Institute, 2009). Microsoft Excel was used to summarize survey data

Spatial and seasonal distribution map of white mango scale was drawn by (QGIS) software from the GPS file using the recorded coordinates of each survey site.

3.2 Field Experiment

3.2.1 Description of the experimental site

Field experiments were conducted at Assosa district in Assosa Administrative Zone, woreda-1 ketena-5, Ethiopia. The specific experimental site lies between $10^0$3,21,, to $10^0$3,16,,N latitude and $34^0$33,18,, to $34^0$33,20,,E longitude and a mean altitude of 1554 meter above sea level. The site is located in Assosa polytechnique mango orchard which was selected purposively by looking accessible uniform size mango trees, naturally infested by white mango scale and easy access to road for day to follow up of the site. It is 687 Km far from Addis Abeba. The major crop grown rounding the area was sorghum, maize, soya been, ground nut, sweet potato, banana and mango fruit (BGRS BoA, 2017).

Figure 3.2 Location map of the experimental sites

3.2.2 Experimental materials

The field experiment was conducted to evaluate the effective management option of eight treatments such as Imidacloprid 20SL, Dimethoate 40% EC, white oil extract, pruning, Imidacloprid 20SL + Pruning, Dimethoate 40% EC + Pruning, white oil extract + Pruning and untreated control (Appendix figure 5).

Imidacloprid 20SL 0.8ml per 1 liter of water dosage rate was used for this experiment. First 5 liter of water was filled in the sprayer tank and then 4ml of Imidacloprid 20SL was added and well shaked and then sprayed for a single mango tree (Varghese, 2000). Dimethoate

40%EC 0.75ml per 1 liter of water dosage rate was used for this experiment. First 5 liter of water was filled in the sprayer tank and then 3.75 ml Dimethoate 40%EC was added and well shaked and then sprayed for a single mango tree (MoA, 2016). White oil extract was prepared by taking an empty plastic bottle, pure edible oil (Trade name: Sekina) was poured in a 250ml cup and mixed with 62.5ml of hand dish wash liquid detergent (Trade name: BEKAS Sine) and shaked well finally turned to white. The sprayer tank was first filled by 5 liter of water and then 10ml from prepared white oil per 1 liter of water calculated a total of 50ml of white oil was added and mixed well and used for a single mango tree for this experiment (https:// www. organicgardener.com.au/ blogs/home-made-pest-remedies, retrieved on 01 June 2018). Average water requirement used for spray was 5 liter per tree. Pruning was done for 12 randomly selected mango by removal of undesirable vegetative parts, crowded branches, insect-infested and diseased branches, leaves, flowers and other plant parts. Small branches were cut first followed by large branches and all debris was removed to clean the surroundings (Williams et al., 2009).

Table 3.2. Dose and formulation of insecticides

Insecticide	Active ingredient	Dosage rate	Mode of application	Source
Gain 20SL	Imidacloprid 20 SL	0.8ml / 1Liter of water	Foliar spray	Chemtrade International
Agro-Thoate 40% EC	Dimethoate 40% (W/V)	0.75 ml / 1Liter of water	Foliar spray	Chemtrade International
White oil extract		10ml /1 Liter of water	Foliar spray	Homemade

Pure edible oil: Tradename - Sekina
Hand dish liquid detergent: Trade name / BEKAS Sine

3.2.3 Treatments, experimental design and procedures

The mango trees at experimental site (Assosa poly technique college mango farm) were used as experimental trees (Appendix figure 6). Mango trees selected for pruning were treated during August 1-15/2018 before the flower induction and right after harvest before spray and spray was taken place during active stage of mango flowering stage (Williams et al., 2009). Mango trees were sprayed three times with the interval of two weeks during December 15-30/2018 and January 15/2019 after 11:00 hour using motorized knapsack sprayer and an untreated check were maintained for comparison purposes. In this experiments Dimethoate 40% EC and Imidacloprid 20SL are systemic insecticides and home-made white oil treatments were arranged separately as well as in combination with pruning.

The experimental design was arranged in a simple randomised complete block design (RCBD) with three replication. The treatments were eight and three mango trees per treatments were used as three replication in each treatment. A total number of 24 mango trees were used in this experiment. Uniform size, same age (16 years old age) and cultivar mango trees (Kent) were selected for experimental unit. Drift problem was protected by using breaker of a plastic cover of the neigbouring mango trees canopy during spraying. The control was wetted three times with water to avoid moisture difference between treatments. All agronomic practices were kept the same among the treatments during experimental period.

Table 3.3. Treatment types for the experiment

Treatment Code	Treatment Application Rate
(T1)	Imidacloprid 20SL@4ml/5 Liter water
(T2)	Dimethoate 40% EC@3.75ml/5 Liter water
(T3)	White oil extract @50ml l/5Liter water
(T4)	Pruning
(T5)	Imidacloprid 20SL@4ml/5Liter water+ pruning
(T6)	Dimethoate 40% EC@3.75ml/5 Liter water + pruning
(T7)	White oil extract @50ml l/5 Liter water+ pruning
(T8)	Untreated Control@ 5 Liter water

3.2.4 Data collection for the experiment

Experimental data from the treated and untreated control were collected randomly three from lower, four from middle and three from top of canopy a total of ten sample leaves and 30 sample leaves from each treatment. The mean number of white mango scale population (sum of live nymph and adult) per 10 leaves before and after the treatments application were taken as the methodology used by Gashawbeza Ayalew et al., 2014 and Ofgaa Djirata et al., 2017. Mean number of white mango scale population per 10 leaves prior to treatment application and Mean number of insects from post treatment was used to assess efficacy of the suggested management option.

The average mango fruit number and yield in Kilo gram per tree per treatment was determined during March and April at harvest. During each sampling time the marketable quality of the fruits was subjectively assessed and judged using a 1-9 rating scale with 1=unusable, 3=unsalable (poor), 5=fair, 7=good, 9=excellent to evaluate the fruit quality.

The size, color, firmness surface defects, sign of pest and shrinkage were used as visual parameters for the rating. Fruits that received a rating of five and above were considered marketable while those rated less than five were considered unmarketable (Mohammed et al., 1999).

3.2.5 Data analysis

Mean number of live nymph and adult of white mango scale per ten leaves per tree per treatment were taken and subjected to analysis. The treatment effect on white mango scale population and mortality were analysed using general linear model (PROC GLM). Count data of white mango scale was subjected to square root transformation ($\sqrt{x}$) and mortality percentages data was subjected to arcsine/angular transformation before analysis to stabilize the variance. Homogeneity of variance of the sample was tested using levene,s test before and after data transformation ($p < .05$) (Gomez and Gomez, 1984 and SAS Institute, 2009). The data were reported in the text using the back transformed values.

Percent reduction in white mango scale population over control was worked out after each treatment using Abbott,s (1925) formula of mortality correction:

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

Where n in T = Population in the treated plot after treatment; n in Co = Population in control after treatment

The treatment effect on average fruit number and yield in Kilogram per tree per treatment were taken and subjected to analysis by using the methods described by Gomez and Gomez (1984) using a general linear model (PROC GLM). Whenever the F-test was significant, significant means were separated by Fisher,s Least Significant Difference (LSD) at 5% or 1% error level. For two group means t-test was used for comparison using PROC TTEST at 5% or 1% error level (Gomez and Gomez, 1984 and SAS Institute, 2009). Microsoft Excel was used for data summary.

3.2.6 Cost-benefit analysis

Cost-benefit analysis using partial budget analysis were subjected to agricultural business (CIMMYT, 1988).

Marginal analysis as used within this context is a procedure for calculating marginal rates of return between treatments, proceeding in a stepwise manner from a lower-cost treatments to the next higher-cost treatments, and comparing marginal rates of return to acceptable minimum rates of return. The minimum acceptable rate of return without asking producers what they considered to be a reasonable rate of return, researchers noted that experience and empirical evidence suggest that a rate between 50% and 100% seems adequate. If the technology is new and requires learning new skills, then the upper-bound should be used. In cases where switching technologies simply represents an adjustment, then the lower-bound may be acceptable. An alternative approach to estimating the minimum rate of return is to double the rate of interest charged by the lending institution. In this context as the experiment was new for the recommendation domain, the upper bound 100% was used as minimum rate of return for selecting profitable treatments.

The marginal rate of return was computed as the marginal net benefit (i.e. the change in net benefits) divided by the marginal cost (i.e. the change in costs), expressed as a percentage.

$$MRR = \frac{DNI}{\quad}$$

The €net benefits• of different treatments were determined by first calculating the €gross field benefit• and the €total costs that vary• in switching treatments. The gross field benefit for each treatment was obtained by multiplying the €adjusted yield• by the farm gate price. The adjusted yield was represented by a fraction of 0.9 of the average marketable yield which obtained under an experimental condition. The farm gate price used in the analysis was the price that the producer receives less any harvesting and marketing costs. The price of mango fruits was based on the average farm gate price of fruit between March and April, obtained from personal communication with mango fruit producers around Assosa main market and .Gulit, which were the nearest market to the experiment site. The total costs that vary for each treatment was computed as the sum of ONLY those costs that were expected to change by using another treatment. The net benefit for a given treatment was then obtained by subtracting the total cost from the gross field benefit. The dominance analysis was done by sorting the treatments on the basis of costs from the lowest to the highest, together with their respective net benefit. The conclusion of a marginal analysis was also checked by using the concept of ……residual,, which was calculated by subtracting the return that farmers require (the minimum rate of return multiplied by the total costs that vary) from the net benefits.

4 RESULTS AND DISCUSSION

4.1 Survey of White Mango Scale

4.1.1 Mango growers' assessment

White mango scale insect pest introduction periods: Table 4.1 illustrates introduction periods of white mango scale in the study areas of Assosa and Bambasi districts. Majority 86% of respondents were replied that the pest was new for the area, but only 14% of the respondents replied that they were familiar with the pest. The period of introduction in to the study was perceived as respondents of 51.4% replied that the pest had been stayed for about 2 – 5 years in their orchards. Respondents of 5.7% and 31.4% were replied that below 2 years and above 5 years respectively and respondents of 11.5% had no any evidence about the period of the pest introduction in the surveyed areas. These implied that the pest was new and introduced at most 5 years and in a few areas more than 5 years even though there was a variation of introduction period in different mango orchards. Similar study results in different mango growing areas also showed that the mango white scale was the newly introduced pest.

The study by Tsegaye Babege et al. (2017) reported that Majority of the respondent in Bench-Maji Zone of south west Ethiopia indicated that the pest is new for the locality. Tesfaye Hailu et al. (2014) also reported that farmers had never ever seen such kind of problem in their mango farm and considered it as new experience for the people of east Wollega. Similarly the study in East and West Wollega administrative Zones by Temesgen Fita (2014) reported that majority of the respondents did not know the name and type of the mentioned insect pest.

Table 4.1. White mango scale introduction periods

Variable	Percent
New pest for the study area	
• Yes	86
• No	14
Introduction period	
• Below 2 years	5.7
• 2 - 5 years	51.4
• Above 5 years	31.4
• Not aware	11.5

White mango scale insect pest damage and identification methods: Table 4.2 illustrates growers, perception on white mango scale damage and identification methods in the study areas of Assosa and Bambasi districts. Respondents of 74.3%, 51.4%, 25.7%, 17.1% and 40% were observed that the pest damaged mango tree Leaves, Fruits, Twigs, Branches and Whole tree parts, respectively. Majority of the respondents observed that the leaves and fruits were the most plant parts attacked by the insect pest. These result supported by the study result of Haggag et al. (2014) who reported that white mango scale insect pest damages mango leaves, branches and fruit, where it causes superficial pink or yellow blemishes to develop, making the fruit unmarketable.

Growers, identification methods were perceived as respondents of 94.3% and 60% were used sign and symptom respectively for identifying the pest from another pest. Growers perceived that white, pink, grey, and yellow color as a sign tool and leaf defoliation, stunting and distortion of fruit, die back of twigs and branches, premature fruit drops and drying of flower as a symptom tool for identification of the pest. Majority of respondents of 91.4% and 100% were used white color sign and leaf defoliation symptom, respectively.

These result supported by Tsegaye Babege et al. (2017) in Bench-Maji administrative Zone of south west Ethiopia reported that farmers identified the pest by colors and symptoms observed such as yellowing, defoliation, die back and white color. Similarly the study in east Wollega by Tesfaye Hailu et al. (2014) also reported that the discussants of mango growers described the symptoms of the pest infestation on leaves whitish materials, spots and drop down from the tree, attack the stem basement of the leave, fruit with conveying its original color with varies spot, change color of the leaf after penetrate inside, fix on the root of the tree along by covering of white small fibers and increasingly substantial led to poor growth and finally drying out the tree. Ofgaa Djirata et al. (2016) study in Central and Eastern Kenya also revealed that the damages that the respondents believed to have been caused by the pest to mango plantation were spots on fruits, yellow spots on leaves, drying and falling off of leaves, and drying of young twigs.

Table 4.2. Growers, assessment of white mango scale damage and identification methods

Variable	Percent
Damaged Plant Parts	
ð§ Leaves	74.3
ð§ Fruits	51.4
ð§ Twigs	25.7
ð§ Branches	17.1
ð§ Whole Tree Parts	40.0
Identification methods	
ð§ Sign	94.3
ð§ Symptom	60.0
Sign	
ð§ White	91.4
ð§ Pink	51.4
ð§ Gray	51.4
ð§ Yellow	25.7
ð§ Not Aware	8.6
Symptom	
ð§ Leaf Defoliation	100.0
ð§ Stunting and Distortion of Fruit	57.1
ð§ Dieback of twigs and branches	45.7
ð§ Premature fruit drops	22.9
ð§ Drying of Flower	22.9

Infestation status and variability: Table 4.3 illustrates white mango scale infestation variability and status assessment in the surveyed areas. Infestation variability over time was perceived as majority of the respondents 48.6% replied as the infestation had been becoming increased over time. Others respondents 37.1% were feeling that the pest stayed at a maximum infestation status with no difference from initial time of introduction. The incidence and severity of infestation status of white mango scale was perceived as medium to high status. These implies that the pest becoming a serious constraint for mango production of the study areas.

These result supported by Tsegaye Babege et al. (2017) reported that various studies in major mango growing areas of the country (Western Ethiopia and central rift valley) established that white mango scale is becoming the most important limiting factor for mango production in Ethiopia. Study in western Ethiopia by Ofgaa Djirata and Emana Getu (2015) reported that Infestation of white mango scale on mango fruits at Different Stages of fruit development study revealed that white mango scale has become a devastating pest to mango fruit in western Ethiopia. The study in Central and Eastern Kenya by Ofgaa Djirata et al.

(2016) also reported that considerable percentage of respondents said that level of the damage showed variations over time since first recognized.

The infestation variability within a year was perceived as there was a high fluctuation of mango white scale infestation within a year. The majority of respondents 85.7% and 71.4% replied that during April and may, respectively there were a highest infestation. Some respondents 54.3% and 48.6% also replied that next peak infestation status were during January and June respectively. These implies that the pest has assumed four peak infestation time within a year indicates that the pest reproduced throughout the year overlapping generation. Respondents also perceived that there was less and invisible infestation of white mango scale during October, November and December during which there may be high number of crawlers 1st instar which is unseen with naked eye and highly mobile within and outside the infested trees which might mislead farmers that their mango tree free from scale infestation.

These result in lined with Ofgaa Djirata and Emana Getu (2015) report that maturation and ripening of mango fruit begin during the first months of rainy season, that is, in March to April and continues for few months, vis-à-vis significant infestation of mango fruits by white mango scale in Western Ethiopia. Abo-Shanab (2012) reported that the lowest population density was observed in the beginning of spring season during the two studies years. However; the current result was not similar to the finding by Tsegaye Babege et al. (2017) who reported that majority of respondents replied that high level of pest prevalence was occurred in winter.

The infestation variability among farm sites was perceived majority of the respondents of 62.9% were replied that backyard mango tree plantation were highly infested than field mango farm because of the dispersal factors mainly humans and animals movement accelerate the spread of the pest in addition to other dispersal factors. These result supported by Andrew (2016) suggested that avoiding of staff movement in areas known to be infested with scale insects otherwise disinfest clothing and equipment after working in such areas since it enhance infestation.

Table 4.3. Infestation status and variability

Variables	Percent
Infestation variability over time	
ð§ Increased	48.6
ð§ Decreased	2.9
ð§ Show no difference	37.1
ð§ Did not know	11.4
Infestation peak months	
ð§ June	48.6
ð§ January	54.3
ð§ April	85.7
ð§ May	71.4
Infestation status	
Incidence	
ð§ High	60
ð§ Medium	40
ð§ Low	0
Severity	
ð§ High	80
ð§ Medium	20
ð§ Low	0

White mango scale infestation impact on mango fruit yield: Table 4.4 illustrates growers, assessment of white mango scale infestation on mango fruit yield in the study districts of Assosa and Bambasi. Mango frut was reduced in quality and quantity after the introduction of this new pest. The mean mango fruit yield before white mango scale infestation was highly significantly higher than after white mango scale infestation (t_{34} = 20.06, p < .01). Growers, perceived that there were minimum and reduced mean yield after white mango scale infestation 248.3±6.4 than before white mango scale infestation 700.3±21.6 which showed that mean fruit yield reduction suspected more than 60% due to this pest infestation.

The growers, assessment approved that in the study area before white mango scale infestation the yield were ranged from 4.5 to 9.6 quintal per a single mango tree. However growers, discouraged because of the decrement yield after white mango scale infestation in a range of 2 to 3.5 quintals were collected per a single mango tree. Growers, also replied that after mango white scale infestation not more than 3.5 quintals were collected from a single mango tree even this production was low in quality and easily perishable. These results also supported by the study in the East and West Wollega Administrative Zones by Temesgen Fita (2014) who reported that survey in the infested districts mango yield obtained before white mango scale emergence was significantly higher than after white mango scale emergence. Mohammed Dawd (2012) also reported that farmers responded that fruit harvest up to 10 quintal before the occurrence of white mango scale had been decreased to 2 to 3 quintal or not at all after the occurrence of mango white scale. Hodges and Harmon (2016) reported that in 2001, losses caused by fruit rejection from Nayarit due to white mango scale infestation were ranged from 50 to 100%.

Table 4.4. Growers, mango fruit estimation

Yield_condition	N	Mean	SD	SE	Min	Max	Cochrant test		
							DF	t Value	Pr > |t|
YBWMS	35	700.3	127.8	21.5979	450	960	34	-20.06	<.0001
YAWMS	35	248.3	38.0778	6.4363	200	350			

YBWMS=yield before white mango scale infestation; YAWMS=yield after white mango scale infest

White mango scale dispersal mechanism and rate: Figure 4.5 illustrates the dispersal mechanism and rate of white mango scale in the surveyed areas. Wind, birds, insect pest, animal and human movement, planting material and others were perceived as dispersal mechanisms. Majority of the respondents 94.3% and 77.1% replied planting materials and next wind were considered as the main dispersal mechanisms. These implied that human activity greatly enhance the expansion of infestation radius. The dispersal rates were varied for different orchards. Majority of respondents replied as WMS infestation periods had taken a week to a month for dispersing to the neighboring mango tree orchards based on the type of dispersal mechanism.

This result supported by Temesgen Fita (2014) reported that initially white mango scale was introduced from India to Green Focus Ethiopia Ltd. through a variety of …Alphonso, and farmers witnessed that the pest dispersed among their mango tree through seedling distribution. Tsegaye Babege et al. (2017) reported that the pest suspected that distributed with planting materials that are hosts to this pest. Similar arguments were made by Gashawbeza Ayalew et al. (2015) who reported the pest introduction to the country is likely to be with planting materials or fruits that are hosts to white mango scale. Earlier study by Great head (1990 and 1997) also confirmed that white mango scale can move with the help of external forces like wind, birds and insect pests. Study result as cited by Haggag et al. (2014) reported that only the crawler stage can move to a new host (adult males can fly but cannot establish a colony), but scale insects can move to new hosts as a result of wind, birds, and insects. Crawlers are capable of moving distances of tens of kilometres on wind currents to infect clean crops.

Table 4.5. White mango scale dispersal mechanism and rate

Variables	Percent
Dispersal Mechanism	
ð§ Wind	77.1
ð§ Birds	42.9
ð§ Insect pests	25.7
ð§ Planting materials	94.3
ð§ Others	5.7
Dispersal Rate	
ð§ Only One Week	37.1
ð§ Utmost One Month	40
ð§ 1 - 2_Month	14.3
ð§ >2_Month	8.6

White mango scale host range: Figure 4.1 illustrates the host range of WMS in the surveyed areas. Majority of the respondents responded that WMS attacked all mango cultivars equally. All respondents did not observe the alternate hosts other than mango trees. The current study result is supported by Tesfaye Hailu et al. (2014) who reported that farmers' observation was taken as the pest is not selective for one or another type of mango varieties. Both improved grafted and local orchards were invariably attacked by the pest. Also Study by Ofgaa Djirata et al. (2016) that the respondents reported that all the mango varieties were affected by WMS but some stressed that the damage to Apple mango was more serious than other varieties.

However different literature described that white mango scale have other alternative hosts. Erichsen and Schoeman (1992) reported that white mango scale was found feeding on avocado in South Africa. Others Malumphy (2014) and Borchsenius (1966) cited in Abo-Shanab (2012) also reported that can attack other alternative hosts. Since the insect introduced not more than a decade there may be a probability to expand their feeding habit so it needs great attention to inspect and monitor mango trees for scale including other alternate hosts.

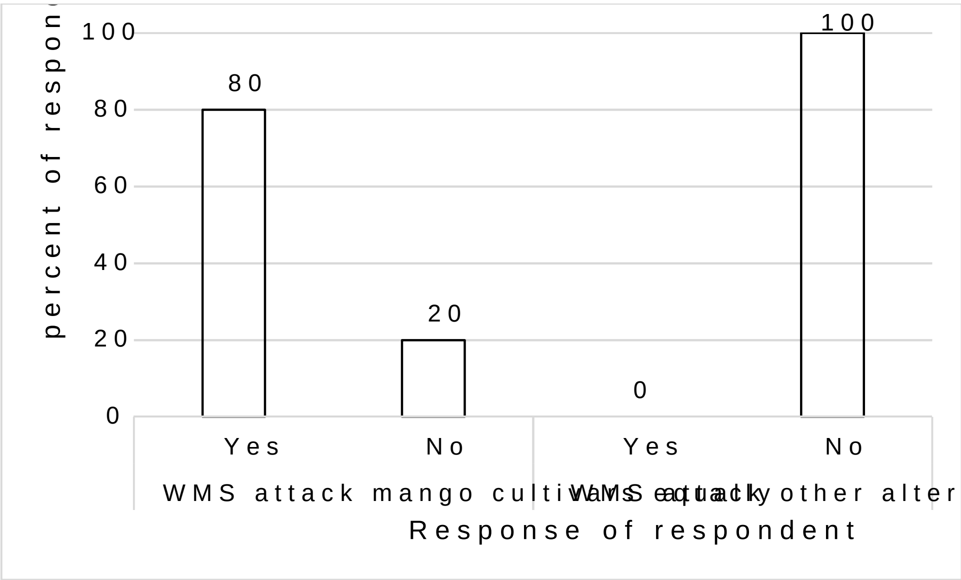

Figure4.1. White mango scale host range

Management practices of white mango scale. Table 4.6 illustrates management practices of white mango scale in the surveyed areas. Major management practices that respondents of 82.9% replied was cultural practices like pruning, smoking, wood ash and site clearing. However 17.1% of the respondents leave the tree without any management measure. The management practices used by most growers, were not successful but few observe to some extent lower the infestation status and others respondents did not aware of the successfulness of the mitigation activities. It was understandable from growers, perception since white mango scale live in the plant and reproduced throughout the year which required continuous monitoring and management. However; it was not adopted such kind of pest control practice for mango trees after plantation establishment. And also unmanageable mango size contributes for unsuccessful management measures.

These result also supported by Temesgen Fita (2014) and Tesfaye Hailu et al. (2014) reported that mango growers were undertaken cultural control methods like pruning, smoking and site clearing in wolde area. Tsegaye Babege et al. (2017) reported that few farmers undertook control measure like pruning of heavily infested twigs and dense branches to eliminate infestations when infestations are on limited parts of the plant.

Table4.6. Management practices of white mango scale

Variable	Percent
Management Practice	
ð§ Cultural	82.9
ð§ Pesticide	0
ð§ No measure	17.1
Cultural Practice	
ð§ Smoking	62.9
ð§ Ash	54.3
ð§ Pruning	45.7
ð§ Site Clearing	31.4
Management Successfulness	
ð§ Yes	0
ð§ To some extent	28.6
ð§ No	57.1
ð§ Not aware	14.3

Extension service for the management of white mango scale: Figure 4.7 illustrates the extension service given to growers, for the management of white mango scale in the surveyed areas. Respondent of 91.4% did not get any extension support but they were showed interest to expertise order and medium to very high commitment level to apply the management option which will be given to growers. Similar report in other in other mango producing areas such as Tsegaye Babege et al., (2017) reported that most of the farmers in Southwest Ethiopia of Bench-Maji Zone were looking for possibilities to take intervention measure and they showed commitment to experts order for any intervention measure. Tesfaye Hailu et al. (2014) also reported that the discussant farmers highly looking for any external assistance on the management.

Table4.7. Extension service for the management of white mango scale

Variables	Percent
Extension service	
ð§ Yes	8.6
ð§ No	91.4
Interest of expertise order	
ð§ Yes	100
ð§ No	0
Commitment Level to apply Expertise Order	
ð§ Low	0
ð§ Medium	25.7
ð§ High	54.3
ð§ Very high	20

4.1.2 Infestation and damage symptom of white mango scale

The insect pest was observed infestation of the leaf, fruit, twigs and branches but leaf and fruit were the most infested and damaged parts. The flowers observed minimally scattered in the canopy and easily fall dawn. Highly infested mango trees canopy were observed whitish appearance and both side of leaf surface appearance after scraped the scale showed yellow color rounding and black lesion at the center of the damaged part and the lesion develops to whole leaf. The attacked mango trees were showed dieback, drying from tip of branches to whole parts were observed progressively dried and finally the mango tree become out of production. The infested fruits showed under coverage of the scale and appeared yellow pinkish color after scraped of the pest. Irregular small sized mango fruits were observed during fruiting and harvesting season. All the entire growth of mango trees were observed being attacked by the insect pest. The Appendix figure 2 illustrates image of damage symptoms of white mango scale

These study result supported by Haggag et al. (2014) that white mango scale attacks mango leaves, branches and fruit, where it causes superficial pink or yellow blemishes to develop, making the fruit unmarketable. The study in Western Ethiopia by Ofgaa Djirata et al. (2015) reported that the heavily infested premature fruits dropping and the mature fruits became small in size with lacking of juice. Mango white scale attacked the fruit leaving pinkish blemish on skin of matured and ripe fruits.

These also confirmed by the study results of El-Metwally et al. (2011) and Abo-Shanab (2012) stated that the damage caused by white mango Scale includes yellowing of leaves, appearance of conspicuous pink blemishes on mature and ripe fruits, and also Nabil et al. (2012) stated that dieback of the plant. Infestation in young trees may lead to excessive fall off leaves, retarded growth and death of the whole plant. The study in Mango Orchards of Nayarit in Mexico by Hodges and Harmon (2016) also reported that white mango scale does not cause direct internal damage to mango fruit but produces chlorotic spots.

4.1.3 Spatial distribution of white mango scale

Abundance of white mango scale: Mean±SE of WMS cluster was highly significantly higher at Assosa 6.59(2.50)± 4.85(0.93) than at Bambasi 5.07(2.14)± 0.4(0.09) (t_{313} = 3.31, $p < .01$) (Table 4.8).

Table 4.8. White mango scale cluster per leaf (pooled data, Assosa and Bambasi)

							Pooled t test		
Districts	N	Mean	SD	SE	min	max	DF	t Value	Pr > |t|
Assosa	180	6.59(2.5)	4.85(0.93)	0.36(0.07)	0.3	16.8	313	3.31	0.001
Bambas	135	5.07(2.14)	4.67(1.01)	0.4(0.09)	0	15			

Table 4.9 illustrates mean number of cluster of the pooled data of orchards were statistically highly significant ($F_{6,252}$ = 395, $p < 0.01$) different. Comparative mean clusters of WMS among orchards were maximally abundant in Amba_14, 7.28(2.65) in Assosa Districts and lowest mean cluster record in Sonika, 4.59(2.00) in Bambasi districts. Insignificant difference of mean clusters between Amba_8, 6.15(2.39) and Megele_32, 6.12(2.39) and also Mender_47, 5.30(2.19) and Mender_48, 5.33(2.20). Mean cluster in Amba_8, 6.15(2.39) and Megele_32, 6.12(2.39) were less abundant than Amba_14, 7.28(2.65) and Amba_5, 6.82(2.55) and more abundant than Mender_47, 5.30(2.19) and Mender_48, 5.33(2.20).

Table 4.9. Mean number of white mango scale clusters per leaf in the study orchards (pooled data, Assosa and Bambasi)

Kebele	Mean
Amba_14	7.28(2.65)a
Amba_5	6.82(2.55)b
Amba_8	6.15(2.39)c
Megele_32	6.12(2.39)c
Mender_48	5.33(2.20)d
Mender_47	5.30(2.19)d
Sonika	4.59(2.00)e
Mean	5.9(2.3)
SEm	0.11(0.04)
LSD	0.13(0.03)
CV%	5.11(3.20)
Sign.difference	**

Values given in parenthesis are square root transformed values; Values in each column of the sa letter are not significantly different, SEm= Standard error of mean; LSD=Least Signific Difference; CV=Coefficient of Variation, * significant at P < 0.05, ** significant at 0.01

Table 4.10 illustrates the comparative mean number of WMS cluster of each study district orchards. The segregated data of WMS cluster of the study orchards in Assosa and Bambasi districts were statistically highly significantly different ($F_{3,168}$ = 119, p < .01) and ($F_{2,124}$ = 88, p < .01) respectively. Comparative mean clusters at Assosa district orchards were more abundant in Amba_14, 7.28(2.65) than Amba_5, 6.82(2.55) but Amba_5 were more abundant than Amba_8, 6.15(2.39) and Megele_32, 6.12(2.39). The mean cluster of WMS insignificant difference between Amba_8, 6.15(2.39) and Megele_32, 6.12(2.39) in abundant. Comparative mean cluster at Bambasi district orchards were insignificantly different between Mender_48, 5.33(2.20) and Mender_47, 5.30(2.19); but both orchards significantly more abundant than Sonika 4.58(2.00) orchard.

Table 4.10. Mean number of clusters of white mango scale in the study orchards and on leaf surface of Assosa and Bambasi Districts

Districts	Kebele	Mean
Assosa	Amba_14	7.28(2.65)a
	Amba_5	6.82(2.55)b
	Amba_8	6.15(2.39)c
	Megele_32	6.12(2.39)c
	Mean	6.6(2.5)
	SEm±	0.15(0.05)
	LSD	0.12(0.03)
	CV%	4.51(3.05)
	Sign.difference	**
Bambasi	Mender_48	5.33(2.20)a
	Mender_47	5.30(2.19)a
	Sonika	4.58(2.00)b
	Mean	5.1(2.1)
	SEm±	0.17(0.06)
	LSD	0.124(0.034)
	CV%	5.87(3.79)
	Sign.difference	**

Values given in parenthesis are square root transformed values; Values in each column of letter are not significantly different; SEm= Standard error of mean; LSD=Least Significant Difference; CV=Coefficient of Variation, * significant at P < 0.05, ** significant at 0.01

Table 4.11 illustrates the comparative mean number of WMS cluster on leaf surface. The mean number of WMS cluster of the pooled data was highly significantly higher on upper leaf surface than lower leaf surface (t_{314} = 11.48, p < .01) in all orchards (Appendix figure 3). Mean number of WMS cluster was more abundant on upper leaf surface than lower leaf surface for all the study orchards. This study result supported by the study in Ethiopia in Arjo and Bako by Ofgaa Djirata et al. (2018) proved that all developmental stages of mango white scale were found to be more abundant on the upper leaf surfaces. The study by Nabil et al. (2012) and Marwa et al. (2017) recorded that white mango scale preferred the upper leaf surface compared to the lower one and the upper leaf surface showed heavier infestation compared with the lower surface

Table 4.11. White mango scale cluster number on upper and lower leaf surface (pooled data, Assosa and Bambasi)

							Cochrant test		
Leaf_surface	N	Mean	Std Dev	Std Err	Min	Max	DF	t Value	Pr > |t|
Upper	315	4.2(2)	3.4(0.8)	0.2(0.04)	0	11.76	314	-11.48	<.0001
Lower	315	1.8(1.4)	1.45(0.48)	0.08(0.03)	0	5.04			

Severity status of white mango scale infestation: The severity status of the infestation were categorized as zero/free for less than one clusters formation per leaf, >1-2 / Minimal for greater than one and less than two clusters formation per leaf, >2-4 / Moderate for greater than two and less than four clusters formation per leaf, >4-5 / Severe for greater than four and less than five clusters formation per leaf and >5 / Very Severe for greater than 5 cluster formation per leaf (Appendix figure 4).

The WMS severity of infestation status for Zero cluster or free severity status of the pooled data from Assosa and Bambasi study orchards were statistically highly significant different ($F_{5, 45} = 31.7$, $p < .01$). The comparative mean cluster of WMS for zero cluster formation per leaf showed that the severity status were maximum at Amba_5, 0.93(1.19) and lowest at Sonika 0.27(0.9) compared with other orchards. The severity status were insignificantly different between Amba_8, 0.67(1.07) and Megele_32, 0.68(1.09) but both significantly different and less severe than Amba_5, 0.93(1.19). Similarly there were insignificant different between Mender_47, 0.46(0.97) and Mender_48, 0.51(0.99), but significantly different and more sever than Amba_8, 0.67(1.07) and Megele_32, 0.68(1.09). No zero cluster formation at Amba_14 orchards (Table 4.12).

The WMS severity of infestation status for one to two cluster formation or minimal severity status of the pooled data from Assosa and Bambasi study orchards were statistically significant different ($F_{6, 24} = 3.16$, $p < .05$). The comparative mean WMS cluster for greater than one to two cluster formation per leaf were maximum at Amba_8, 1.72(1.49) and Amba_5, 1.74(1.49) and lowest severity status at Amba_14, 1.22(1.31) compared with other orchards. Comparative minimal severity status between Amba_8 and Amba_5 was insignificantly different. The minimal severity status in descending order were Amba_5, 1.74(1.49) and Amba_8, 1.72(1.49); mender_48, 1.64(1.45); Sonika 1.58(1.44); Mender_47, 1.4(1.38); Megele_32, 1.28(1.33) and Amba_14, 1.22(1.31) respectively (Table 4.12).

The WMS severity of infestation status for two to four cluster formation or moderate severity status of the pooled data from Assosa and Bambasi study orchards were statistically highly significant different ($F_{6, 42} = 21.08$, $p < .01$). The comparative mean WMS for two to four clusters formation per leaf showed that the severity status were maximum in Sonika 3.58(2.02) and lowest severity status in Mender_47, 2.4(1.7) compared with other orchards. Comparative moderate severity status of Amba_8, 3.11(1.9) with Amba_14, 3.05(1.88) and Megele_32, 2.82(1.81) with mender_48, 2.84(1.82) were similar. The moderate severity status in descending order were Sonika 3.58(2.02); Amba_5, 3.28(1.95); Amba_8, 3.11(1.9); Amba_14, 3.05(1.88); mender_48, 2.84(1.82); Megele_32, 2.82(1.81) and Mender_47 2.4(1.7) respectively (Table 4.12).

The WMS severity of infestation status for four to five cluster formation or severe severity status of the pooled data from Assosa and Bambasi study orchards were statistically insignificant different ($F_{5, 17} = 1.05$, ns). All the study orchards had same severe severity status excluding Megele_32 in which there was no severe severity status recorded during the study month (Table 4.12).

The WMS severity of infestation status for greater than five cluster formation or very severe severity status of the pooled data from Assosa and Bambasi study orchards were statistically highly significant different ($F_{6, 141} = 168.65$, $p < .01$). The comparative mean WMS cluster for greater than five cluster formation per leaf showed that the severity status were maximum in Amba_14, 10.74(3.31) and lowest severity status in Megele_32, 9.52(3.11) and Mender_47, 9.7(3.14) compared with other orchards. Comparative of very severe severity status of Sonika 10.25(3.25) with Amba_5, 10.26(3.31); mender_48, 9.94(3.19) with Amba_8, 9.96(3.18) and Megele_32, 9.52(3.11) with Mender_47, 9.7(3.14) were insignificantly different. The very sever severity status in descending order were Amba_14, 10.74(3.31); Sonika 10.25(3.25); Amba_5, 10.26(3.31); Amba_8, 9.96(3.18); mender_48, 9.94(3.19); Mender_47, 9.7(3.14) and Megele_32, 9.52(3.11) respectively (Table 4.12).

Table 4.12. Severity of infestation of white mango scale in the study orchards (pooled data, Assosa and Bambasi districts)

	Mean				
Kebele	Free	Minimal	Moderate	Sever	Very Sever
Amba_14	N_r	1.22(1.31)[d]	3.05(1.88)[bc]	4.54(2.24)[a]	10.74(3.31)[a]
Amba_8	0.67(1.07)[b]	1.72(1.49)[a]	3.11(1.9)[bc]	4.75(2.29)[a]	9.96(3.18)[c]
Amba_5	0.93(1.19)[a]	1.74(1.49)[a]	3.28(1.95)[ab]	4.25(2.18)[a]	10.26(3.31)[b]
Megele_32	0.68(1.09)[b]	1.28(1.33)[cd]	2.82(1.81)[c]	N_r	9.52(3.11)[d]
Mender_47	0.46(0.97)[c]	1.4(1.38)[bcd]	2.4(1.7)[d]	4.4(2.21)[a]	9.7(3.14)[d]
Mender_48	0.51(0.99)[c]	1.64(1.45)[ab]	2.84(1.82)[c]	4.64(2.27)[a]	9.94(3.19)[c]
Sonika	0.27(0.9)[d]	1.58(1.44)[abc]	3.58(2.02)[a]	4.58(2.25)[a]	10.25(3.25)[b]
Mean	0.5(0.99)	1.5(1.41)	3.0(1.87)	4.5(2.24)	10.0(3.2)
SE_m	0.05(0.04)	0.09(0.04)	0.11(0.04)	0.11(0.024)	0.11(0.021)
LSD	0.165(0.081)	0.32(0.113)	0.31(0.09)	0.45(0.10)	0.18(0.032)
CV%	31.06(7.78)	15.6 (5.99)	9.195(4.034)	6.1(2.83)	2.95(1.63)
Sign.difference	**	*	**	ns	**

Values given in parenthesis are square root transformed values; Values in each column of the letter are not significantly different; SEm= Standard error of mean; LSD=Least Signific Difference; CV=Coefficient of Variation; * significant at P < .05; ** significant at .01; ns=Non_significant; N_r=Not Recorded Number of white mango scale clus; ns=Non_significant

The WMS severity of infestation status for Zero clusters or free severity status of the segregated data of Assosa study orchards was statistically significant different ($F_{2, 13}$ = 5.45, $p < .05$). The comparative WMS mean cluster for zero cluster formation per leaf showed that the severity status were maximum in Amba_5, 0.93(1.19) and lowest in Amba_8, 0.67(1.08) and Megele_32, 0.68(1.09). The severity status between Amba_8 and Megele_32 was insignificantly different. No zero cluster formation was found at Amba_14 study orchards (Table 4.13).

The WMS severity of infestation status for one to two cluster formation or minimal severity status of the segregated data of Assosa study orchards was statistically highly significantly different ($F_{3, 13}$ = 11.32, $p < .01$). The comparative mean clusters for greater than one to two cluster formation per leaf showed that the minimal severity status were maximum at Amba_8 (1.72(1.49)) and Amba_5 (1.74(1.49)) and lowest at Amba_14 (1.22(1.31)) and Megele_32, (1.28(1.33)). Mean cluster record at Amba_8 and Amba_5 and also at Amba_14 and Megele_32 were similar (Table 4.13).

The WMS severity of infestation status for two to four cluster formation or moderate severity status of the segregated data of Assosa study orchards was statistically highly significant different ($F_{3, 31}$ = 21.65, $p < .01$). The comparative WMS mean clusters for two to four cluster formation per leaf showed that the severity status were maximum in Amba_8, 3.11(1.89) and Amba_5, 3.28(1.94) and lowest severity status in Megele_32, 2.82(1.81) compared with Amba_14, 3.05(1.88) orchards. Mean cluster records of Amba_8 and Amba_5 was insignificantly different. The severity status for moderate severity status in descending order were Amba_5, 3.28(1.94); Amba_8, 3.11(1.89); Amba_14, 3.05(1.88) and Megele_32, 2.82(1.81) respectively (Table 4.13).

The WMS severity of infestation status for four to five clusters formation or sever severity status of the segregated data of Assosa study orchards was statistically insignificant different ($F_{2, 6} = 3.39$, ns). All study orchards had insignificantly different sever severity status excluding Megele_32 in which there was no a record of sever severity status (Table 4.13).

The white mango scale severity of infestation status for greater than five clusters formation or very sever severity status of the segregated data of Assosa study orchards was statistically highly significant different ($F_{3, 90} = 89.83$, $p < .01$). The comparative WMS cluster for greater than five clusters formation per leaf showed that the severity status were maximum in Amba_14, 10.74(3.31) and lowest severity status in Megele_32, 9.52(3.11) compared with other orchards. The severity status for very sever severity status in descending order were Amba_14, 10.74(3.31); Amba_5, 10.26(3.23); Amba_8, 9.96(3.18) and Megele_32, 9.52(3.11) respectively (Table 4.13).

Table 4.13. Severity of white mango scale infestation in orchards of Assosa

			Mean		
Kebele	Free	Minimal	Moderate	Sever	Very Sever
Amba_14	N_r	1.22(1.31)b	3.05(1.88)ab	4.54(2.24)a	10.74(3.31)a
Amba_8	0.67(1.08)b	1.72(1.49)a	3.11(1.89)a	4.75(2.29)a	9.96(3.18)c
Amba_5	0.93(1.19)a	1.74(1.49)a	3.28(1.94)a	4.25(2.18)a	10.26(3.23)b
Megele_32	0.68(1.09)b	1.28(1.33)b	2.82(1.81)b	N_r	9.52(3.11)d
Mean	0.74(1.1)	1.5(1.41)	3.06(1.88)	4.5(2.24)	10.12(3.21)
SEm	0.07(0.05)	0.07(0.027)	0.13(0.04)	0.1(0.022)	0.14(0.022)
LSD	0.197(0.095)	0.21(0.08)	0.25(0.067)	0.44(0.098)	0.16(0.027)
CV%	20.29(6.5)	9.92(3.81)	8.69(3.75)	4.44(1.99)	2.86(1.5)
Sign.difference	*	**	**	ns	**

Values given in parenthesis are square root transformed values; Values in each column of letter are not significantly different; SEm= Standard error of mean; LSD=Least Signific Difference; CV=Coefficient of Variation; * significant at P < .05; ** significant at .01; ns=Non_significant; N_r=Not Recorded Number of white mango scale cluster

The white mango scale severity of infestation status for Zero clusters or free severity status of the segregated data of Bambasi study orchards was statistically highly significant different ($F_{2, 31} = 21.81, p < .01$). The comparative WMS mean cluster for zero cluster formation per leaf showed that the severity status were maximum in Mender_48, 0.51(0.99) and Mender_47, 0.46(0.97) compared with Sonika 0.27(0.86). Mean cluster of WMS between Mender_47 and Mender_48 orchards were not significantly different (Table 4.14).

The WMS severity of infestation status of the segregated data of Bambasi study orchards for one to two cluster formation or minimal severity status ($F_{2, 11} = 0.84$, ns), for two to four clusters formation or moderate severity status ($F_{2, 11} = 0.79$, ns) and for four to five clusters formation or sever severity status ($F_{2, 11} = 0.95$, ns) were insignificantly different respectively (Table 4.14).

The WMS severity of infestation status for greater than five clusters formation or very sever severity status of the segregated data of Bambasi study orchards was statistically highly significant different ($F_{2, 48} = 30.97, p < .01$). The comparative WMS clusters for greater than five clusters formation per leaf showed that the severity status were maximum in Sonika 10.25(3.25) and lowest severity status in Mender_47, 9.65(3.14) compared with Mender_48, 9.94(3.19). The severity status for very sever severity status in descending order were Sonika, Mender_48 and Mender_47 respectively (Table 14).

Table 4.14. Severity of white mango scale infestation in orchards of Bambasi

	Mean				
Kebele	Free	Minimal	Moderate	Sever	Very Sever
Mender_48	0.51(0.99)[a]	1.64(1.45)[a]	2.8(1.82)[a]	4.64(2.27)[a]	9.94(3.19)[b]
mender_47	0.46(0.97)[a]	1.4(1.38)[a]	2.4(1.7)[a]	4.4(2.21)[a]	9.65(3.14)[c]
Sonika	0.27(0.86)[b]	1.58(1.44)[a]	3.58(2.02)[a]	4.58(2.25)[a]	10.25(3.25)[a]
Mean	0.39(0.93)	1.54(1.42)	2.94(1.84)	4.5(2.24)	9.92(3.19)
SE_m	0.1(0.045)	0.18(0.06)	0.18(0.05)	0.57(0.06)	0.18(0.032)
LSD	0.14(0.068)	0.43(0.15)	0.43(0.12)	0.43(0.0998)	0.21(0.036)
CV%	41.04(8.55)	20.14(7.8)	10.54(4.77)	6.83(3.19)	3.199(1.66)
Sign.difference	**	ns	ns	ns	**

Values given in parenthesis are square root transformed values; Values in each column of letter are not significantly different; SEm= Standard error of mean; LSD=Least Signific Difference; CV=Coefficient of Variation, * significant at P < .05, ** significant at .01, ns=Non_significant

Similar study study in the East and West Wollega Zones by Temesgen Fita (2014), the study in Bench Maji Zone South West Ethiopia by Tsegaye Babege et al. (2017) and the study in

Central and Eastern Kenya by Ofgaa Djirata et al. (2016) reported that the white mango scale infestation record was varied spatially among the study site.

4.1.4 Seasonal fluctuation of white mango scale

Seasonal fluctuation of white mango scale abundance: Mean WMS cluster of pooled data from Assosa and Bambasi during the study month were highly significantly different ($F_{8,252}$ = 6313, $p < .01$). The mean cluster was peak in April 15.1(4.0) and lowest record during December 0.57(1.01). The mean cluster of WMS record during the study month from August/2018 to April/2019 in descending orders were April 15.1(4.0), March 12.1(3.6), February 8.1(2.3), January 6.1(2.6), August 5.097(2.4), September 3.097(1.9), October 2.097(1.6), November 1.23(1.3) and December 0.57(1.01) respectively (Table 4.15.)

Table 4.15. Mean number of clusters of white mango scale during the month of the study period (pooled data, Assosa and Bambasi)

Month	Mean
August	5.097(2.4)[e]
September	3.097(1.9)[f]
October	2.097(1.6)[g]
November	1.23(1.3)[h]
December	0.57(1.01)[i]
January	6.1(2.6)[d]
February	8.1(2.3)[c]
March	12.1(3.6)[b]
April	15.1(4.0)[a]
Mean	5.9(2.3)
SE_m	0.1(0.03)
LSD	0.14(0.035)
CV%	5.11(3.20)
Sign.difference	**

Values given in parenthesis are square root transformed values; Values in the column of the same letter are not significantly different; SEm= Standard error of mean; LSD= Least Significant Difference; CV=Coefficient of Variation; * significant at P < .05; ** significant at .01; ns=Non_significant

Mean cluster of WMS from the segregated data of Assosa study orchards during the study months were showed highly significantly different ($F_{8, 168}$ = 3230, $p < .01$). The comparative mean cluster was peak in April 15.82(4.0) and lowest record during December 0.86(1.2). The mean cluster of WMS among the study month in descending order were April 15.82(4.0), March 12.82(3.7), February 8.82(3.1), January 6.82(2.7), August 5.82(2.5), September 3.82(2.1), October 2.82(1.8), November 1.78(1.5) and December 0.86(1.2) respectively (Table 4.16).

Mean cluster of WMS from the segregated data of Bambasi study orchards during the study months were showed highly significantly different (F $_{8,124}$ = 2575.15, p < .01). The mean cluster was peak in April 14.14(3.8) and lowest record during December 0.19(0.8). The comparative mean cluster abundance among the study months in descending orders were April 14.14(3.8), March 11.14(3.4), February 7.14(2.8), January 5.14(2.4), August 4.14(2.2), September 2.14(1.6), October 1.14(1.3), November 0.5(1.0) and December 0.19(0.8) respectively (Table 4.16).

Table 4.16. Mean number of clusters of white mango scale during the month of the study period in the study districts of Assosa and Bambasi

Month	Mean	
	Assosa	Bambasi
August	5.82(2.5)^{e}	4.14(2.2)^{e}
September	3.82(2.1)^{f}	2.14(1.6)^{f}
October	2.82(18)^{g}	1.14(1.3)^{g}
November	1.78(1.5)^{h}	0.5(1.0)^{h}
December	0.86(1.2)^{i}	0.19(0.8)^{i}
January	6.82(2.7)^{d}	5.14(2.4)^{d}
February	8.82(3.1)^{c}	7.14(2.8)^{c}
March	12.82(3.7)^{b}	11.14(3.4)^{b}
April	15.82(4.0)^{a}	14.14(3.8)^{a}
Mean	6.6(2.5	5.1(2.1)
SE_m	0.1(0.03)	0.1(0.03)
LSD	0.19(0.047)	0.1867(0.82)
CV%	4.51(3.05)	5.87(3.79)
Sign.difference	**	**

Values given in parenthesis are square root transformed values; Values in the column of the same letter are not significantly different, SEm= Standard error of mean; LSD=Least Significant Difference; CV=Coefficient of Variation, * significant at P < .05, ** significant at .01, ns=Non_significant

Interaction effect of study areas and month: Mean cluster record during same month across each orchards showed a highly significant varation (F $_{48, 252}$ = 4.85, p < .01). the interaction effect sliced by month in decreasing order of study period was shown as October (F $_{6, 252}$ = 99.51, p < .01), November (F $_{6, 252}$ =89.98, p < .01), September (F $_{6, 252}$ =68.4, p < .01), August (F $_{6, 252}$ =42.91, p < .01), December (F $_{6, 252}$ =36.67, p < .01), January (F $_{6, 252}$ =36.03, p < .01), February (F $_{6, 252}$ =27.64, p < .01), March (F $_{6, 252}$ =18.35, p < .01), April (F $_{6, 252}$ =15.27, p < .01) respectively (Appendix Table 6).

Fluctuation of white mango scale cluster across orchards during study periods. Figure 4.2 showed that the abundance of white mango scale mean cluster during the study period across orchards showed rapid decrease from August to October and during November and December were stayed low and being undetectable. The clusters were started progressive increase from January to February and rapid increase to peak from March to April.

Figure 4.2. Fluctuation of white mango scale cluster across orchards during study periods

Seasonal fluctuation of severity status of white mango scale infestation. The white mango scale severity of infestation status of the pooled data from Assosa and Bambasi study orchards during the study months for Zero cluster or free severity status were statistically highly significantly different ($F_{2, 45} = 43.89$, $p < .01$). Mean WMS cluster for zero cluster formation per leaf was maximum in October 0.65 (1.07) and November 0.57 (1.02) and lowest in December 0.44 (0.954). The severity status during October and November were insignificantly different but both significantly higher severity status than December. Zero cluster formation were not recorded during the study months of August, September, January, February, March and April (Table 4.17).

The white mango scale severity of infestation status of the pooled data from Assosa and Bambasi study orchards during the study months for one to two clusters or minimal severity status were statistically significant different ($F_{3, 24}$ = 3.15, $p < .05$). Mean WMS cluster for one to two cluster formation per leaf were insignificantly different during September 1.65 (1.46), November 1.61 (1.5) and October 1.52 (1.42) but significantly higher than December 1.22 (1.31). One to two clusters formation were not recorded during the study months of August, January, February, March and April (Table 4.17).

The white mango scale severity of infestation status of the pooled data from Assosa and Bambasi study orchards during the study months for two to four clusters or moderate severity status were statistically highly significant different ($F_{3, 42}$ = 37.99, $p < .01$). Mean WMS cluster for two to four clusters formation per leaf showed that the severity status were maximum during August 3.65 (2.04) and lowest during November 2.5 (1.74). The severity status was insignificantly different between September 3.06 (1.88) and October 2.9 (1.85). Two to four clusters formation were not recorded during the study months of December to April (Table 4.17).

The white mango scale severity of infestation status of the pooled data from Assosa and Bambasi study orchards during the study months for four to five clusters or sever severity status were statistically insignificant different ($F_{2, 17}$ = 2.19, ns). The mean WMS cluster formation were similar among August 4.52 (2.24), September 4.46 (2.22) and January 4.7 (2.3). Formation of four to five clusters was not recorded during the study months of October, November, December and February to April (Table 4.17).

The white mango scale severity of infestation status of the pooled data from Assosa and Bambasi study orchards during the study months for greater than five clusters or very sever severity status were statistically insignificantly different ($F_{4, 141}$ = 4241, $p < .01$). Mean WMS cluster for greater than five cluster formation per leaf showed that the severity status were maximum during April 15.1 (3.95) and lowest during August 5.9 (2.5). The severity status in descending order were April 15.1 (3.95), March 12.1 (3.6), February 8.1 (2.93), January 6.4 (2.62) and August 5.9 (2.5) respectively. No greater than five cluster formation or very sever severity status were recorded during the study months of September, October, November and December (Table 417).

Table4.17. Severity of infestation of white mango scale during the month of the study period (pooled data, Assosa and Bambasi districts)

Month	Mean				
	Free	Minimal	Moderate	Sever	Very Sever
August	N_r	nr	3.65(2.04)[a]	4.52(2.24)[a]	5.9(2.5)[e]
September	N_r	1.65(1.46)[a]	3.06(1.88)[b]	4.46(2.22)[a]	N_r
October	0.65(1.07)[a]	1.52(1.42)[a]	2.9(1.85)[b]	N_r	N_r
November	0.57(1.021)[a]	1.61(1.5)[a]	2.5(1.74)[c]	N_r	N_r
December	0.44(0.954)[b]	1.22(1.31)[b]	N_r	N_r	N_r
January	N_r	N_r	N_r	4.7(2.3)[a]	6.4(2.62)[d]
February	N_r	N_r	N_r	N_r	8.1(2.93)[c]
March	N_r	N_r	N_r	N_r	12.1(3.6)[b]
April	N_r	N_r	N_r	N_r	15.1(3.95)[a]
Mean	0.5(0.99)	1.5(1.41)	3.0(1.87)	4.5(2.24)	10.0(3.2)
SE_m	0.05(0.03)	0.08(0.03)	0.08(0.01)	0.09(0.021)	0.1(0.02)
LSD	0.13(0.06)	0.25(0.09)	0.26(0.071)	0.3(0.07)	0.16(0.027)
CV%	31.06(7.8)	15.60(5.99)	9.2(4.03)	6.1(2.8)	2.95(1.63)
Sign.difference	**	*	**	ns	**

Values given in parenthesis are square root transformed values; Values in each column of letter are not significantly different; SEm= Standard error of mean; LSD=Least Signific Difference; CV=Coefficient of Variation; * significant at P < .05; ** significant at .01; ns=Non_significant; N_r=Not Recorded Number of white mango scale cluster

The WMS severity of infestation status of the segregated data of Assosa orchards during the study month for Zero cluster or free severity status were statistically significantly different ($F_{2, 13} = 7.63$, $p < 0.05$). Mean WMS cluster for zero cluster formation per leaf showed that the severity status of October 0.9(1.18), November 0.9(1.18), December 0.7(1.09) were insignificant difference. The zero cluster formation were not recorded during the study months of August and September and January to April (Table 4.18).

The WMS severity of infestation status of the segregated data of Assosa orchards during the study month for one to two cluster or minimal severity status were statistically highly significantly different ($F_{2, 13} = 8.25$, $p < .01$). Mean WMS cluster for one to two clusters formation per leaf showed that the severity status were maximum during October 1.75(1.5) and November 1.61(1.45) and insignificantly different severity status between October and November but significantly higher than December 1.22(1.31). One to two clusters formation were not recorded during the study months of August and September, January to April (Table 4.18).

The WMS severity of infestation status of the segregated data of Assosa orchards during the study month for two to four cluster or moderate severity status were statistically highly significantly different ($F_{2, 31} = 53.77$, $p < .01$). Mean WMS cluster for two to four cluster formation per leaf showed that the severity status were maximum in September 3.47(1.99) and lowest in November 2.53(1.74). The severity status in descending order were September 3.47(1.99), October 2.93(1.85) and November 2.53(1.74) respectively. Two to four cluster formations were not recorded during the study months of August and December to April (Table 4.18).

The WMS severity of infestation status of the segregated data of Assosa orchards during the study month for four to five clusters or severe severity status were statistically insignificantly different ($F_{2, 6} = 0.8$, ns). Formation of four to five cluster were not recorded during the study months of October to December and February to April (Table 4.18).

The WMS severity of infestation status of the segregated data of Assosa orchards during the study month for greater than five clusters or very sever severity status were statistically highly significantly different ($F_{4, 90} = 3390.21$, $p < .01$). Mean WMS cluster for greater than five cluster formation per leaf showed that the severity status were maximum during April 15.82(4.0) and lowest during August 5.93(2.54). The severity status in descending order were April 15.82(4.0), March 12.82(3.65), February 8.82(3.05), January 6.82(2.7) and August 5.93(2.54) respectively. No greater than five cluster formation or very sever severity status were recorded during the study months of September to December (Table 4.18).

Table 4.18. Severity of white mango scale infestation during the study month in Assosa and Bambasi districts

District	Month	Mean				
		Free	Minimal	Moderate	Severe	Very Sever
Assosa	August	N_r	N_r	N_r	4.75(2.29)a	5.93(2.54)e
	September	N_r	N_r	3.47(1.99)a	4.46(2.22)a	N_r
	October	0.9(1.18)a	1.75(1.5)a	2.93(1.85)b	N_r	N_r
	November	0.9(1.18)a	1.61(1.45)a	2.53(1.74)c	N_r	N_r
	December	0.7(1.09)a	1.22(131)b	N_r	N_r	N_r
	January	N_r	N_r	N_r	4.75(2.29)a	6.82(2.70)d
	February	N_r	N_r	N_r	N_r	8.82(3.05)c
	March	N_r	N_r	N_r	N_r	12.82(3.65)b
	April	N_r	N_r	N_r	N_r	15.82(4.0)a
	Mean	0.8(1.2)	1.5(1.41)	3.06(1.88)	4.6(3.4)	10.0(3.2)
	SEm	0.05(0.03)	0.05(0018)	0.09(0.024)	0.07(0.015)	0.09(0.015)
	LSD	0.21(0.099)	0.23(0.08)	0.24(0.064)	0.3(0.07)	0.18(0.031)
	CV%	20.29(6.5)	9.92(3.81)	8.69(3.75)	4.44(1.99)	2.86(1.5)
	Sign.difference	*	**	**	ns	**

Values given in parenthesis are square root transformed values; Values in each column of the sa letter are not significantly different; SEm= Standard error of mean; LSD=Least Signi Difference; CV=Coefficient of Variation; * significant at P < .05, ** significant at .01, ns=Non_significant; N_r=Not Recorded; Number of white mango scale cluster

The WMS severity of infestation status of the segregated data of Bambasi orchards during the study month for Zero cluster or free severity status were statistically highly significant different ($F_{2, 31} = 37.87$, $p < .01$). Mean WMS cluster for zero cluster formation per leaf showed that the severity status were maximum during October 0.65(1.07) and lowest during December 0.19(0.82) compared with November 0.5(0.99). The severity status in descending order were October, November, and December respectively. The zero cluster formation were not occurred during the study months of August, September, and January to April (Table 4.19).

The WMS severity of infestation status of the segregated data of Bambasi orchards during the study month for one to two clusters or minimal severity status were statistically insignificant different ($F_{2, 11} = 1.67$, ns). The severity status of September 1.65(1.46), October 1.47(1.39) and November 1.47(1.39) were insignificantly different. One to two cluster formation were not occurred during the study months of August and December to April (Table 4.19).

The WMS severity of infestation status of the segregated data of Bambasi orchards during the study months for two to four clusters or moderate severity status were statistically highly significant different ($F_{2, 11} = 14.9$, $p < .01$). Mean WMS cluster for two to four cluster formation per leaf showed that the severity status were maximum during August 3.65(2.04) and lowest during September 2.47(1.72) and October 2.47(1.72). Two to four cluster formation were not occurred during the study months of November to April (Table 4.19).

The WMS severity of infestation status of the segregated data of Bambasi orchards during the study months for four to five clusters or severe severity status were statistically insignificant different ($F_{2, 11} = 1.72$, ns). Mean WMS cluster for four to five cluster formation per leaf were insignificantly different between August 4.47(2.23), September 4.47(2.23) and January 4.65(2.27). Formation of four to five cluster were not occurred during the study months of October to December and February to April (Table 4.19).

The WMS severity of infestation status of the segregated data of Bambasi orchards during the study months for greater than five clusters or very severe severity status were statistically highly significant different ($F_{3, 48} = 1750$, $p < .01$). Mean WMS cluster for greater than five cluster formation per leaf showed that the severity status were maximum during April 14.14(2.44) and lowest during January 5.47(2.44). The severity status in descending order were April 14.14(2.44), March 11.14(3.41), February 7.14(2.76) and January 5.47(2.44) respectively. No greater than five cluster formation or very severe severity status were recorded during the study months of August to December (Table 4.19).

Table 4.19. Severity of white mango scale infestation during the study month in Assosa and Bambasi districts

District	Month	Mean				
		Free	Minimal	Moderate	Sever	Very Sever
Bambasi	August	N_r	N_r	3.65(2.04)a	4.47(2.23)a	N_r
	September	N_r	1.65(1.46)a	2.47(1.72)b	4.47(2.23)a	N_r
	October	0.65(1.07)a	1.47(1.39)a	2.47(1.72)b	N_r	N_r
	November	0.5(0.99)b	1.47(1.39)a	N_r	N_r	N_r
	December	0.19(0.82)c	N_r	N_r	N_r	N_r
	January	N_r	N_r	N_r	4.65(2.27)a	5.47(2.44)d
	February	N_r	N_r	N_r	N_r	7.14(2.76)c
	March	N_r	N_r	N_r	N_r	11.14(3.41)b
	April	N_r	N_r	N_r	N_r	14.14(3.83)a
	Mean	0.39(0.93)	1.54(1.42)	2.94(1.84)	4.5(2.24)	9.92(3.19)
	SEm	0.06(0.03)	0.1(0.03)	0.1(0.03)	0.1(0.03)	0.11(0.018)
	LSD	0.15(0.073)	ns	0.36(0.10)	ns	0.25(0.042)
	CV%	41.04(8.55)	20.14(7.8)	10.54(4.77)	6.83(3.19)	3.199(1.66)
	Sign.difference	**	ns	**	ns	**

Values given in parenthesis are square root transformed values; Values in each column of the s letter are not significantly different; SEm= Standard error of mean; LSD=Least Signi Difference; CV=Coefficient of Variation; * significant at P < .05, ** significant at .01; ns=Non_significant; N_r=Not Recorded Number of white mango scale cluster

The seasonal white mango scale abundance and severity status variation result also supported by different study results such as: The study by Ofgaa Djirata et al. (2018) revealed that the white mango scale population fluctuation showed significance variation among the study month. Tsegaye Babege et al. (2017) also reported that white mango scale infestation variation among the study districts and season. Other countries were reported that different population fluctuations of mango white scale, some of these are study by Kwaiz and Fayza (2009) who stated that *A. tuberculauis* had three peaks of seasonal abundance on mango trees in Egypt. Similarly, Abo-Shanab (2012) recorded four annual peaks of seasonal abundance for white mango scale on mango trees in Egypt.

4.1.5 Spatial and seasonal distribution map of white mango scale

Spatial distribution map of white mango scale: Figure 4.3 illustrates the spatial distribution of WMS in the study site of Assosa and Bambasi districts. The spatial distribution from the reference of the experimental site, Assosa Town, Assosa Poly Technique College was ranged from 5.003 km to 33.922km air distance. Table 4.20 illustrates WMS distribution of average air distance within orchards and from experimental site at the study districts.

Table 4.20. Spatial distribution of white mango scale

Study Districts	Kebele	Mean Air Distance Within Orchards (Km)	Mean Air Distance From Experiment Site (Km)
Assosa	Amba 14	4.292	9.296
	Amba 5	4.099	8.151
	Amba 8	2.386	5.946
	Megele 32	1.845	5.424
Bambasi	Menider 47	3.885	23.610
	Menider 48	3.785	26.280
	Sonika	4.239	33.922

Figure 4.3. Spatial distribution map of white mango scale

Seasonal distribution map of white mango scale: Figure 4.4 illustrates seasonal WMS distribution map indicates that severity status varied during the study month in the study orchards. WMS severity of infestation in the study month of August (Moderate to Very severe), September (Minimal to Moderate), October (Free to Moderate), November (Free to Minimal except in Amba_14 Moderate), December (Free to Minimal), January (Moderate to Very severe), and February to April (Very severe) severity status were recorded in the study orchards.

Figure4.4. Seasonal distribution map of white mango scale

4.1.6 Factors contributing for infestation of white mango scale

Correlations of white mango scale with meteorological data: In Assosa orchards mean cluster abundance was more strongly negatively related to relative humidity (r_{178} = -0.532, $p < .01$) than to rain fall (r_{178} = -0.277, $p < .01$). These finding indicated that mean cluster abundance some how more varied by relative humidity than rain fall. In Bmabasi orchards of Bambasi also mean cluster abundance was strongly negatively related to rainfall (r_{133} = -0.380, $p < .01$). In both Assosa and Bambasi orchards mean cluster was more strongly positively related to temperature (r_{178} = 0.898, $p < 0.01$) and (r_{133} = 0.838, $p < .01$) respectively (Table 4.21, Appendix Table 7 and 8).

Table 4.21. Correlations of white mango scale cluster abundance per leaf with rain fall, temperature and relative humidity in Assosa and Bambasi orchards

		Rain Fall	Temperature	Humidity
Assosa	r_{178}	-0.277	0.898	-0.532
	p	0.0002	<.0001	<0.0001
Bambasi	r_{178}	-0.380	0.838	-
	p	<.0001	<.0001	-

RF=rain fall (cm); Max T^0 (^{0}c) = maximum temperature in degree Celsius; Min T^0 (^{0}c) = minimum temperature in degree Celsius, RH=relative humidity

Progressive change of white mango scale with Rain fall, Temprature and Relative humidity: Figure 4.5 illustrates the impact of rain fall and temperature on mean cluster abundance per leaf at Bambasi district. Maximum cluster abundance 14.1 per leaf was recorded at the maximum temperature records of the study period during April, 2019 at maximum temperature 35.64^{0}c and minimum temperature 20.84^{0}c and rain fall 39.2mm. Mean cluster abundance per leaf was observed decreasing while there was a continued and high rain fall from August a rain fall record of 263mm to December a minimum rain fall record of 5.2mm during which a minimum 0.19 cluster abundance per leaf was recorded

Figure 4.6 illustrates the impact of rain fall, temperature and relative humidity on mean cluster abundance per leaf in Assosa. Mean cluster abundance per leaf was decreased from August to December coincides with lowering of relative humidity. Building up of cluster abundance coincides with a startup of relative humidity and rain fall increment starting from March. Maximum cluster abundance 15.8 per leaf was recorded at the maximum temperature records of the study period April, 2019 at maximum temperature 32.9 ^{0}c, minimum temperature 17.8 ^{0}c and optimum rain fall 42mm and relative humidity 32%. Cluster abundance per leaf was observed decreasing while there was a continued and high rain fall during August a rain fall record of 218.9mm to December 1.5mm a minimum rain fall record during which a minimum cluster abundance 0.86 was recorded.

These study result also supported by different literature such as: Ofgaa Djirata et al (2018) reported that temperature variation affect the white mango scale populations, peak populations were recorded in the months with maximum monthly temperatures of 35 and 31°C at Arjo and Bako of western Ethiopia, respectively. Extremely low population level below 10 mm average monthly rain fall (highly affected by drought) and in contrary heavy and continued rain fall decreases the population. Ofgaa Djirata et al. (2015) reported that maturation and ripening of mango fruit begin during the first months of rainy season, that is, in March to April and continues for few months, vis-à-vis significant infestation of mango fruits by white mango scale, in Western Ethiopia. However; this result contradicted with the earlier finding of Labuschagne et al. (1995) that white mango scale had a low tolerance to high temperature, and as a result its population declined in temperatures above 30°C.

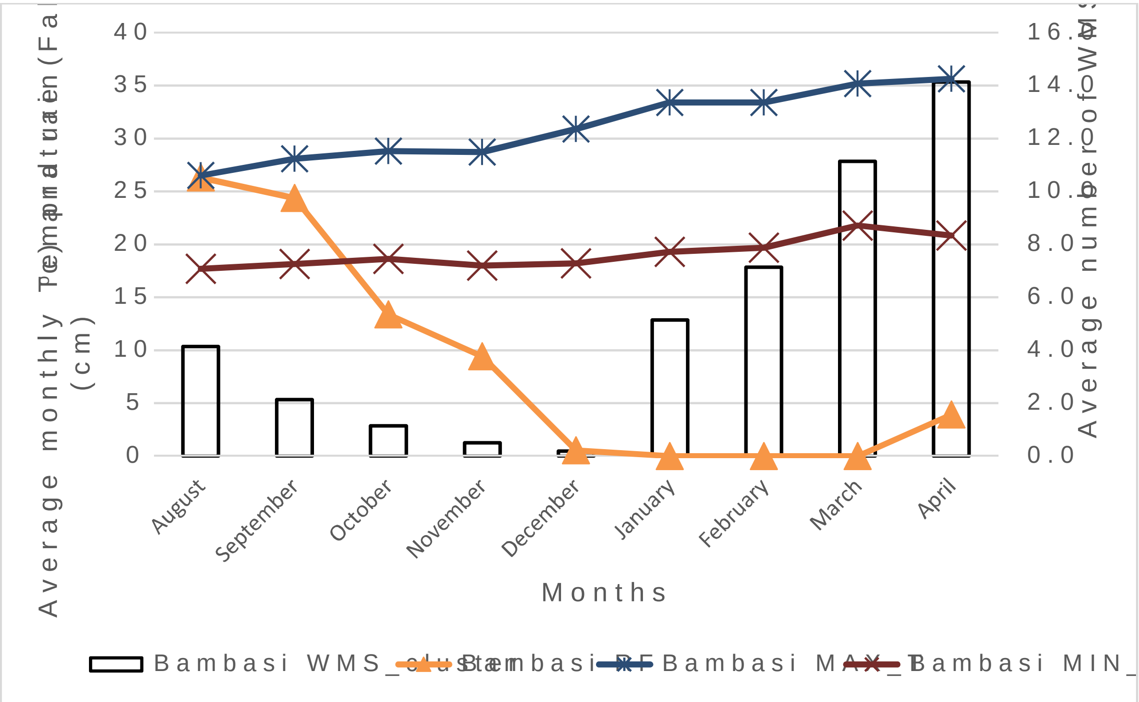

Figure4.5. Progressive change of mean cluster/leaf with Rain fall and Temprature at Bambasi

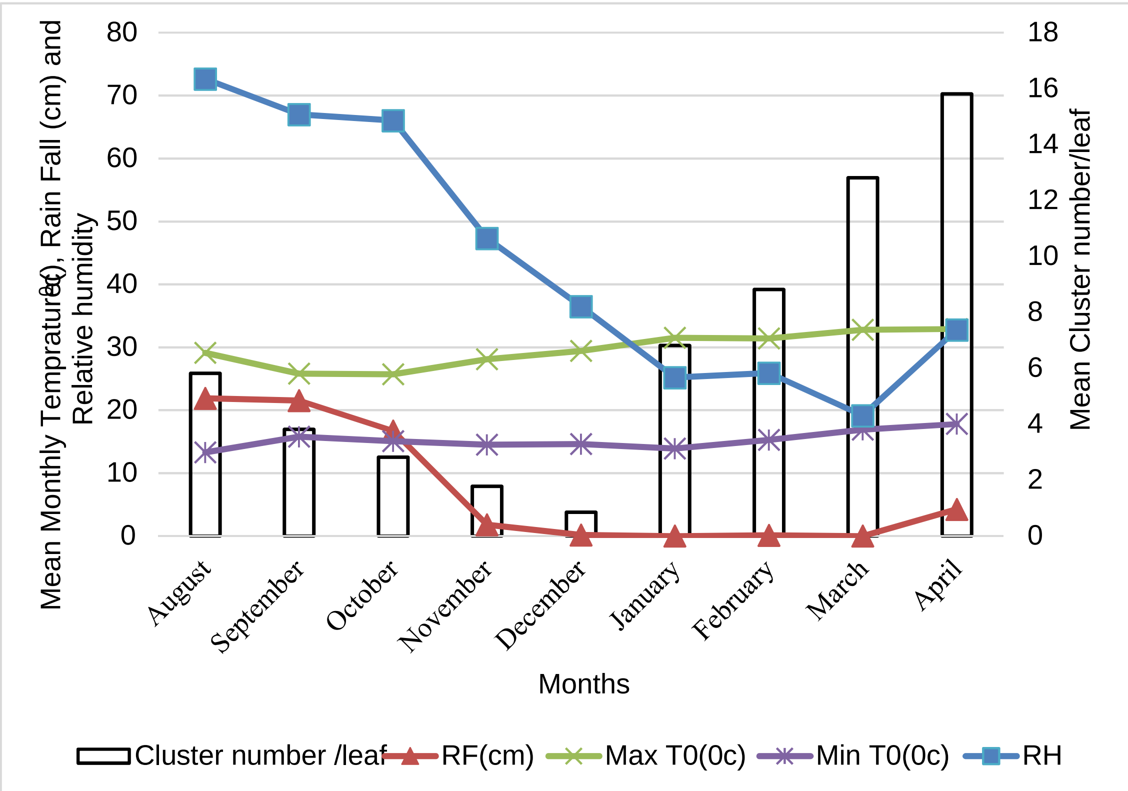

Figure4.6. Progressive change of mean cluster/leaf with Rain fall, Temprature and Relative humidity at Assosa

Effect of mango orchard characteristics to white mango scale severity status of infestation:

Table 4.22 illustrates white mango scale severity status variability with variation of surveyed mango orchards, characteristics during the study period August/2018 to April/2019.

White mango scale insect pest infestation status significantly varied for different age category of mango trees (X^2.95 (2) = 7.48, p < .05). Mango orchards in age less than 10 years old age group were at 51% lower risk of minimal to moderate severity status compared to greater than 20 years old age mango trees group (OR: 0.49; 95% CI: 0.29-0.817). This implied that mango trees age was a factor for infestation varability in the study orchards. Old age mango trees were observed more likely at risk of minimal to moderate severity status. Since the mango trees leave without any agronomic management which become suitable for the reproduction of the pest and used for source of infestation. The study result of Seid Hussen and Zeru Yimer (2013) also revealed that according to the oldness of the trees age most farmers did not give attention to mango trees plantation.

White mango scale insect pest infestation status significantly varied for different height category of mango trees (X^2.95 (3) = 11.8, p < .05). Mango orchards in short height group were at 60% lower risk of minimal to moderate severity status compared to very long height mango trees group (OR: 0.40; 95% CI: 0.22-0.739). This implied that very long height mango trees were observed more likely at risk of minimal to medium severity status. Since unmanageable sized mango trees significantly contribute for white mango scale infestation. This result also supported by Griesbach (2003) reported that tall trees present a harvesting problem and create difficulties during spraying and pruning.

White mango scale insect pest infestation status significantly varied for different canopy volume category of mango trees (X^2.95 (3) = 8.18, p < .05). Mango orchards in crowded canopy group were at 2.079 times more at risk of minimal to moderate severity status compared to uncrowded canopy mango trees group (OR: 2.08; 95% CI: 1.248-3.465). This implied that uncrowded canopy volume in which sun light easily penetrate to inner canopy and also free air movement made lower infestation of white mango scale. This result supported by Bally (2006) who reported that well managed orchard trees require regular annual pruning to maintain an open canopy of manageable size which allows air and sunlight to penetrate, which reduces pests and diseases. Lal and Mishra (2007) reported that pruning is an important cultural operation for obtaining quality yield from the fruiting trees which reduces incidence of pests and disease occurs due to high relative humidity. Study by Sharma et al. (2001) also suggested that regular canopy management necessary for mango yield improvement.

White mango scale insect pest infestation status significantly varied for different planting pattern or spacing of mango orchards (X^2.95 (1) = 5.62, p < .01). Mango orchards in not recommended planting pattern group were at 75% more likely at risk of minimal to moderate severity status compared to recommended planting pattern mango trees group (OR: 1.75; 95% CI: 1.102-2.774). This implied that mango trees planted with recommended planting space which is used regularly 10m X 10m as general guide the study districts were observed less likely at risk of minimal to moderate severity status. This study result supported by Seid Hussen and Zeru Yimer (2013), Olaniyan (2004), Khan et al. (2015), Sharma et al. (2001) and Griesbach (2003) who reported that since mango trees grow in to large specimen need appropriate spacing; high-density planting show a progressive decline in crop yield after 14/15 years, due to overcrowding of canopies, which results in the production of fewer fruits which are apt to be poorly colored and infected with pests. Also Andrew (2016) suggested that adequate plant spacing which allows greater air movement and increases pesticide coverage and also reduces ideal environments for scale insects to develop and increases the ease of detection.

White mango scale insect pest infestation status significantly varied by intercropping condition of mango orchards (X^2.95 (1) = 7.37, p < .01). Mango orchards in not intercropped group were at 44% lower risk of minimal to moderate severity status compared to intercropped mango trees group (OR: 0.56; 95% CI:-0.8571). This implied that mango trees intercropped with other plants were highly at risk of white mango scale. The intercropped plants might be used to harbor the pest. White mango scale insect pest infestation status significantly varied for different weed infestation status category of mango orchards (X^2.95 (2) = 8.18, p < .01). Mango orchards in low weed infested group were at 52% lower risk of minimal to moderate severity status compared to medium weed mango trees group (OR: 0.48; 95% CI: 0.289-0.802). This also implied that mango trees infested by weed more likely attacked by white mango scale comparatively high infestation status. These result supported by Andrew (2016) who suggested that for scale management removing crop debris and disinfest the growing area and free of weeds since scale may survive for weeks on crop debris and in egg masses that have fallen off plants.

Table4.22 Effect of mango orchard characteristics to white mango scale severity status

Effect		Odds Ratio Estimates Point Estimate	95% Wald Confidence Limits		Pr >ChiSq
Moderate vs Free	Intercept				<.0001
Minimal vs Free	Intercept				<.0001
Age					0.0237
10_20Years vs>20 Years		0.7	0.433	1.137	0.9792
<10 Years>20 Years		0.49	0.29	0.817	0.0212
Moderate vs Free	Intercept				<.0001
Minimal vs Free	Intercept				<.0001
Height					0.0081
Long vs Very Long		0.73	0.428	1.238	0.2899
Medium vs Very Long		0.45	0.254	0.809	0.1388
Short vs Very Long		0.4	0.22	0.739	0.0476
Moderate vs Free	Intercept				<.0001
Minimal vs Free	Intercept				<.0001
Canopy					0.0167
CD vs Un_CD		2.08	1.248	3.465	0.0074
L-CD vs Un_CD		1.37	0.803	2.334	0.8174
Moderate vs Free	Intercept				<.0001
Minimal vs Free	Intercept				<.0001
Intercropping					0.0066
No vs Yes		0.561	0.37	0.851	0.002
Moderate vs Free	Intercept				<.0001
Minimal vs Free	Intercept				<.0001
Planting pattern					0.0177
N_R vs R		1.75	1.102	2.774	0.0177
Moderate vs Free	Intercept				<.0001
Minimal vs Free	Intercept				<.0001
Weed					0.0167
High vs Medium		0.66	0.405	1.07	0.8174
Low vs Medium		0.48	0.289	0.802	0.0266

N_R= Not recommended, R= Recommended CD=Crowded Un_CD=uncrowded
L_CD=less crowded

4.2 Field Experiment

4.2.1 Effects of treatments on white mango scales population

The pretreatment observation on white mango scales population 333.33(18.23) to 370(19.22) per ten leaves per tree, which was statistically insignificant ($F_{7, 14} = 2\ 44$, ns), which indicated uniform distribution of the pest among different treatments. The observations were recorded on WMS population with 14th day,s interval of post first, post second and post third spray application (Table 4.23).

The data revealed that after first spray mean WMS population ranged from 141.33(11.88) to 407(20.16) per ten leaves per tree in different treatments were highly significantly different ($F_{7, 14} = 2\ 44$, $p < .01$). The lowest WMS population were observed in Imidacloprid 20SL+pruning treatment 141.33(11.88) compared to other treatments. The comparative WMS population among treatments against WMS at fourteenth day after first spraying found in descending order were untreated Control 407(20.16), Pruning 285.33(16.86), White oil 267.67(16.35), Dimethoate 40% EC 261.33(16.14), Imidacloprid 20SL 252.67(15.84), White oil extract + pruning 251(15.8), Dimethoate 40% EC+ pruning 222.67(14.89) and Imidacloprid 20SL+pruning 141.33(11.88) respectively. All the treatments were significantly different from untreated control. White oil extract + pruning 251(15.8) and Imidacloprid 20SL 252.67(15.84) which were found to be at par with each other. White oil extract 267.67(16.35) and Dimethoate 40% EC 261.33(16.14) which were found to be at par with each other (Table 4.23).

The data revealed that after second spray the mean WMS population ranged from 89.33(9.44) to 447.67(21.14) per ten leaves per tree in different treatment were highly significantly different ($F_{7, 14} = 68.62$, $p < 0.01$). The lowest WMS population was observed in Imidacloprid 20SL + pruning treatment 89.33(9.44) compared to other treatments. The comparative WMS population among treatments at fourteenth day after second spraying found in descending order were Control 447.67(21.14), Pruning 234(15.24), White oil extract 224(14.93), Dimethoate 40% EC 184.33(13.52) , Imidacloprid 20SL 163(12.63), White oil extract + pruning 161.33(12.58), Dimethoate 40% EC+ Pruning 138.67(11.68) and Imidacloprid 20SL+ pruning 89.33(9.44) respectively. All the treatments were significantly different from untreated control. Pruning 234(15.24) and White oil extract 224(14.93) which were found to be at par with each other. Imidacloprid 20SL 163(12.63) and White oil extract + Pruning 161.33 (12.58) which were found to be at par with each other (Table 4.23).

The data revealed that after third spray mean WMS population ranged from 24 (4.87) to 492.67 (22.18) per ten leaves per tree in different treatment were highly significantly different ($F_{7, 14} = 90.81$, $p < .01$). The lowest WMS population were observed in Imidacloprid 20SL + Pruning treatment 24 (4.87) compared to other treatments. The comparative WMS population among treatments at fourteenth day after third spraying found in descending order were Control 492.67 (22.18), Pruning 187.33 (13.52), White oil extract 165.67 (12.77), Dimethoate 40% EC 92 (9.44), Imidacloprid 20SL 74 (8.46), White oil extract + pruning 78.67 (8.74), Dimethoate 40% EC + pruning 66.33 (8.013) and Imidacloprid 20SL + pruning 24 (4.87) respectively. All the treatments were significantly different from untreated control. Pruning 187.33 (13.52) and White oil 165.67 (12.77) which were found to be at par with each other. Dimethoate 40% EC 92 (9.44), Imidacloprid 20SL 74 (8.46) and White oil extract + Pruning 78.67 (8.74) which were found to be at par with each other (Table 4.23).

The mean of the three spray data revealed that the mean WMS population ranged from 85 (9.21) to 449.33 (21.18) per ten leaves per tree in different treatment were highly significantly different ($F_{7, 14} = 98.63$, $p < .01$). The lowest WMS population were observed in Imidacloprid 20SL + Pruning treatment 85 (9.21) compared to other treatments. The comparative white mango scales population among treatments against white mango scale found in descending order were Control 449.33 (21.8), Pruning 235.67 (15.28), White oil 219.33 (14.78), Dimethoate 40% EC 179.33 (13.34), Imidacloprid 20SL 163.33 (12.69), White oil extract + Pruning 163.67 (12.72), Dimethoate 40% EC + Pruning 142.67 (11.89) and Imidacloprid 20SL + Pruning 85 (9.21) respectively. All the treatments were significantly different from untreated control. Pruning 235.67 (15.28) and White oil extract 219.33 (14.78) which were found to be at par with each other. Imidacloprid 20SL 163.33 (12.69) and White oil extract + Pruning 163.67 (12.72) which were found to be at par with each other (Table 4.23).

Table 4.23. Mean number of white mango scales in the experimental mango orchards

	Mean				
Treatment	PrT	PFS	PSS	PTS	MS
Control	370(19.22)	407(20.16)^{a}	447.67(21.14)^{a}	492.67(22.18)^{a}	449.33(21.18)^{a}
Pruning	348.33(18.64)	285.33(16.86)^{b}	234(15.24)^{b}	187.33(13.52)^{b}	235.67(15.28)^{b}
White oil extract	355(18.84)	267.67(16.35)^{bc}	224(14.93)^{b}	165.67(12.77)^{b}	219.33(14.78)^{b}
Dimethoate	333.33(18.23)	261.33(16.14)^{bc}	184.33(13.52)^{c}	92(9.44)^{c}	179.33(13.34)^{c}
Imidacloprid	340(18.41)	252.67(15.84)^{c}	163(12.63)^{cd}	74(8.46)^{c}	163.33(12.69)^{cd}
White oil + pruning	358.33(18.9)	251(15.8)^{c}	161.33(12.58)^{cd}	78.67(8.74)^{c}	163.67(12.72)^{cd}
Dimethoate+ pruning	351.67(18.72)	222.67(14.89)^{d}	138.67(11.68)^{d}	66.33(8.013)^{cd}	142.67(11.89)^{d}
Imidacloprid + pruning	353.33(18.78)	141.33(11.88)^{e}	89.33(9.44)^{e}	24(4.87)^{d}	85(9.21)^{e}
Mean	351.3(18.7)	261.1(15.99)	205.3(13.9)	147.6(10.99)	204.8(13.89)
SE_m	4.4(0.11)	5.8(0.17)	6.8(0.25)	9.2(0.34)	6.4(0.21)
LSD	21.8(059)	28.7(0.85)	33.46(1.27)	45.44(1.68)	31.77(1.064)
CV%	3.53(1.79)	6.28(3.044)	9.31(5.199)	17.58(8.72)	8.86(4.37)
Sign.difference	ns	**	**	**	**

Values given in parenthesis are square root transformed value; Values in each column of the same letter are not significantly different; $SE_m\pm$ Standard error of mean; LSD=Least Significant Difference; CV=Coefficient of Variation; * significant at P < .05; ** significant at .01; ns=Non_significant; PrT=Pre_Treatment WMS count/10 leaves, PFS=Post First Spray WMS count/10 leaves, PSS=Post Second Spray WMS count/10 leaves, PTS Spray WMS count/10 leaves, MS=mean WMS count/10 leaves after all spray

4.2.2 Effects of treatments on white mango scales mortality

The WMS mortality percentages over control was worked out after each treatment using Abbott,s (1925) formula of mortality correction (Table 4.24)

The mortality percentage of WMS fourteen_days after the first application was highly significantly different among treatments ($F_{7, 14}$ = 136, p < .01). The highest mortality percentage was observed in Imidacloprid 20SL + pruning treatment 65(53.73) compared to other treatments. The comparative mortality percentage among treatments in descending order were Imidacloprid 20SL + pruning 65(53.73), Dimethoate 40%Ec + pruning 45.33(42.27), White oil extarct + pruning 38.67(38.42), Imidacloprid 20SL 38.33(38.18), Dimethoate 40%EC 36(36.9), White oil 34(35.5), Pruning 30.33(33.3) and Control 0(0.33) respectively. All the treatments were significantly different from untreated control. Dimethoate 40%EC + pruning 45.33(42.27) and White oil extracc + pruning 38.67(38.42) which was found to be at par with each other. Dimethoate 40EC 36(36.9) and White oil extract 34(35.5) which were found to be at par with each other.

The mortality percentage of WMS fourteen_days after the second application were highly significantly different among treatments ($F_{7, 14}$ = 167, p < .01). The highest mortality percentage was observed in Imidacloprid 20SL + pruning treatment 80(63.44) compared to other treatments. The comparative mortality percentage among treatments in descending order were Imidacloprid 20SL + pruning 80(63.44), Dimethoate 40%EC + pruning 69(56.3), Imidacloprid 20SL 64(53.1), White oil extract + pruning 64(53.3), Dimethoate 40% EC 59(50.2), White oil extract 50(45.0), Pruning 47.67(43.7) and Control 0(0.33) respectively. All the treatments were significantly different from untreated control. Imidacloprid 20SL 64(53.1) and White oil extract + pruning 64(53.3) which were found to be at par with each other. White oil extract 50(45.0) and Pruning 47.67(43.7) which were found to be at par with each other.

The mortality percentage of WMS fourteen_days after the third application were highly significantly different among treatments ($F_{7, 14}$ = 168.1, p < .01). The highest mortality percentage was observed in Imidacloprid 20SL + pruning treatment 95(77.12) compared to other treatments. The comparative mortality percentage among treatments in descending order were Imidacloprid 20SL + pruning 95(77.12), Dimethoate 40%EC + pruning 87(69.1), Imidacloprid 20SL 85.33(67.7), White oil + pruning 84.67(67.1), Dimethoate 40% EC

81.67(64.9), White oil extract 66(54.5), Pruning 62.33(52.4) and Control 0(0.33) respectively. All the treatments were significantly different from untreated control. Dimethoate 40%EC + pruning 87(69.1), Imidacloprid 20SL 85.33(67.7), White oil extract + pruning 84.67(67.1) and Dimethoate 40%EC 81.67(64.9) which were found to be at par with each other. White oil extract 66(54.5) and Pruning 62.33(52.4) which were found to be at par with each other.

Mortality percentages of WMS showed a progressive increase from first spray to third spray application for all treatments compared to untreated control. The progressive increase of mortality percentage of each treatments Imidacloprid 20SL + pruning Dimethoate 40%EC + pruning Imidacloprid 20SL, White oil extract + pruning Dimethoate 40%EC, White oil extract and Pruning were 65 to 95, 45.33 to 87, 38.33 to 85.33, 38.67 to 84.67, 36 to 81.67, 34 to 66 and 30.33 to 62.33 respectively.

Table 4.24. Mortality percentage of white mango scales in response of treatments in the experimental mango orchards

Treatment	Mean		
	first spray mortality %	second spray mortality %	third spray mortality %
Imidacloprid + Pruning	65(53.73)[a]	80(63.44)[a]	95(77.12)[a]
Dimethoate + Pruning	45.33(42.27)[b]	69(56.3)[b]	87(69.1)[b]
Imidacloprid	38.33(38.18)[c]	64(53.1)[bc]	85.33(67.7)[b]
White oil + Pruning	38.67(38.42)[b]	64(53.3)[bc]	84.67(67.1)[b]
Dimethoate	36 (36.9)[cd]	59(50.2)[c]	81.67(64.9)[b]
White oil	34(35.5)[cd]	50(45.0)[d]	66(54.5)[c]
Pruning	30.33(33.3)[d]	47.67(43.7)[d]	62.33(52.4)[c]
Control	0(0.33)[e]	0(0.33)[e]	0(0.33)[d]
Mean	35.97(34.8)	54.22(45.7)	70.3(56.6)
SE_m	1.3(0.8)	1.5(0.9)	1.9(1.14)
LSD	6.49(3.97)	7.34(4.5)	9.24(5.6)
CV%	10.31(6.5)	7.73(5.7)	7.51(5.7)
Sign.difference	**	**	**

Values given in parenthesis are angular transformed value, Values in each column of the same letter are not significantly different; $SE_{m\pm}$ = Standard error of mean, LSD=Least Significant Difference; CV=Coefficient of Variation, * significant at P < .05, ** significant at .01; ns=Non_significant

4.2.3 Effects of treatments on mango fruit number and yield (kg/tree)

The mean marketable fruit number ranged from 43.33 to 262 per tree in different treatments were highly significantly different ($F_{(7, 14)}$ = 23.68, p < .01). The lowest marketable fruit number was untreated control (43.33) compared to other treatments. The comparative marketable fruit number among treatments found in descending order were Imidacloprid 20SL+ pruning (262), Dimethoate 40%EC+ pruning (170.67), Imidacloprid 20SL (145.33), White oil extract + pruning (142.33), Dimethoate 40%EC (137.33), White oil extract (115.67), Pruning (112), untreated control (43.33) respectively. Imidacloprid 20SL (145.33), White oil extract + pruning (142.33) and Dimethoate 40%EC (137.33) which were found to be at par with each other. White oil extract (115.67) and Pruning (112) which were found to be at par with each other (Table 4.25).

The mean unmarketable fruit number ranged from 83.33 to 176.67 per tree in different treatments were highly significantly different ($F_{7, 14} = 6.46$, $p < .01$). The lowest unmarketable fruit number was Imidacloprid 20SL + pruning treated 83.33 compared to other treatments. The comparative marketable fruit number among treatments found in descending order were untreated control (176.67), Pruning (154.67), White oil extract (147), White oil extract + pruning (144.67), Dimethoate 40%EC (132.67), Dimethoate 40%EC+pruning (130), Imidacloprid 20SL (122.33), and Imidacloprid 20SL+pruning (83.33) respectively. Pruning (154.67), White oil extract (147) and White oil extract + pruning (144.67) which were found to be at par with each other. Dimethoate 40%EC (132.67), Dimethoate 40%EC+ pruning (130) and Imidacloprid 20SL (122.33) which were found to be at par with each other (Table 4.25).

The mean total fruit number ranged from 345.33 to 220 per tree in different treatments were significantly different ($F_{7, 14} = 3.66$, $p < 0.05$). The lowest total fruit number was untreated control 220 compared to other treatments. The comparative total fruit number among treatments found in descending order were Imidacloprid 20SL + pruning (345.33), Dimethoate 40%EC+ pruning (300.67), White oil extract+ pruning (287), Dimethoate 40%EC (270), Imidacloprid 20SL (267.67), Pruning (266.67), White oil extract (262.67) and untreated control (220) respectively. Dimethoate 40%EC (270), Imidacloprid 20SL (267.67), Pruning (266.67) and White oil extract (262.67) which were found to be at par with each other (Table 4.25).

The mean marketable fruit yield ranged from 10.83 to 65.5 per tree in different treatments were significantly different ($F_{7, 14} = 23.68$, $p < .01$). The lowest marketable fruit yield was untreated control (10.83) compared to other treatments. The comparative marketable fruit yield among treatments found in descending order were Imidacloprid 20SL + pruning (65.5), Dimethoate 40%EC + pruning (42.67), Imidacloprid 20SL (36.33), White oil extract

+ pruning (35.58), Dimethoate 40%EC (34.33), White oil (28.92), Pruning (28), untreated control (10.83) respectively. Imidacloprid 20SL (36.33), White oil extract + pruning (35.58) and Dimethoate 40%EC (34.33) which were found to be at par with each other. White oil extract (28.92) and Pruning (28) which were found to be at par with each other (Table 4.25).

The mean unmarketable fruit yield ranged from 20.83 to 44.17 per tree in different treatments were significantly different ($F_{7, 14} = 6.46$, $p < 0.01$). The lowest unmarketable fruit yield was Imidacloprid 20SL + pruning treated (20.83) compared to other treatments. The comparative unmarketable fruit yield among treatments found in descending order were untreated control (44.17), Pruning (38.67), White oil extract (36.75), White oil extract + pruning (36.17), Dimethoate 40%EC (33.17), Dimethoate 40%EC + pruning (32.5), Imidacloprid 20SL (30.58), and Imidacloprid 20SL + pruning (20.83) respectively. Pruning (38.67), White oil extract (36.75) and White oil extract + pruning (36.17) which were found to be at par with each other. Dimethoate 40%EC (33.17), Dimethoate 40%EC + pruning (32.5) and Imidacloprid 20SL (30.58) which were found to be at par with each other (Table 4.25).

The average total fruit yield ranged from 55 to 86.33 per tree in different treatments were significantly different ($F_{7, 14} = 3.66$, $p < 0.05$). The lowest total fruit yield was untreated control 55 compared to other treatments. The comparative total fruit yield among treatments found in descending order were Imidacloprid 20SL + pruning (86.33), Dimethoate 40%EC + pruning (75.17), White oil extract + pruning (71.75), Dimethoate 40%EC (67.5), Imidacloprid 20SL (66.92), Pruning (66.67), White oil extract (65.67) and untreated control (55) respectively. Dimethoate 40%EC (67.5), Imidacloprid 20SL (66.92), Pruning (66.67) and White oil extract (65.67) which were found to be at par with each other (Table 4.25).

Table4.25. Mean number of mango fruit and yield per tree in response of treatments in experimental mango orchards

Treatment	Fruit mean (Number per tree)			Fruit Yield mean (kg/tree)		
	Marketable	Unmarketable	Total	Marketable	Unmarketable	Total
Imidacloprid + Pruning	262a	83.33c	345.33a	65.5a	20.83c	86.33a
Dimethoate+ Pruning	170.67b	130b	300.67ab	42.67b	32.5b	75.17ab
Imidacloprid	145.33bc	122.33b	267.67bc	36.33bc	30.58b	66.92bc
White oil + Pruning	142.33bc	144.67ab	287b	35.58bc	36.17ab	71.75b
Dimethoate	137.33bc	132.67b	270bc	34.33bc	33.17b	67.5bc
White oil	115.67c	147ab	262.67bc	28.92c	36.75ab	65.67bc
Pruning	112c	154.67ab	266.67bc	28c	38.67ab	66.67bc
Control	43.33d	176.67a	220c	10.83d	44.17a	55c
Mean	141.1	136.4	277.5	35.3	34.1	69.4
SEm	7.8	6.6	11.5	1.9	1.9	2.7
LSD	38.41	32.54	56.91	9.6	8.13	14.23
CV%	15.54	13.62	11.71	15.54	13.62	11.71
Sign.difference	**	**	*	**	**	*

Values in each column of the same letter are not significantly different; $SE_{m\pm}$= Standard error of mean; LSD=Least Significant Difference; CV=Coefficient of Variation; * significant at P < .05; ** significant at .01; ns=Non_significant

Generally treatments against white mango scale population found in descending order were Pruning at par with White oil extract > Dimethoate 40% EC > Imidacloprid 20SL at par with White oil extract + Pruning > Dimethoate 40% EC + Pruning > Imidacloprid 20SL + Pruning respectively. Treatments against mortality percentage found in descending order were Imidacloprid 20SL + pruning > Dimethoate 40%EC + pruning, Imidacloprid 20SL, White oil + pruning and Dimethoate 40% EC at par with each other > White oil extract at par with Pruning respectively. Fruit number and yield among treatments found in descending order were Imidacloprid 20SL + pruning > Dimethoate 40%EC + pruning > White oil extract + pruning > Dimethoate 40%EC, Imidacloprid 20SL, Pruning, White oil extract at par with each other respectively.

Management of white mango scale using pruning results in lined with Cunningham (1989) who reported post-harvest pruning is an effective control measure and also helps the penetration of chemical sprays through the tree canopy. Also the study of Bautista-Rosales et al. (2013) stated that pruning significantly reduced the number of females per leaf. Lal and Mishra (2007) reported that pruning is an important cultural operation for obtaining quality yield from the fruiting trees which reduces incidence of pests and disease occurs due to high relative humidity. However; Lal et al. (2000) reported poor mango fruit yield during the first year after pruning, which kept increasing in the successive years. Since in this experiment the pretreatment data showed that white mango scale natural infestation was similar infestation which means comparatively similar dead leaf, twigs and branchs which was unproductive and used for harbouring the pest which in turn contribute infestation of the newly emerged leaf. So in this case the yield was componseted comparatively with other unpruned treatments.

Management of white scale using white oil extract efficacy in lined with Tesfaye Hailu, et al. (2014) reported that white oil is recommended for control of white mango scale. Also Mark et al. (2019) reported that scale insects are suffocated by oils and dried out by insecticidal soaps. Insecticidal soaps disrupt the waxy cuticle or €skin• of the insect, which eventually causes the insect to dry out or desiccate and Prasannath (2016) supports to use such type of botanical control due to biodegradable nature, systemicity after application, capacity to alter the behaviour of target pests and favourable safety profile.

Management of white scale using Imidacloprid 20SL efficacy in lined with Hegde and Nidagundi, 2009 and Patil et al. (2009) reported that Imidacloprid is a new class of insecticide and its potency against sucking insect is well reported in different countries of the world Some studies show that imidacloprid gives an outstanding result against sucking insects (Kencharaddai and Balikai, 2012 and Joshi and Sharma, 2009). It is comparatively safer than other conventional insecticides and once it is applied, the action continued for a longer period. On the other hand, the action of imidacloprid persisted at least up to day 10 which raises the possibility that once it enters into the plant system, the imidacloprid remains comparatively for a longer period of time (Robson et al., 2007 and Shi et al., 2011). These study result also supports as this imidacloprid is comparatively less toxicity to human and environment.

Control of white scale using dimethoate 40%EC efficacy supported by Swaminathan et al. (2010) who reported that dimethoate was effective in reducing the effect of sucking insect pest. Earlier study by Howard (1989) showed that Dimethoate 40%EC was used to control of white mango scale. Dimethoate is organo phosphate class which is now in modern crop protection is not recommended due to its hazardous nature to water, soil, environment and human health compared with neonicotinoides new type insecticides like imidacloprid.

Control of white mango scale using white oil extract, imidacloprid 20SL and dimethoate 40%EC integrating with pruning increases the efficacy which in lined with Cunningham (1989) and Andrew (2016) reported post-harvest pruning is an effective control measure which helps the penetration of chemical sprays through the tree canopy.

4.2.4 Cost benefit analysis

Partial budget analysis for white mango scale management experiment. Table 4.26 illustrates the partial budget analysis of treatments. ETB18/Kg was used as farm gate price. Adjusted yield, total costs that vary and net benefit was done for each treatment.

Table4.26. Partial budget analysis for white mango scale management experiment

	Treatments							
Item	Control	Pruning	White oil extract	Dimethoate 40%EC	White oil extract + pruning	Imidacloprid 20SL	Dimethoate 40%EC + pruning	Imidacloprid 20SL + pruning
Average yield (kg/tree)	10.83	28	28.92	34.33	35.58	36.33	42.67	65.5
Adjusted yield (kg/tree)	9.747	25.2	26.028	30.897	32.022	32.697	38.403	58.95
Gross field benefits (ETB/tree)	175.446	453.6	468.504	556.146	576.396	588.546	691.254	1061.1
cost of insecticide (ETB/tree)	0	0	0	3.94	0	9.36	3.94	9.36
cost of white oil (ETB/tree)	0	0	10.3		10.3	0	0	0
Cost of labor to apply insecticide (ETB/tre	0	0	0	90	0	90	90	90
Cost of sprayer rental (ETB/tree)	0	0	40	60	40	60	60	60
Cost of labor to apply white oil (ETB/tree)	0	0	30	0	30	0	0	0
Cost of labor for pruning (ETB/tree)	0	75	0	0	75	0	75	75
Total costs that vary (ETB/tree)	0	75	80.3	153.94	155.3	159.36	228.94	234.36
Net benefits (ETB/tree)	175.446	378.6	388.204	402.206	421.096	429.186	462.314	826.74

Dominance analysis for white mango scale management experiment: Table 4.27 illustrates Dominance analysis between treatments. In moving from the lowest to the highest, there were no dominated treatments obtained which costs more than the previous. Therefore all treatments were taken in to MRR analysis.

Table 4.27. Dominance analysis for white mango scale management experiment

Treatment	Total costs that vary (ETB/tree)	Net benefits (ETB/tree)	Dominancy
Untreated Contro	0	175.446	
Pruning	75	378.6	No
White oil extract	80.3	388.204	No
Dimethoate 40% EC	153.94	402.206	No
White oil extract + pruning	155.3	421.096	No
Imidacloprid 20SL	159.36	429.186	No
Dimethoate 40% EC + pruning	228.94	462.314	No
Imidacloprid 20SL + pruning	234.36	826.74	No

Marginal analysis for white mango scale management experiment: Table 4.28 illustrates calculating the MRR between treatments. The MRR by switching from untreated control to pruning treatment was 270.87%, well above the minimum. Hence, a 270.87% MRR in switching from untreated control to pruning treatment implied that for each ETB invested in the new treatment, the producer can expect to recover the 1ETB invested plus an additional return of 2.7087ETB. Therefore pruning was certainly a worthwhile alternative to the untreated control. By switching from pruning to white oil treatment the marginal rate of return was 181.21%, also well above the minimum. Hence, a 181.21% MRR in switching from pruning to white oil treatment implied that for each ETB invested in the new treatment, the producer can expect to recover the 1ETB invested plus an additional return of 1.8121ETB, and therefore white oil was certainly a worthwhile alternative to pruning management option. By switching from white oil to Dimethoate 40%EC treatment the MRR was 19.014%, and below the minimum. Hence, a 19.014% MRR in switching from pruning to white oil treatment implied that for each ETB invested in the new treatment, the producer can expect to recover the 1ETB invested plus an additional return of 0.19014ETB which was less than white oil treatment. Therefore Dimethoate 40%EC treatment had been eliminated from consideration. But the MRR between Dimethoate 40%EC treatment and white oil + pruning was 1388.97% and above the minimum rate of return which seems profitable. However the MRR by switching from white oil to white oil + pruning was 43.86%, below the minimum. Hence, a 43.86% MRR in switching from white oil to white oil + pruning implied that for each ETB invested in the new treatment, the producer can expect to recover the 1ETB invested plus an additional return of 0.4386ETB which was less than white oil treatment. Therefore white oil + pruning had been eliminated from consideration. By switching from white oil + pruning to Imidacloprid 20SL treatment the MRR was 199.26%, well above the minimum, which seems profitable however the MRR by switching from white oil to Imidacloprid 20SL treatment was 51.85%, below the minimum. Hence, a 51.85% MRR in switching from white oil to Imidacloprid 20SL treatment implied that for each ETB invested in the new treatment, the producer can expect to recover the 1ETB invested plus an additional return of 0.5185ETB which was less than white oil treatment. Therefore Imidacloprid 20SL treatment had been eliminated from consideration. By switching from Imidacloprid 20SL treatment to Dimethoate 40%EC + pruning the MRR was 47.61%, below the minimum and also by switching from white oil to Dimethoate 40%EC + pruning the MRR was 49.85, below the minimum. Hence, a 49.85% MRR in switching from white oil to Dimethoate 40%EC + pruning treatment implied that for each ETB invested in the new treatment, the producer can expect to recover the 1ETB invested plus an additional return of 0.4985ETB which was less than white oil treatment. Therefore Dimethoate 40%EC + pruning treatment had been eliminated from consideration. By switching from Dimethoat 40%ECe + pruning to Imidacloprid 20SL+ pruning treatment the MRR was 6723.72%, well above the minimum which seems unrealistic since which was seen from not profitable treatment. But by switching from white oil to Imidacloprid 20SL + pruning treatment the MRR was 284.65%, also well above the minimum. Hence, a 284.65%, MRR in switching from white oil to Imidacloprid 20SL+ pruning treatment implies that for each ETB invested in the new treatment, the producer can expect to recover the 1ETB invested plus an additional return of 2.8465ETB which was greater than white oil treatment. Therefore Imidacloprid 20SL + pruning treatment was certainly a worthwhile alternative to all management option. Therefore white oil and pruning should be considered as second and third alternative to producers.

Researchers should continue to experiment white oil, pruning and Imidacloprid 20SL + pruning treatment which seems to be a promising alternative to producers white mango scale management. Dimethoate 40%EC, white oil + pruning, Imidacloprid 20SL, and Dimethoate 40%EC+ pruning treatments gave higher yield and statistically significant different from pruning and white oil treatment but their costs were such that they did not provide an acceptable rate of return. However Imidacloprid 20SL + pruning treatment costs higher compared with all other treatment but gave higher yield and acceptable rate of return.

Table 4.28. Marginal analysis for white mango scale management experiment

Treatment	Total costs that vary (ETB/tree	Net benefits (ETB/tree	Marginal rate of return (MRR)%				
Untreated Control	0	175.446					
			270.87%				
Pruning	75	378.6					
			181.21%				
White oil extract	80.3	388.204					
			19.01				
Dimethoate 40% EC	153.94	402.206					
			1388.9				
White oil extract + pruning	155.3	421.096		43.9			
			199.26				
Imidacloprid 20SL	159.36	429.186			51.9		
			47.61				
Dimethoate 40% EC + pruning	228.94	462.314				49.8	
			6723.7				
Imidacloprid 20SL + pruning	234.36	826.74					284.6

Residual analysis for white mango scale management experiment: Table 4.29 illustrates the computation of residual of treatments. The treatments were arranged in order from lowest to highest total costs that vary. Since producers will be interested in the treatment with the highest residual. The treatment with highest residual was Imidacloprid 20SL + pruning treatment and the second and third highest residual were white oil and pruning respectively which was the same conclusion reached in the previous MRR analysis.

Table 4.29. Residual analysis for white mango scale management experiment

	1	2	3	4
Treatment	Total costs that vary (ETB/tree)	Net benefits (ETB/tree)	Return required [100%*(1)] ETB/tree	Residual [(2)-(3)] ETB/tree
Untreated Control	0	175.446	0	175.446
Pruning	75	378.6	75	303.6[c]
White oil extract	80.3	388.204	80.3	307.904[b]
Dimethoate 40% EC	153.94	402.206	153.94	248.266
White oil extract + pruning	155.3	421.096	155.3	265.796
Imidacloprid 20SL	159.36	429.186	159.36	269.826
Dimethoate 40% EC + pruning	228.94	462.314	228.94	233.374
Imidacloprid 20SL + pruning	234.36	826.74	234.36	592.38[a]

a / The first Maximum residual, b / The second Maximum residual, c / The third Maximum residual

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Mango growers, perceived that white mango scale insect pest infestation varied from medium to high incidence and severity status which attack all mango cultivar and made the trees whitish colour canopy cover, leaf defoliation, stunting and distortion of fruits, dieback of twigs and branches premature fruit drop and drying of flower and results a significant yield reduction. Growers, believed that the pest mainly dispersed through planting materials and as well its management was difficult with their unmanageable mango size nature and majority of mango trees were grown in the backyards farms made difficulty for insecticide spraying and cultural management due to this they eager to expertise solution. Unless the growers, used proper management for white mango scale the infestation become serious.

White mango scale insect pest infestation was varied spatially and seasonally based on mango orchards management, rain fall, temperature and relative humidity. It was higher at Assosa than at Bambasi orchards and more abundant on upper leaf than on lower leaf. Infestation status was a rapid decreased from August to October, stayed low and undetectable between November and December and a progressive increased from January to February and a rapid increased from March to peak during April. Temperature influence the infestation positively and a maximum record during maximum temperature of the study month during April. High and continued rain fall and relative humidity influence infestation negatively; however optimum rain fall and relative humidity enhance infestation. The unmanaged mango tree orchards condition was contributed for infestation enhancement.

Experiment against white mango scale infested mango trees using Imidacloprid 20 SL + pruning treatment was the most effective than others treatments. The cost benefit analysis of the management option used for this experiment against white mango scale insect pest was revealed that Imidacloprid 20 SL + pruning treatment provide a promising alternative to producers against white mango scale insect pest. Since Imidacloprid 20SL is ecologically safe insecticide compared to Dimethoate 40%EC; therefore it is more preferable for white mangoscale insect pest management. Management of white mango scale using integrate management approach as used in this experiment is effective to reduce the infestation and contribute for mango fruit yield improvement in quality and quantity.

5.2 Recommendations

From the study recommendation are made for the management of white mango scale to agricultural extension service and researchers. Agricultural Extension service should focus to regular inspection and monitoring of white mango scale insect pest since white mango scale insect pest reproduce throughout mango tree growing year. It should be interested to give attention for awareness creation to growers, about this pest reproduction nature for the sake of effective management. Develop a strong domestic quarantine among regions and within regions since this pest has dispersed phoretically; it can be dispersed through planting materials, animals and others. Since the unmanaged huge sized and old age mango trees used as white mango scale infestation source, so it is important to replace such type of mango trees through grafting to manageable size and also focusing to plantation of short height mango varieties. Focus to integrated pest management approach since management of white mango scale using a combination of different cultural and IPM (integrated pest management) compatible insecticide as used in this experiment can combat white mango scale insect pest effectively. Researchers also should give attention to investigate resistance varieties of mango trees and further screening of IPM compatible insecticide for the sake of providing to growers, sustainable management approach of white mango scales for the improvement of mango fruit yield in quality and quantity.

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APPENDIX

Appendix Table 1. Questionnaires used for mango growers, perception

A. Environments (locality)

Region________________Zone______________District ____________

Location ______________North___________East__________Altitudes

B. Name of Farmers__________________ State or private farm___________

1. What is your Educational level? 0=no education 1=primary 2=secondary 3=institution 4=university
2. How many mango tree in your mango orchards do you have? Age ________
3. What are the major problem of your mango tree? (1) Insect (2) Diseases (3) Not aware
4. If the answer for Q3 is insect, what type of insect?____________________
5. Is there any local name given to this pest? (1) Yes (2) No
6. If the answer is …Yes, for Q5 what is the name?____________________
7. Is this pest new to your mango tree? (1) Yes (2) No
8. When the period of time since white mango scale has been known in the survey area? (1) Below 5 years (2) 5-10 years (3) not aware
9. What was the extent of incidence in your respective?
   (1) High (2) Medium (3) Low
10. What was the extent of severity in your respective?
    (1) High (2) Medium (3) low
11. Which parts of the plants attacked by the pest?________________
12. By which ways you identify the pest? 1. Color/sign 2. Symptom
13. What is the color/sign you used for identification?____________________
14. What type of symptom you used for identification?____________________
15. How the pest distribute / spread?______________________________
16. How long take to spread to your neighborhood farms (weeks/months)?_________
17. In which season the white mango scale insect pest become serious?
18. On which farm site you observed the pest infestation were serious?
    (1) Field farm (2) Backyard (3) No difference (4) Not aware
19. Did you have observation whether the pest was affected the local varieties and exogenous ones equally or not? (1) Yes (2) No
20. If they answer, no, please ask them the reason why?______________________
21. Did you observe other than mango tree which is attacked by MWS? (1) Yes (2) No
22. If …Yes, for Q21, ask what type of plant?__________________________
23. What was the pest prevalence level variation over time?
    (1) Increasing (2) Decreasing (3) Show no difference (4) Not aware

24. What type of management practice you attempt to control white mango scale?

    (1) Cultural (2) Pesticide (3) No measure

25. If Q24 pesticides were used as one type of control measure, what type of pesticide used?
26. If Q24 cultural practices were used as one type of control measure, what type of cultural practices used?____
27. Did the management option you used was successful?

    (1) Yes (2) To some extent (3) No (4) Not aware

28. What was the average mango production collected from a tree before this pest in k/g?____
29. What was the average mango production collected from a tree after this pest in k/g?_____
30. Did you get extension service for the management of white mango scale? (1) Yes (2) No
31. If the Q30…No, do you have interest to take intervention from experts order? (1) Yes (2) No
32. What is your level of commitment? (1) low (2) medium (3) high (4) very high
33. Please ask if any other comment concerning the pest______________________________

Appendix Table 2. White mango scale infestation survey data collection format

Orchards /mango farm field/growe name						
Number of Mango tree per observed orchard						
Varity	Improved		Indigenous		Unknown	
Age of mango trees						
Growth stage of mango tree						
Mango tree heigh						
Location	Latitude		Longitude		Altitude	
Planting Methods						
Cropping system						
Pesticide used						
Weed density						
Fertilization used						
Mango trees canopy densi	Uncrowded					
	Less crowded					
	Crowded					
	Very crowded					
Mango white scale clusters/le						
Measure severity of infestatio	Free					
	Minimal					
	Moderate					
	Severe					
	Very Severe					

Appendix Table 3. White mango scale identification key

WMS	Description	Source
Female	Opaque white armor is circular, flat, thin and often wrinkled. Exuviae is near the margin, and is yellowish-brown, with a median black ridge, forming a dark distinct median line	Hamon, 2016; Tagaki, 2010; Ben-Dov, 2012
Male	Armors are small, white, sides nearly parallel and distinctly tricarinate	
Crawler	Crawlers are deep bright brick red	

AppendixTable4. Monthly average number of white mango scale per leaf

Districts	kebele	Aug	Sept	Oct	Nov	Dece	Janu	Febru	Mar	Apr
Assosa	Amba_14	6.8	4.8	3.8	2.7	1.2	7.8	9.8	13.8	16.8
		6.3	4.3	3.3	2.3	1.1	7.3	9.3	13.3	16.3
		6.6	4.6	3.6	2.7	1.2	7.6	9.6	13.6	16.6
		6.6	4.6	3.6	2.6	1.5	7.6	9.6	13.6	16.6
		6.4	4.4	3.4	2.5	1.1	7.4	9.4	13.4	16.4
	Amba_5	6.4	4.4	3.4	2.4	1.2	7.4	9.4	13.4	16.4
		5.8	3.8	2.8	1.8	0.8	6.8	8.8	12.8	15.8
		6.1	4.1	3.1	2	1	7.1	9.1	13.1	16.1
		6	4	3	1.9	1	7	9	13	16
		6	4	3	1.8	0.9	7	9	13	16
	Amba_8	4.9	2.9	1.9	0.9	0.4	5.9	7.9	11.9	14.9
		4.6	2.6	1.6	0.8	0.3	5.6	7.6	11.6	14.6
		5.8	3.8	2.8	1.8	0.8	6.8	8.8	12.8	15.8
		5.8	3.8	2.8	1.7	0.8	6.8	8.8	12.8	15.8
		5.6	3.6	2.6	1.6	0.7	6.6	8.6	12.6	15.6
	Megele_32	5.5	3.5	2.5	1.5	0.7	6.5	8.5	12.5	15.5
		5.4	3.4	2.4	1.3	0.7	6.4	8.4	12.4	15.4
		5.4	3.4	2.4	1.2	0.6	6.4	8.4	12.4	15.4
		5.2	3.2	2.2	1.1	0.6	6.2	8.2	12.2	15.2
		5.1	3.1	2.1	1	0.5	6.1	8.1	12.1	15.1
Bambasi	Mender_47	4.6	2.6	1.6	0.8	0.3	5.6	7.6	11.6	14.6
		4.5	2.5	1.5	0.7	0.3	5.5	7.5	11.5	14.5
		4.4	2.4	1.4	0.7	0.2	5.4	7.4	11.4	14.4
		4.3	2.3	1.3	0.6	0.2	5.3	7.3	11.3	14.3
		4.2	2.2	1.2	0.6	0.2	5.2	7.2	11.2	14.2
	Mender_48	4.1	2.1	1.1	0.5	0.2	5.1	7.1	11.1	14.1
		4.1	2.1	1.1	0.5	0.2	5.1	7.1	11.1	14.1
		4	2	1	0.3	0.1	5	7	11	14
		5	3	2	1	0.5	6	8	12	15
		5	3	2	0.9	0.4	6	8	12	15
	Sonika	3.8	1.8	0.8	0.3	0.1	4.8	6.8	10.8	13.8
		3.7	1.7	0.7	0.2	0	4.7	6.7	10.7	13.7
		3.6	1.6	0.6	0.1	0	4.6	6.6	10.6	13.6
		3.5	1.5	0.5	0.2	0.1	4.5	6.5	10.5	13.5
		3.3	1.3	0.3	0.1	0	4.3	6.3	10.3	13.3

AppendixTable5. Coordinates and elevations of the of survey areas

RegionName Benishangul Gumuz, Code 06   ZoneName Assosa

Woreda name	Kebele	ORCHARD CODE	Latitude	Longitude	Altitude(m)
Assosa	AMBA 14	AK1OR1	10.00701	34.61298	1497
		AK1OR2	10.01646	34.60047	1492
		AK1OR3	9.98912	34.606	1454
		AK1OR4	10.022	34.58699	1475
		AK1OR5	9.99621	34.59629	1480
	AMBA 5	AK2OR1	10.12734	34.60467	1602
		AK2OR2	10.11447	34.60608	1570
		AK2OR3	10.09401	34.59006	1587
		AK2OR4	10.08645	34.57551	1610
		AK2OR5	10.11862	34.59488	1579
	AMBA 8	AK3OR1	10.11835	34.54211	1536
		AK3OR2	10.1057	34.54414	1528
		AK3OR3	10.09086	34.55095	1547
		AK3OR4	10.11086	34.53231	1544
		AK3OR5	10.09138	34.55858	1525
	MEGELE 32	AK4OR1	10.03276	34.52379	1527
		AK4OR2	10.01432	34.52702	1512
		AK4OR3	10.02275	34.51743	1523
		AK4OR4	10.02553	34.52647	1486
		AK4OR5	10.00628	34.53121	1507
Bambasi	Menider 47	BK1OR1	9.89977	34.64738	1450
		BK1OR2	9.88696	34.66182	1457
		BK1OR3	9.8753	34.67765	1442
		BK1OR4	9.86269	34.68318	1457
		BK1OR5	9.86922	34.6505	1457
	Menider 48	BK2OR1	9.89372	34.67865	1447
		BK2OR2	9.88775	34.69193	1453
		BK2OR3	9.86499	34.70295	1453
		BK2OR4	9.85146	34.70106	1451
		BK2OR5	9.85869	34.69024	1463
	Sonika	BK3OR1	9.7852	34.67419	1460
		BK3OR2	9.77894	34.68704	1464
		BK3OR3	9.77061	34.70776	1469
		BK3OR4	9.79433	34.70705	1475
		BK3OR5	9.81785	34.69107	1460

Appendix Table 6. Interaction of month*kebele effect sliced by month for white mango scale across orchards during study periods

	Least Squares Means (square root transformed value)				
Interaction	DF	Sum of Squares	Mean Square	F Value	Pr > F
month*kebele	48	1.31	0.02	4.85	<.0001
April*kebele	6	0.52	0.09	15.27	<.0001
August*kebele	6	1.45	0.24	42.91	<.0001
December*kebele	6	1.24	0.21	36.67	<.0001
February*kebele	6	0.93	0.16	27.64	<.0001
January*kebele	6	1.22	0.20	36.03	<.0001
March*kebele	6	0.62	0.10	18.35	<.0001
November*kebele	6	3.04	0.51	89.98	<.0001
October*kebele	6	3.36	0.56	99.51	<.0001
September*kebele	6	2.31	0.38	68.4	<.0001

Appendix Table 7. Simple Statistics of Correlation coefficient among WMS cluster, RF, T^0 and RH at Assosa and Bambasi orchards

The CORR Procedure

Districts=Assosa

4 Variables: cluster, RF, T, RH

Variable	N	Mean	Std Dev	Sum	Minimum	Maximum
cluster	180	6.59333	4.84754	1187	0.3	16.8
RF	180	7.38244	9.17447	1329	0	21.89
T^0	180	22.43889	1.67312	4039	20.4	25.35
RH	180	43.62	19.27809	7852	19.16	72.67

Districts=Bambas

3 Variables: cluster, RF, T, R

Variable	N	Mean	Std Dev	Sum	Minimum	Maximum
cluster	135	5.07407	4.67005	685	0	15
RF	135	8.65556	10.00501	1169	0	26.3
T^0	135	25.16056	2.1971	3397	22.1	28.48

Appendix Table 8. Meteorological data of districts for August 2018 to April 2019

	Assosa				Bambasi		
Month	RF(cm)	Max T^0(^{0}c)	Min T^0(^{0}c)	RH	RF(cm)	Max T^0(^{0}c)	Min T^0(^{0}c)
August	21.89	29.1	13.3	72.67	26.3	26.5	17.7
September	21.55	25.8	15.8	67	24.36	28.07	18.16
October	16.71	25.7	15.1	66.03	13.38	28.8	18.62
November	1.78	28.1	14.5	47.33	9.42	28.71	18
December	0.15	29.4	14.6	36.5	0.52	30.9	18.2
January	0	31.5	13.9	25.19	0	33.4	19.29
February	0.14	31.4	15.3	25.9	0	33.4	19.7
March	0	32.8	16.9	19.16	0	35.18	21.78
April	4.222	32.9	17.8	32.8	3.92	35.64	20.84

RF=rain fall in cm, Max T^0 (^{0}c)= maximum temperature, Min T^0 (^{0}c)= minimum temperatur RH=relative humidity Data Source: National Meteorology Agency Benshangul Gumuz Reg Meteorological Service Center

(a) to (e) mango growers, photo were taken from Amba_14; (f) to (h) mango growers, phot were taken from megele_32

Appendix Figure 1. Mango growers, assessment

Appendix Figure 2. Damage symptom of white mango scale

Appendix Figure 3. Infestation of white mango scale on upper and lower leaf surface

Appendix Figure 4. Severity status of white mango scale

Appendix 5. Experimental materials

Appendix Figure 6. Treatments and spraying activities

BIOGRAPHICAL SKETCH

The author, Bizuayehu Jemaneh Woldesenbet was born in December 5, 1984 in Oromia National Regional State, Arsi administrative zone, Sire districts, Ethiopia. He attended his elementary school at Haile Abamessa (1990-1995). He also attended his secondary education and junior education at Sire Senior Secondary School (SSSS) from 1996-2001. He took the Ethiopian School Leaving Certificate Examination (ESLCE) in 2001. In 2001, he joined Mekelle University and graduated with Bachelor of Science Degree in Dry Land crop Science in July, 2005. In September, 2005, he was employed in Ministry of Agriculture at Benshangul Gumuz Region, Homosha woreda and served there as Crop Production and Protection Expert (2005-2012). He joined the Benshangul Gumuz Region Plant Health Clinic in 2012 and served there as director. He joined MSc in Plant Protection Graduate Program, Bahirdar University in 2017 majoring in Plant protection