DISTRIBUTION OF ENSET ROOT MEALYBUG (*Paraputo ensete*) AND EVALUATION OF SOME BOTANICALS AGAINST THE INSECT IN DAWURO ZONE SOUTH WESTERN ETHIOPIA

MSc. THESIS

BY

ERMIAS ELIAS

JUNE, 2024

JIMMA, ETHIOPI

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Ermias Elias

Submitted to Department of Horticulture and Plant Sciences, College of Agriculture and Veterinary Medicine Jimma University in the Partial Fulfillment for the Requirement of Master of Science Degree in Agricultural Entomology

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COLLEGE OF AGRICULTURE AND VETERINARY MEDICINE

MSC THESIS APPROVAL SHEET

We , the undersigned , member of the board of Examiners of final open defense by **Ermias Elias Ashenga** have read and evaluated his/her thesis entitled **'Distribution of Enset Root Mealybug (*Paraputo ensete*) and evaluation of some botanicals against the insect in Dawuro zone south western Ethiopia ''** and examined the candidate. This is therefore to certify that the thesis has been accepted in the Partial Fulfillment for the Requirement of Master of Science Degree in **Agricultural Entomology**

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DEDICATION

I would like to dedicate this thesis manuscript to my parents in general; my beloved Father Elias Ashenga and my beloved mother Tewabech Asaro for their dedicated partnership in the success of my life.

STATEMENT OF THE AUTHOR

First, I declare that this thesis is my own work. I have followed all ethical and technical principles of scholarship in the preparation, data collection, data analysis and compilation of the thesis. Any scholarly matter that is included in the thesis has been recognition through citation.

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BIOGRAPHICAL SKETCH

The author Ermias Elias was born on 4th November 1995 G.C in Dawuro Zone Mari Manisa District Southwest Ethiopian Region. He was attended primary School in Kawaka from 2001 to 2009 G.C, and Mari Secondary High School from 2010-2011 G.C and Preparatory school at Waka from 2012-2013 G.C. He also attended higher education from 2014-2016 G.C at Asossa University and graduated with Bachelor of Science Degree in Plant Science in 2016 G.C. He was employed in agricultural, Environmental Protection and Cooperative office and served at Dawuro zone Mari Mansa district. He joined Jimma University College of Agriculture and Veterinary Medicine in 2021 G.C to pursue MSc. Degree in agricultural entomology.

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LIST OF ABBREVIATIONS AND ACRONYMS

AARC	Areka agricultural research Center
ANOVA	Analysis of Variance
CRD	Completely Randomized Design
CSA	Central Statistical Agency
CFSVA	Comprehensive food security and vulnerability analysis
DA	Development Agent
DZAD	Dawuro Zone Agricultural Department
DZFED	Dawuro Zone Finance and Economic Development
EIAR	Ethiopian institute of agricultural research
FL	Fiducial limit
FAs	Farmers associations
FYM	Farmyard manure
FGDs	Focused Group Discussions
HA RC	Hawassa Agricultural Research Center
HSD	Honestly significant difference
IPM	Integrated pest management
JUCAVM	Jimma University College of Agriculture and Veterinary Medicine
M.A.S.L	Meter above sea level
MT	Metric tons
SNNPR	Southern Nations, Nationalities, and Peoples' Region
SWE	South Western Ethiopia

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ABSTRACT

Enset root mealybug (Paraputo ensete) is a major pest of enset plant that hinders the growth and productivity of the enset plant in study area. In the study area, there is no information available to enset producing farmers on enset root mealybug; no study has been conducted on distribution, management practices. Therefore, this study was conducted to assess the distribution of enset root mealybug and evaluation of some botanicals against this pest. *A total 153 households were interviewed through semi-structured questioner and information was gathered on their knowledge of P. ensete, damage symptom, spread, and management from three purposively selected districts of Dawuro and nine FAs that represent areas of high, medium and low altitudes. The infestation and Enset samples were collected from 145 households (HHs): five from PAs and fifteen from each three districts, and the levels of infestations were assessed and the populations of enset root mealybugs were record. A total 180 enset were assessed in three districts at the study site. The efficacy of six botanical extracts; Allium sativum, Piper betle, Moringa oleifera, Zingiber officinale, Eucalyptus globulus and Datura Stramonium, were evaluated on the second instar nymphs of the enset root mealybug under laboratory conditions. Four botanical resulted highest efficacies in laboratory was evaluated at once and twice drenching in pot experiment. The majority (98%) of enset farmers do not have any information on enset root mealybug. However, the remaining (2%) of the farmers were able to describe enset root mealybug when the picture was presented to them during the assessments. The highest infestation (41.6%) of enset root mealybug and population density (44.5 per enset) were recorded in the Mari Manias district and the lowest infestation (25%) and population density (30.75 per enset were in Tocha district. The infestations of enset root mealybug were mostly observed on enset plants of two to five years. The finding verified that, the most of the enset root mealybug (84.5%) occupied the root parts, while 15.5% occupied the corm parts in the infested enset. The bioassay study showed that, all the botanicals tested caused significant effects against the second instar nymphs of P. ensete after 24 h, 48 hr and 72 hr exposures. Among the botanicals A. sativum and E. globulus extracts caused the highest mortality than the others. A. sativum caused 100% mortality at 15% of concentration under laboratory test. There were interactions between the concentration of the botanicals and time on the morality of the second instar nymphs for all botanical extracts. In potted trials, drenching two times had the highest reduction of the mealybug population than drenching one time of potted enset seedlings with E. globulus extract. However, Diazinon 60% EC caused complete mortality of the mealybug in a single drenching.* Evaluated botanical extracts can be effective against controlling of *P. ensete. Further study on other botanicals and insecticides is needed to evaluate of enset root mealybug under laboratory and field condition. Agricultural specialists and stakeholders should require teaching farmers about the distribution and management practices of the enset root mealybug in their enset farm and farmers training center. Further regular assessing of infestation of the P. ensete on enset root and corm during transplanting enset seedling from temporary field to the main field will be needed.*

Key word; *Allium sativum, Piper betle, Moringa oleifera, Zingiber officinale, Eucalyptus globulus and Datura stramonium, mortality, second instar, distribution.*

1. INTRODUCTION

1.1. Background

Enset [*Ensete ventricosum* (Welw.) Cheesman] is monocotyledon of the Scitamineae order, Musaceae family, and the genus *ensete.* Enset was first described by Bruce 1970 and later classified under the genus Musa by Gmelin in the 13th edition of Systema Naturae in the 1791. Horaninow renamed the species enset in 1862 (Cheesman, 1947). Enset is an enormous herbaceous perennial banana-like plant in morphology, but distinct in utility and life cycle (Tafesse *et al.*, 2021; Totin, 2022).

In the southern parts of Ethiopia, root and tuber crops are widely cultivated, which are supporting the major portion of the country's population as source of food. Enset plays a crucial economic role, providing a higher and more dependable yield compared to other crops in Ethiopia (Yemataw *et al.*, 2020). Enset has a significant role in food, economic and social life in more than 25 million of people in country (Refera *et al.*, 2023 ; Dilebo *et al.*, 2023). In southern, southwestern and central parts of Ethiopia people cultivate and eat enset in different ways, due to the different social, cultural, and environmental circumstances in which the production and consumption of enset plants occur (Sirany *et al*., 2022; Boyana & Getahun, 2018). Enset plant is cultivated from mid altitude to highlands and grows under a wide range of agro-ecological zones within altitudes of 1200 to 3100 m. a. s. l, and average temperature of 10–20 °C and annual rainfall of 1000–1800 mm dispersed in 8–10 months (Borrell *et al.*, 2019 ; Amamo, 2018 ; Abebe, 2005; Jacobsen *et al*., 2018; Olango *et al*., 2015). Enset thrives in a variety of soil types with appropriate nutrition and drainage, pH values ranging from 5.6 to 7.3, and 2–3% organic (Workneh & Satheesh, 2019).

In the southern region of Ethiopia, Enset is a multi-year crop that cover 80% of its production, it is the main food supply and contributes to food security (Bonso *et al.*, 2022). An estimated land area used for enset cultivation is over 300,000 hectares of land, one of the largest areas for perennial food crops in the country (Jacobsen *et al.,* 2019; Olango *et al*., 2014; Yemataw *et al*., 2016). The total area under enset crop was estimated to 312.17 thousand ha, whereas the 217 thousand in SNNPRS, 94 thousand in Oromia and 0.382 thousand in Gambella region hectares of total area enset in Ethiopia (CSA, 2021).

The enset production area has increased 46% in two decades, while increased 12 doubling over the same period, making enset plant the most produced crop species in the Ethiopia (Jacobsen *et al*., 2020). The 127.3 million of enset plants were harvested and produced from kocho, bulla and Amicho, respectively. In the same year, 45.7 million enset plants were harvested and produced, 11.9 million quintals of kocho, 680.6 thousand quintals of bulla and 10.1 million quintals of Amicho in Oromia region from Ethiopian private peasant. The average kocho yield per plant was 72 kg, 138kg from bulla and 2.9 kg of fiber yield was recorded ((Tafesse et al., 2021).

Dawuro Zone is one of the exceptional enset accommodated Zone in region, where the total community depends on Enset for their food, source of income, for marketing and other purposes (Agize *et al.,* 2013 ; Haile *et al.,* 2020). In the zone, more than 90 % of the total population depends on enset. The ensets are grown in all areas of the zone at different agro ecology and large portions at high and middle altitudes and fewer portions located in low altitude (kola) (Asfawu, 2018 ; Ayele & Sahu, 2014).

Even though, enset plant plays a vital role in food security and economy of the country its production and productivity is strongly constrained abiotic and biotic factors. Among the biotic major factors, Bacterial wilt, bacterial corm rot and sheath rot , viruses and nematodes are insect pest are identified and reported (Quimio, 1992 ; Yirgou, 1968 ; Mekuria *et al.*, 2016).

Bacterial wilt is widely distributed in many enset-growing regions of country and threatening enset based farming system, affects the enset at all stages (Tadesse *et al.,* 2003). Other factors like insect pests, vertebrate animals, weed, mole rate, porcupine, wild pig, poor soil fertility, lack of resistance varieties, improper agricultural techniques are also endangering the production and productivity of enset plant (McKnight, 2013 ; Zerfu *et al*., 2018 ; Gebriel, 2020; Yemataw *et al*., 2020).

Mealybugs are oval, soft-bodied insects that feed extensively on the phloem sap of their host plants (Pai, 2020). The minor and major pests of enset plant that have been recorded in Ethiopia are tobacco whitefly, banana aphid, purple scale, black stripped jassid, and Enset root mealybug (Tadesse, 2009). The has become the major vital insect pest of enset plant (Addis *et al.*, 2010a).

The enset root mealybug was observed in household gardens in the southern Ethiopian region of Gedeo Zone under natural condition (Tsedeke, 1988 ; Erenso *et al*., 2023). enset root mealybug is found below the soil surface and feeds on the root, the basal stem touching the soil and root hairs of plant (Mani & Ummer, 2017).

The second instar nymphs of enset root mealybug has 18 day of duration from the first instar, and the nymph is active more susceptible and main mobile development stage of enset root mealybug. The other main sources of constraints are floods during the rainy season, sharing of different farm equipment, crushing by animal hooves and failures in soil fertility (Beyene & Mekonnen , 2014; Kusse *et al.*, 2021).

1.2. Problem Statement

The enset plant production and productivity is challenged by both biotic and abiotic factors. The primary factors that threaten enset production and cause serious damage to cultivar diversity and yield losses were include diseases, insects pest, wild animal, soil infertility, and drought (Garedew & Ayiza, 2018 ; Blomme *et al*., 2017). According to Addis *et al.*, (2008) and Garedew & Ayiza (2018) report, enset root mealybug reduce the growth and yield of enset plants. Several insect pests, diseases, vertebrate pests, drought, and declining soil fertility contribute to the 82.2% decrease in enset production. Due to their consumption in the pseudo stem and corm, mammals and other vertebrates such as crows, porcupines, grivet monkeys , and mole rats have been identified as factors influencing the quantity and quality of enset plant output (Bizuayehu, 2002 ; Sandford & Kefale, 1991 ; Earecho, 2015) .The enset root mealybug is damaging at all stages of the growth of the enset plant, but it is most dangerous when the plants are young. When there is moisture stress, enset root mealybug is known to produce damage related to sap uptake (Anonymous, 2000 ; Bizuayehu, 2002). Although enset is the oldest major food plant in the study area (Dawuro zone), factors such as diseases, insect pests, vertebrate pests and wild animals have limited its production and uses.

In the study area, farmers lack knowledge about the enset root mealybug; and they are unaware of the enset root mealybugs method of distribution or symptoms of injury in the study area. Locally available botanical control methods with the recommended insecticides management of enset root mealybugs have not been studied. On the other hand, the poor agronomic practices of farmers, which served as the primary source of enset root mealybug dispersal, were caused by their lack of knowledge of the enset root mealybug. In the study area, primary issues include the sharing and use of infected enset suckers, seedlings and unclean planting equipment that they purchase from their neighboring farmers. To maintain sustainable enset production in the study area (Dawuro zone), it is crucial to have knowledge about the distribution and management of the enset root mealybug.

Therefore, this study assessed the distribution of enset root mealybug (*Paraputo ensete*) in Dawuro zone, southwestern of Ethiopia, (Tocha, and Mareka and Mari Mansa districts) and evaluated of some botanicals against and to provide baseline data for future study.

1.3. Objective of the Study

1.3.1. General Objective

To understand the distribution and infestation of enset root mealybug and to evaluate the of botanicals for management of enset root mealybug.

1.3.2. Specific objectives

- To assess farmers' knowledge and management practices of the enset root mealy bug in the study area.
- To assess the infestation of enset root mealybug on enset plant in selected districts of Dawuro zone, SW-Ethiopia.
- To evaluate the efficacy of some botanicals under laboratory and potted experiment in farmers training centers.

2. LITERATURE REVIEW

2.1. Origin and Distribution of Enset

Ethiopia is one of the centers of origin and diversity of Enset plant (*Ensete ventricosum*) and various agricultural crops such as Teff (*Eragrostis*), Niger seed (*Guizotia Absyssiinica*) (Cheesman, 1947 ; Genet, 2004 ; Magule *et al* 2014). Enset (Ensete ventricosum) is endemic and derived from wild relatives from which Ethiopian highlands to be the primary center of origin. Enset was fully domesticated between 10,000 years back and 5,000 years ago, and initially farmed in a system of shifting cultivation in Ethiopia (Yemataw *et al.*, 2018).

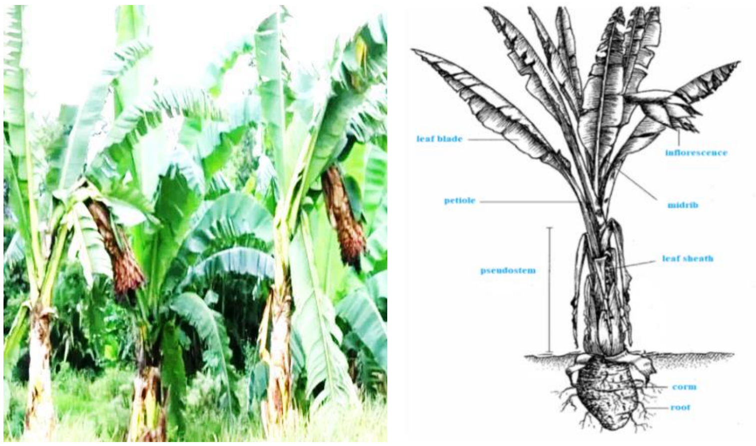
In Ethiopia, enset is endemic and derived from wild relatives of highlands mainly southern and southwestern parts. Ancient people, who migrated out of the lowland grasslands due to prolonged dry period, and settled in the highlands of southwestern Ethiopia and they probably started consuming and finally cultivating it, have domesticated Enset in Ethiopia (Brandt, 1996 ; Jacobsen *et al*., 2018).The distribution of enset is varied according to environmental conditions, altitude, soil, and climate in the mid-to highlands of;- the Southern Nations Nationalities Peoples Regional State (SNNPRS), the Oromia region Arsi-Bale, and western Oromia including West Shewa, Jimma, Ilubabor and Welega, the Oromo people bordering the Sidama, the central and northern highlands of Ethiopia around Lake Tana, the Simien Mountains, the Eastern and Gambela regions, and as far north as North Adigrat, as well as in the Kofele district of Oromia region of Ethiopia *(*Borrell *et al.,* 2020 ; Gezahegn & Mekbib,2016). Enset, also known as Workie for Oromo, Asset for Gurage, Wase for Sidama, Enset for Amhara, Uto for Kaffa, and uts'aa for Dawuro, is a term used to refer to numerous ethnic groups in Ethiopia (Tsehaye & kebebew, 2006).

2.2. Enset Production in Ethiopia

In Ethiopia, enset is one of the indigenous root crops widely cultivated in the south and southwestern parts (Refera *et al*., 2023). Enset is very essential plant contributing for food security and rural livelihoods about 25% of the country's population (Stanley,1996 ; Blomme *et al* 2018). As perennial plant, it is resistant to drought, heavy rain, and seasonal flooding (Borrell *et al.*, 2020). Enset is harvested at any growth stage over a period of several years from five up 12 years, until flowering and most frequently at 4–6 at any time during the year.

The productivity of enset per unit area of land is significantly higher than that of other common Ethiopian staples crops (Gezahagn, 2022).

Total 157,705,763 enset plants were harvested in the 2020 cropping year in the enset-growing regions. Of those, about 4,408,831, 4,894,388 and 147,504 (Mt.) were taken from Amicho, Koch and Bula (CSA , 2021). The Enset crop has potential to contribute to food security to ameliorate or withstand famine and its food culture saves millions of people during prolonged periods of famine Sudden in enset producing region (Kudama *et al.*, 2022). Enset increases in a variety of soil types with appropriate nutrition and drainage (Workneh & Satheesh, 2019).



(Birmeta, 2016)

Figure 1 Enset plant,

Enset agronomy is more concentrated in the southern part of the country due to the suitability for plant growth in region's (Boyana *et al.*,2018 ; Degefa and Dawit, 2018). The (25.49%) of enset is cultivated in their home garden), (21.64%) at main field and (41.67%) are both home garden and main as food and fiber crop (Garedew *et al*., 2017).

2.4. Significances of enset plant

The different parts of enset are used for different daily routines in the south and Southwestern parts of the country (Negash, 2001; Borrell *et al.*, 2019). The leaves and stem are the most commonly used parts for medicine. It has been traditionally used to treat bone fractures, diarrhea, abdominal pain, and delivery issues in humans and livestock (Olango *et al*., 2015; Abdella, 2016). The main starch-rich food products of enset Kocho, bulla, and Amicho; -Kocho fermented product from the corm and pseudo stem, Bulla dehydrated product of the juice from the decortication of the pseudo stem and grating of corm. Amicho is the stripped corm, boiled and consumed (Forsido *et al.*,2013 ; Yemataw *et al*., 2018).

Enset is mostly essential for animal feed during the dry seasons when other feeds are scarce (Mohammed *et al*., 2013). used as livestock feed during the wet season is a common practice in enset producing areas (Senbeta *et al*., 2022). The major component of enset starch products has crucial function in numerous industrial processes, such as food. Pharmaceuticals, cloth ,paper and adhesives products (Gebre, 2016). The high quality fiber of enset can be used for the production of specialty like currency notes, and tea bags that require durable fiber (Gessesse, 2016).

2.5. Constraints of enset plant production

Bacterial wilts (*Xanthomonas campestris pv. musacearum*)

Bacterial wilt is first reported in the Ethiopia in 1930 (Castellani, 1939). In addition, enset bacterial wilt was first identified and reported by Yirgou on enset plant in Ethiopia in 1968 (Yirgou and Bradbury, 1968). Bacterial wilt is the major destructive disease of enset plant (Aytenfsu & Haile, 2020). Bacterial wilt disease is the most economically important threat of the sustainability of enset farming system and production when comparing with other constraints of enset plant. This disease reportedly infects 80% of the enset plant farms (Desalegn and Addis, 2015 ; Yematawu *et al*., 2017). The disease affect the quantity and quality of enset production and the long term maturity behavior of enset and food insecurity in Ethiopia (Shumbulo *et al.*, 2012 ; Tewodros and Tesfaye , 2014).

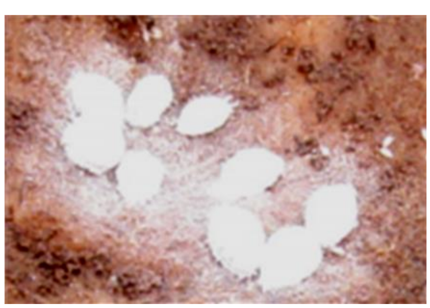
The bacterium is spread by everything that gets in contact with an infected enset plant , like cutting tool, sucking nectar of feeding on ripened fruits, grazing animals, unintentional moving of infected soil on boot and other (Mikias *et al*., 2011). The symptoms enset bacterial wilt include yellowing of leaves, wilting frequently together with the loss of turgor and collapse of the petiole) and the secretion of yellowish bacterial secretions (exudate) from cut tissue (Thwaites, 2000 ; Tushemereirwe *et al*., 2004). Enset wilt caused by *Xanthomonas campestris* pv, *musacearum* is potentially destructive to enset plant , has wide destruction and limits the production of the plant in the various parts of Ethiopia (Negash *et al.*,2023).

2.6. Description of Enset root mealybugs

The enset root mealybug can feed roots and corms, particularly young ones in the top layer of soil, which reducing the host plant's capability to absorb nutrients and water The insect's body is coated in white sticky powder like the one cornmeal, thus the name mealybug is expressive of the insect's body. The common names are derived from the excretion of mealy wax that is often covered by their food. Mealybugs have an elongated to oval form, are segmented into the head, thorax and abdomen, and have a white, powdery secretion coating both their dorsal and ventral body surfaces (Mani & Shivaraju, 2016).The adult enset root mealy bug has two short, well-developed legs and two long, eight-segmented antennae that measure between 450 and 550 micrometers respectively. An insect made was in documentation with the clarifications made by (Williams and Matile-Ferrero , 1999) that also identified the species as *Paraputo ensete*. The insect is a small phloem-sucking bug that lives under the soil's surface. The bugs only feed roots and corms , particularly young ones in the top layer of soil, which reducing the host plant's capability to absorb nutrients and water (Hara *et al*., 2001 ; Miller *et al.*, 2002) .

2.6.1. Biology of enset root mealybugs

Enset plants can support the development of the *P. ensete* throughout the year. Its generations overlap and all of its life stages have been found together (Williams and Matile-Ferrero , 1999). According to Addis *et al*., (2008), enset root mealybug develop from crawling bright to yellow-orange in color then moving quickly through the initial instars. The first instar that settled and secreted wax gave the body a white look. Second and third instars start to develop distinct lateral and caudal spines, grow in size, and begin to excrete a large amount of honeydew. Male mealy bugs are unknown for enset root mealy bugs. The waxes are integrated into the fresh wax secretions at each subsequent molting, but they are not a part of the insect's body (Daane *et al*., 2012 ; Sreerag *et al*., 2014).



(Azerfegn *et al., 2009)*

Figure 2 Adult enset root mealy bug

The life span of the adult female was 50.0±0.5 days, and the average development period from the first instar to the adult female was 54.1±1.0 days. When subjected to constant malnutrition in the absence of plants, all stages died after three weeks. In its lifetime, an adult female enset root mealy bug gives birth to 156-383 nymphs and is give birth rather than laying eggs. Primarily, the young crawlers decided to live with their mother for a few days, moving quickly to choose areas that were ideal for feeding and reproduction. The life span of enset root mealy bug 94–113 days. The adult female enset root mealy bug give six nymphs on average each day. The body size of mature mealy bugs ranges from 2.8 to 4.0 mm in length & 2.85 to 3.70 mm in width (Addis , 2005 ; Addis *et al* , 2008).

2.6.2. Distribution of enset root mealybug

Azerefegne *et al.,* (2014), majority 79 % *P. ensete* colonized roots and 21% was found corm. About 99% were found in the upper soil layer, while about 90% were within a 60 cm radius from the plants and about 63 % from the corm and on the roots within a twenty centimeter radius from the corm (Addis *et al*., 2008). The infestation of enset root mealybug was found to be most serious at an elevation b/n 1400 to 2200 meter above sea levels. The highest level of infestation was between elevations of 1600-1800 meter above sea levels. Enset root mealy bugs were not verified at altitudes greater than 2600 m.a.s.l and below 1400 m.a.s.l (Addis, 2005).

2.6.3. Host range of enset root mealybug

The *Syzgium guineense* (Dokuma: Common name) was identified as primer alternative host for enset root mealybug. Grasses in general were also identified as alternative host (Kefelegn, 2014).

2.6.4. Means of dispersal of enset root mealybug

Once established in area, *P. ensete* immature crawlers are very mobile due to their cryptic behavior and small size, allowing them to spread into appropriate roots to feed (Hara *et al*., 2001 ; Díaz Arzola, 2014). **Nymph crawlers**: most of the movement from root to root occurred by first instar nymphs. And can be responsible for spreading to new host plants and from plant to plant (Mani & Ummer, 2017). **Water**- These nymphs were easily transported from one location to another by irrigation or rainfall when floods occurred. **Infested corms** - The use of infested sucker has facilities the spread of enset root mealybug to new not infested enset field and transplanting the infested seedling was leads to further dispersal of enset root mealybug from one enset to the others or enset plant of enset field (Addis, 2005). **Ants**: Ants are the ones that cause the root mealy bugs to spread. During cultivation, weeding, transplanting, and harvesting, when the mealy bugs are disturbed, ants transport them to other plants or root sections (Jahn *et al.*, 2003 ; Smitha *et al*., 2005)

2.6.5. Damage symptoms of enset root mealy bugs

The enset root mealybug sucks on enset plants of all ages, but especially on the young ones. They suck sap from the main, lateral, root hairs, and corm of enset. This cause the plants to lose vigor, become yellow, wilt, and eventually die, as well as to lose yield (Pai, 2020). Under moisture stress, the insects the enset plants will have stunted development and eventually die. The damage inhibits roots' capacity to take up nutrients and water. The majority of the lateral leaves on infested plants dry, but the core stalk will remain green. As *P. ensete* is found underground, it is difficult notice their effects on the plant's aboveground parts until they do significant damage (Azerefegne *et al*., 2014 ; Grace & Hara, 2003). They colonize the lateral roots with the main root, and result in drying of such roots; general weakening of the plants, yellowing and narrowing of leaves (Mani & Ummer, 2017).

2.7. Management of enset root mealybug

2.7.1. Prevention

Enset root mealybugs are difficult to control with a single management strategy, because of their cryptic habits, waxy body coat, creation of dense colonies with several generations that overlap. As a result, prevention is crucial for the management of enset root mealybug. Prevention include examining the enset roots of newly obtained plants, tools, removing infested plant hosts from the locations, assessing the presence of enset root mealybug from root and corm parts before transplanting to the permanent field (Azerefegne *et al*.,2009 ; Hara *et ai.,2001*). **Extension**: Farmers awareness on damage symptoms and management on the Enset root mealybug is the crucial to a successful eradication. Consequently, extension programmers on management strategies should be strengthened (Addis *et al.*, 2008). **Quarantine of *P. ensete*** : According to (Pai, 2020), quarantine are importance and strict regulations to be undertaken to prevent the spread of pest infestation to other areas. would prevent the infested seedling, planting materials to neighboring area and designed to prevent further spread of the insect to different parts around the area (Ferdu *et al.*, 2009 ; Hara *et al.*, 2001).

2.7.2 .Cultural control measures of *P. ensete*

Farmyard manure- According to Hawassa Agricultural Research Center , (Anonymous, 2002) report farm yard manure enhances enset growth, improve the soil and root health conditions of enset and control the enset root mealybug. The application of farmyard 20 kg / plant directly prevent mealybug development, had visibly lower numbers of enset root mealybug, grew well and had less damage signs (Azerefegne *et al.*, 2014; Tadesse et al., 2013). **Ant control**s - Ants are observed in association with the mealybug infestation in all places and disperse *P. ensete*. When the root mealybugs are disturbed at the time of cultivation, weeding, transplanting and harvesting, ants carry and take them to new plants or root parts, and help them to find hidden places in the roots and corm, which are very difficult to reach even with insecticides. Removal of ant vectors has also proven successful in reducing mealybug infestations and will reduce mealybug population (Jahn *et al*., 2003 ; Malsch *et al*., 2001).

Hot water treatment- The immersion of enset root and corms of all size in water at 95°C for at least 10 and up to 30 seconds earlier to resulted in complete control of enset root mealybugs without affecting the growth and establishment of the suckers (Lemawork *et al.*, 2018). Farmers could apply this method when adult mealybugs are observed on corms and roots during transplanting and preparation of corms for sucker propagation in order to obtain mealybug free suckers. Hot water treatments eliminate enset root mealybugs' nymphs and ants Cultivation**-** Repeated ploughing, transplanting, and removal of weeds and grasses in enset farm my help to eradicate the enset root mealybug population(Addis, 2005, 2008b; Tadesse *et al*., 2003).

2.7.3. Biological control of enset root mealybug

The biological control system imposes no adverse effects on the environment (Roy, *et al.*, 2010). According to Pundt, (2003) the commercially produced entomopathogenic fungus, *Beauvaria bassiana* has been used in the control of root mealy bugs. Entomopathogenic fungi of *Beauvoir bassiana* isolates were the highest levels of mortality in controlling Enset root mealybugs. The ladybird beetle is most effective when there is high population of mealybug; the larvae are very effective predator, adult also feed mealybug. Parasitic wasp, *leptomastix dactylopii*, can be used in combination with the predator.

Due to high searching efficiency and they fly away from area to low pest population density, the ladybird beetle is most effective. The use of chemicals against mealybug often provides ineffective control due to natural and biology of pest. Due to the favorable temperature and controlled condition that often prevail in greenhouse mealybugs are likely to be successfully controlled by the natural enemies in long-term crops or plant collections (Blumberg, 2001) .The fungus secrets an enzyme that dissolves the insect's cuticle, after it enters in to the insect body, it produces a toxin that weakens the insects immune system (Pundt, 2003 ; *Lacey et al.*,2001).

2.7.4. Botanicals control measures of *P. ensete*

Botanical pesticides are biodegradable and they could be a sustainable alternative to synthetic insecticides and are environmentally safer, and rich source of biologically active compounds manage pests (Delvin and Zettel, 1999 ; Rajendra, 2020 ; Belmain *et al.*, 2001).Tadesse *et al*., (2010) indicated that different plant-extract such as (*Millettia ferruginea Azadirachta indica*, *Melia azedarach*, *Phytolaca dodecandra* and *Schinus molle*) are effective in controlling enset root mealybugs. Drenching a seed-water suspension of 10% *M. ferruginea* into the root-zone of infested Enset plants in the field was found to be effective against the Enset root mealybugs. *M. ferruginea* seed water suspension was found to be superior than the other botanicals in terms of causing mortality to enset root mealybugs. Drenching of soil with seed-water suspensions in infested enset plants root-zones cause mortality to enset root mealybugs (Bekele, 2002).

2.7.5. Chemical control measures of enset root mealybugs

Due to the presence of waxy coating, high reproduction rate, protection by ants and lifestyle of forming dense colonies of multiple generations of this pest status make them so difficult to control by means of insecticides (Mamoon *et al*., 2021). Chemical control of root mealybugs requires soaking of the root ball and potting medium to a degree that allows the pesticide to penetrate the pests' white, waxy secretion drenching with liquid insecticide is more effective than applying a granular formulation (Manil *et al*., 2016). Hawassa agricultural research center were tested on sixteen different insecticides on areas where root mealy bug damage is serious among tested, Chloropyrifos forty eight percent (forty-eight percent) gave good result to control enset root mealy bugs. According to Tadesse *et al*., (2006) report more than 90% were kill within fourteen days of application at high levels of mortality and the ninety eight percent root mealy bug mortality rate reached about at forty 45 after application of the chemicals. The application of common insecticides, Malathion, Dimethoate, Endosulfan, Fenitrothion, Chlorpyrifos and Diazinon application has got the significant results at control the root mealy (Bekele, 2001). IPM is the comprehensive and coordinates to reduce a pest population below an acceptable threshold and using IPM controlling method is found to be the latest management systems against the root mealy bug pest (Riyaz *et al*., 2019 ; Farms, 2020 ; Megersa *et al*., 2022).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The study was carried out in the Dawuro zone south western of the Ethiopian region, which is one of the largest enset growing zones in the region. It is geographically located between 6 ° 36 ′ to 7 ° 21 ′ N and 36 ° 68 to 37 ° 52 ′ E in the altitudinal range between 550–2820 meter above sea level, with an average annual rainfall of 1,211 mm (DZAD, 2021). Three districts, namely Mareka and Tocha Mari Manisa were selected purposely based on their high enset production and the problem of the enset root mealybug.

Mareka district is located at 544 km of south west of Addis Ababa, the capital of Ethiopia. Essera Woreda borders on the south by Loma; on the west by Zaba gazo, Gena and Tarcha zuria on the north by the Mari Mansa District and on the east. The enset is their main basic crop, but other cash crops are also grown. Its geographical position is between 37° 0°, 37° 1° E 7 ° 0 ° and 7 ° 1 N . The district is divided into three agro-ecological zones. It consists of Highland (Dega), > 2500 m (36%), Midland (Woyina Dega), 1500-2500 (51%) and Lowland (kola) < 1500 m (13%). The mean annual rainfall ranges from 1400 to 1800 mm.

Tocha district is located 560 km south-west of Addis Ababa, the capital of Ethiopia. Its geographical location is between 6 °18' 12.69"N 36 ° 36' 20.58"E. Isara and Kechi district's border the district on the south, on the west by the Keechi and Tarcha zuria district, on the north by Tarcha Zuria district, and on the east by Mari Mansa district. This district falls into three agro ecological, of which kola within (500-1500 ma-s l), Woyina Dega within (1501-2500 m.a.s.l.), and Dega above (> 2500 m.a.s.l.). Enset and maize are the main subsistence crops of highland and lowland inhabitants. Mixed agricultural is the main livelihood strategy in districts.

The Mari-Manisa district is located 535 km from Addis Ababa. Its geographical position is between 6 54- 7˚ 5ˈN; and 37 1 -37 9 E. It is neighbored by the Essera district in the south, the, Tocha district in the west, Mareka district in the east, and the Tarcha Zuria district in the north direction. Perennial crops such as enset other crop like; bean crops, wheat, barley, pea, maize, Teff, sorghum, potato, vegetables, rarely coffee production, and bamboo tree. Altitude ranges from 1302-2540 m.a.s.l and of this; 19.3% is high land, 63.1 % midland and 17.6% low land areas. The average temperature is 19.7 ° C, and ranges from 13 °C - 26.4 °C. Mean annual rainfall ranges from 1314 mm to1516 mm (BoFED-SNNPRS-, 2019).

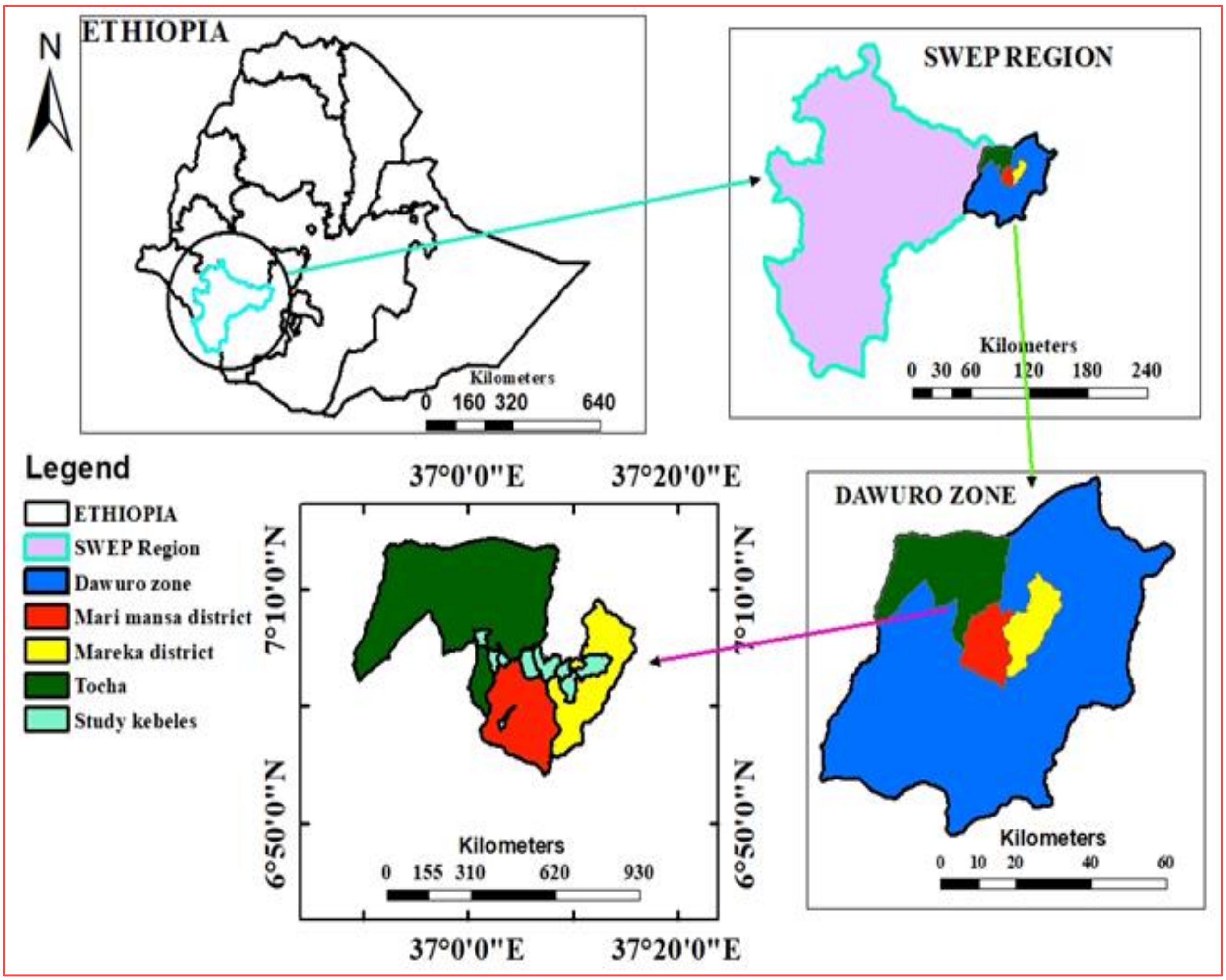


Figure 3.Map of the study area and location of three in Ethiopian administrative structure

(Source own, 2024)

3.2. Sampling procedure of survey

The following selection processes were used to choose respondents from farmer households for the survey. Primarily, the Dawuro zone was purposely selected based on the potential of enset production and due to the problem of enset root mealybug. Second, three districts, namely (Tocha, Mari Manisa and Mareka), were selected based on high production potential, of the enset plant. Finally, based on the potential for enset production, three associations of farmers; Gani, Gebira, and Botor from (Tocha), Daka, Ocha and Desh from (Mari Manisa) and Gozo, Maydi and Eyesus from (Mareka districts) were purposefully chosen from each district chosen, representing areas of high, medium and low altitude (Fig. 4). Agriculture offices of districts were consulted during the peasant association selection process. Farmers were chosen at random through discussions with the agricultural extension experts (DA) and the PA administrative office (Garedew & Ayiza, 2018 ; Mesele *et al.*, 2019).

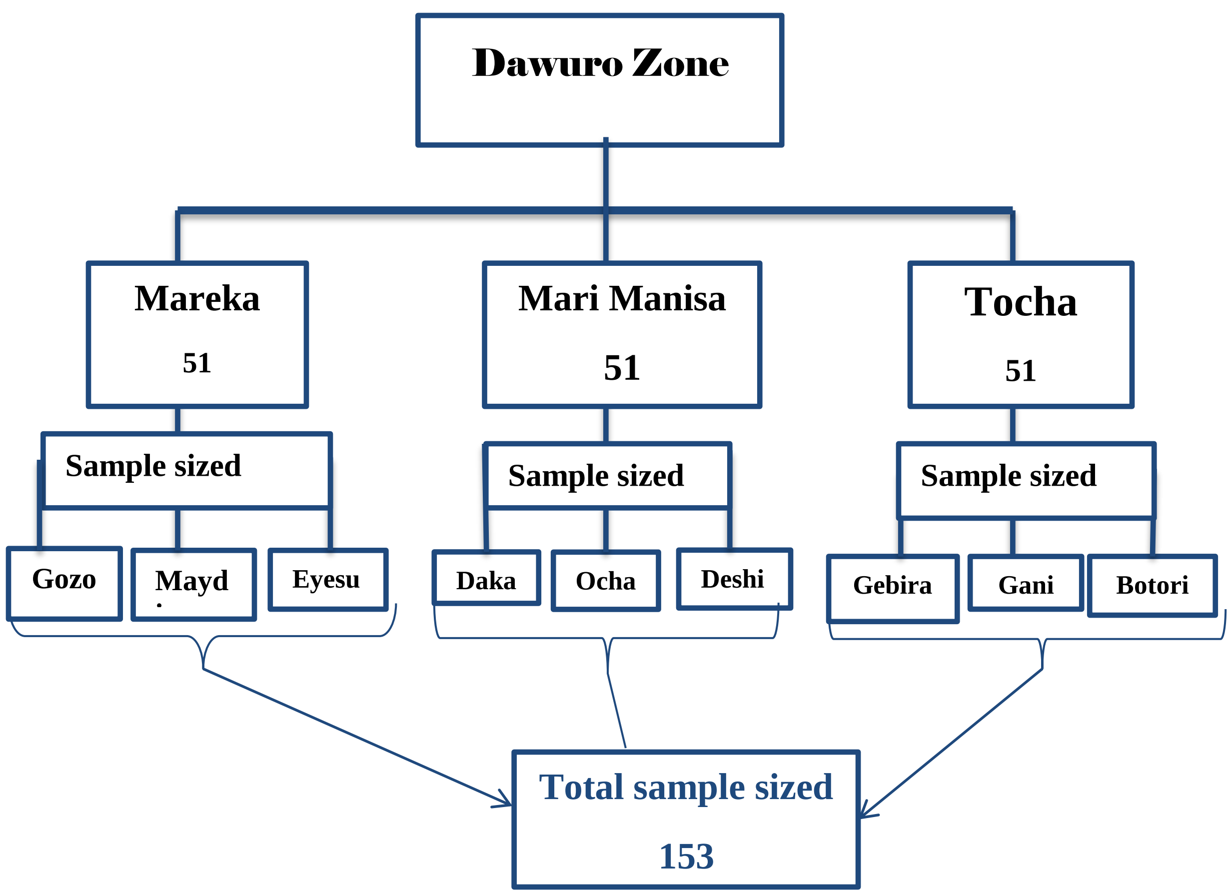


Figure 4 Diagrammatical presentation of sampling procedures

3.2.1 .Sample size determinations

The sample size (n) was chosen and calculated from a total of N households in each PA to employ questionnaires to collect survey data from the respondent farmers.

The sample size were determined by using Yamane, (1967) formula as indicated in the given below

$$\boldsymbol{n} = \frac{N}{1+N(e)^2}$$

Where,

N = the total population that will be studied

n = the required sample size

e = the acceptable sample error is = (8%), where the confidence interval level is 92%.

1= designates the probability that the event were occur

N = 3210

e =0.08

$$\boldsymbol{n} = \frac{3210}{1+3210(0.08)^2} \quad = 153$$

Table 1 Total number of enset producing HHs from Districts and their respective sample sized

Districts	PAs	Total no of enset producing HHS in PAs	Sample size in FAs
Mareka	Gozo	498	25
	Maydi	430	19
	Eyesus	256	13
Mari Manisa	Daka	435	21
	Ocha	456	16
	Deshi	195	11
Tocha	Gebira	300	15
”	Gani	345	19
	Botori	295	14
Total		3210	153

Note= FAs; Farmer’s Association, HHs; Households (source own, 2024)

3.2.2. Household Survey

Semi-structured questionnaires were used to conduct individual in-person interviews with respondent farmers in three enset producing districts (Mari, Mareka, and Tocha) to assess the distribution of enset root mealybug in each FA selected and their management practices within the study area. Before distributing the survey questionnaires to the selected PAs, the relevant district agriculture office granted permission to participate in the survey. The interviewers, who are model farmers in enset production and have good background knowledge of the enset plant and the enset root mealybug. The researcher explained to the respondents the need for the survey and the study's objectives.

A total of 153 enset farmers found in the three districts were interviewed. The questionnaires were first prepared in English and translated into the local language (Dawuro) in order not to lose any information and to easily understand by the respondents. During the household survey, the agricultural extension experts of the PA worked closely with each PA. Enset root mealybugs were on the infested enset roots and corms and the damage symptom; were shown to the respondents during the interview, the means of dispersal and the management practices by the farmers were assessed.

Focus group discussions were held in order to gather baseline data from participants using questioners, to support and crosscheck the information given by individual respondents, and to obtain relevant background information, indigenous knowledge of enset plant production, and enset root mealybug management and other related topics that were not included in the individual interview. Nine focus group discussions (FGD) with six to ten participants in each were conducted in each of the selected PAs. Participants in the FGDs were selected voluntarily, which included men, women and DAs agricultural experts. Each discussion took thirty to forty-five minutes.

3.2.3. Assessment of infestation and Sample Collection

The assessment was carried out in the potential enset growing area in the three districts. At each PA in the study area, five enset fields were used for infestation assessment and sample collections. The sampled enset fields were selected by each PA's administration based on their enset area coverage.

A total 45 farmer fields were sampled, five from PA and 15 from districts. The samples were made on young aged enset of two - five-year growth stages. At this stage, the plant has a well-developed root system and is vulnerable to enset root mealybug attacks (Addis *et al*.,2008). Sampling Of the mealybug population was conducted on10*10 m quadrats of the enset field. In each quadrat four ensets were selected and tagged. Using the "W" sampling method, the quadrate enset field was sampled by starting at one corner, crisscrossing the field four times, and then going to the other corner on the same side. Then the selected enset was dug out and uprooted whole parts the population recorded and infestation assessment.

In total, 180 enset were assessed in the three districts. Other nearby plant species and weeds were assessed for presence of mealybug. The average numbers of *C. ensete* populations per sampled enset field from the corm and root were calculated.

Figure 5 Assessed enset parts and infestation of enset root mealybug in Dawuro, south Ethiopia (Source, own 2024)

3.3. Evaluation of botanicals for the control of enset root mealy bugs

3.3.1. Insect Culture

The Colonies of adult female enset root mealybugs were collected from infested enset (corm and root) from the study sites. The mealybugs with plant parts were brought to the laboratory condition at farmers training center and the enset root mealybugs were reared based on the methods of Addis *et al*., (2008) and Gullan, (2000).

The pumpkin fruits, about 4-5 cm long roots, and slices of enset corm were used for rearing. Before transferring adult enset root mealybugs, pumpkin fruits and roots were cleaned and washed with tap water. The adult female enset root mealybug was placed in boxes covered in black muslin cloth and placed in a dark room. The adult female *P.ensete* was established on the pumpkin fruit and started feeding. The emerged second instar nymphs of enset root mealybugs were used among the three instars based on instars based on duration of stages for the botanical bioassay.

3.3.2. Botanical collection and extraction procedures

The botanicals listed below were bio assayed for control of the enset root mealybug.

Table. 2. Different botanicals extracts evaluated under laboratory conditions against 2nd instar nymphs of *P. ensete.*

Common Names	Scientific Name	Family	Parts	References
Moringa	*Moringa oleifera*	Moringaceae	Leaf	(Dougoud *et al*., 2020); El-masry & Saleh, 2020)
Eucalyptus	*Eucalyptus globulus*	Myrtaceae	Leaf	Bala *et al.*, 2019 ; Majeed *et a.*,2018)
Ginger	*Zingiber officinale*	Zingiberaceae	Rhizomes	(El-Ashram, D.; Abd El-Mageed, S.A.M. and Shaaban, 2020) ; Avila *et al*., 2023)
Datura	*Datura stramonium*	Solanaceae	Leaf	(Pande *et al.*, 2011 ; Meenakshi *et al.*, 2023)
Betel pepper	*Piper betle*	Lauraceae	Leaf	(Avila et al., 2023) ; (Jana, 2017)

Garlic	*Allium sativum* L	Alliaceae	Bulb	(Hincapié Ll et al., 2008) (Dougoud et al., 2020); (Meriga et al., 2012)

(Own source, 2024)

The fresh matured bulbs of *Allium sativum*, *Piper betle* leaf, *Moringa oleifera* leaves, and rhizomes of *Zingiber officinale*, *Eucalyptus globulus* leaves, and Datura *stramonium* leaves were collected by cutting with cutlass in the early morning to avoid possible degradation of the substance and maintain freshness (Appendix Figure 4). After cleaning with tap water the collected botanicals were dried in the laboratory at ambient conditions for ten days at (21-28 ° C and 65± 5 % relative humidity) to avoid loss of active compounds. Using a wooden pestle and mortar, the dried materials were grounded to a fine powder (Appendix, Figure 5).

3.3.2.1. Laboratory bioassay

All powdered botanicals were steeped in 100 ml of distilled water to obtain crude extracts at the concentration levels 5%, 10%, and 15% based on the preliminary observed result (appendix table 6). The prepared botanical extracts were filtered twice through clean muslin cloth, shaken thoroughly for about 5 minute to ensure the solute was uniformly distributed and stored at room temperature with plastic box (10 cm width and 13 cm in height) for full mixing overnight (24 hr) before use. The laboratory bioassay experiment were conducted based on the methods (Reddy & Seetharama, 2020 ; Tadesse *et al.*, 2010 ; Dougoud *et al.*, 2020). Treatments were arranged in Completely Randomized Design (CRD) with three replications. The second instar nymphs' population were carefully separated and conserved. For each replication of treatment, 10-second instar nymphs of enset root mealybugs were placed in small plastic bottles with a diameter of 7 cm. Four milliliters of filtered solution were dropped on the second instar nymphs of P.ensete and maintained in the laboratory. Data on the number live and dead mealybug were recorded at 24hr, 48, and 72hrs after treatment. The dead 2nd instar nymphs were counted and removed at each data collection date.

3.3.2.2. Pot experiments for evaluation of botanicals for of 2nd instar of P.ensete control

Four botanical extracts, *E. globulus*, *A. sativum*, *Z. officinale and D. stramonium* that caused high mortality against the second instar nymphs under laboratory bioassay were selected and used for this experiment. The enset seedlings were collected from the enset fields. Thirty-second instar nymphs, which are healthy and active, were selected by using a hand lens on root and corms among the collected enset seedlings. Only the second instar nymphs were used for the pot experiment, the other instar nymphs and the adult enset root mealybug were removed using a camelhair brush from the root and corms of the infested young enset seedlings (Fig. 6).

Figure 6 . Preparation of the second instar nymphs for the pot experiment

The same protocols used in the laboratory conditions were followed previously for botanical extract. Based on the methods Tadesse *et al.,(*2010), already the enset seedling with second instar nymph were placed in a plastic polybags (44 cm wide by 55 cm high) potted with infestation-free soil that was collected from non enset field. For the pot experiment, 990 ml of each botanical extracts were prepared at 0, 15% concentration per plastic polybag and used for application.

The botanicals were drenched at the root and corm part of the potted enset seedling once and twice at ten-day interval. Each potted enset seedling was used as replicates (Tadesse *et al.*, 2010) (Figure 7).

Figure 7 Potted enset seedling with 2nd instar nymphs of enset root mealybug

Diazinon 60% EC was used as a positive control by diluting 9.9 ml of diazinon in 5 L of water and 990ml of the solution was drenched to each pot (Tadesse *et al.*, 2010). The prepared insecticide was drenched similar to the botanicals. The insecticide efficacy against the mortality of the second nymphs was evaluated by uprooting the potted enset seedling and assessing the root.

3.4. Data Collection Procedure

3.4.1. Households Questioners

Semi-structured questionnaires and FGD were used to gather survey data (Appendix.1). Data collected during the survey were included: socioeconomic and demographic characteristics; some constraints and agronomic practices of enset, farmer awareness of damage symptoms; methods of dispersal; and farmers' management practices of enset root mealybug as reported by respondents who were interviewed in the study area.

3.4.2. The infestation and enset root mealy bug population

Data recorded during infestation were included: the age of the infested enset, the local name of the infected (Appendix Table.1), and the number of infested enset per total assessed.

The percentage of infestation was calculated by dividing the infected enset by the total assessed enset plant and multiplied by 100.

$$\% \text{ infestation} = \frac{Numbe\ of\ infested\ enset\ plant}{Total\ number\ of\ {\scriptstyle assesed}\ plant} \times 100 \quad \text{(Gupa \& Zira, 2023)}$$

The enset root mealybug population was recorded by dividing the number of *P.ensete* per sampled enset in field.

Popn of *P.ensete* = $\frac{Number\ of\ enset\ root\ mealy\ bug}{number\ of\ assessed\ \ enset\ \ in\ farm}$ (Addis *et al*., 2008).

3.4.3. Botanical bioassay and pot experiment data

The numbers of dead second instar nymphs of *P. ensete* were recorded after 24 hr, 48 hr and 72 hr exposure. When handled with a hairbrush, second-instar nymphs that showed no signs of movement were considered dead. The percentage mortality was calculated by considering the data obtained from the (control) and the treatments by using Abbott formula (Abbott, 1925).

% corrected mortality = $\frac{\%\ Mortality\ in\ treatments - \%Mortality\ in\ control}{100 - \%Mortality\ in\ control} \times 100$

The morality of the pot experiment data were also corrected by Abbott formula.

3.6. Data Analysis

The collected survey data from the respondent was summarized and visually verified to ensure that they were accurate, and then data entry was done using Microsoft Excel 2010.

The analyzes were made using descriptive statistics (means, chi-square and percentages) using software (Statistix sxw.exe) to assess differences regarding the socio-demographic, distribution and their management practices of enset root mealybug of respondents the farmers. The normality of the collected bioassay data was checked by using the Shapio-Wilk test before calculating the percentage mortality. The efficacy of botanical data regarding to percentage mortality of the second instar nymphs of enset root mealybug under laboratory were subjected to two-way analysis (ANOVA) using Statistix software version 8.1 to determine the statistically significant difference among the botanicals. The pot experiment data was analysis by this software. To compare the treatments, the statistical differences among the mean comparison were subjected to Turkey's Studentized multiple ranges (HSD) test at the (5%) significant level. The minimum lethal concentrations (LC_{50}) and the lethal time (LT_{90}) to 50% and 90% mortality values at 72hr at the 95% fiducial limit of the lower and the upper confidence limit were analyzed by probit analysis (Finney, 1971) by using SAS software version 9.3.

4. RESULTS AND DISCUSSION

4.1. Background profile of the farmers

4.1.1. Socioeconomic and Demographic Characteristics of Farmers

The majority of the respondent households were male (68.6%) in the three districts. There is no significant gender difference between the three districts ($\chi^2 = 2.36$, $P= 0.26$) (Table 3).
Most of the surveyed farmers were male headed families, this may be because males are more active and strong in hard labor than their female spouses> Males are more involved in enset plant agronomical activities , who are likely to influence and affect the management of enset root mealybug and enset farming activities. The majority of the respondents (41.8%) in the three districts were between the ages of 41– 50, followed by (33.3%) of the farmers in the age range 31 to 40. The respondents greater than 50 years were 18.3%.

This suggest that the majority of respondent are at middle age and active and engage in lots of enset field activities , have good work experience on their enset field, and have background information regarding to the cultural control of enset root mealybug than the younger respondents.
Most of the farmers (49.6%) had not received formal education, while 20.3% and 18.3% of the respondents had attended secondary and primary school, respectively. Only (11.7%) of the respondents had completed a diploma or higher. The educational attainment of farmers in three districts were significantly different ($\chi^2 =15.9$, $p= 0.01$).

Most of the respondents have informal education. They have experience of enset plant production and good understanding of the enset plant Furthermore, farmers are aware of agricultural management practices, particularly cultural and quarantine control practices

Among the farmers surveyed,78.4%) were married and (15.8%) were single. the remainder (6%) were widowed. Married farmers were more likely than single farmers (Table. 3)
According to the survey results, the majority (43.2%) of farmers households in the study area had a family size range of 5-8, while an additional (39.2%) of the respondents had a family size range of 1-4. Although the remaining (17.6%) of the farmers had their family size between 9-12.

This could be indicated that the larger family member were more contributed the labor force during the enset plant cultivation, high field activities regular weeding field sanitation per year to reduce the infestation and control of enset root mealybug population and high accumulation of knowledge and sharing.

Table 3. Socioeconomic characteristics of the respondent households in the study area

Variable	Description	Assessed districts			Mean	χ^2	P-value
		Mareka (N=51)	Mari Manisa (N=51)	Tocha % (N=51)			
Gender %	Male	64.7	74.5	66.7	68.6	2.63	0.26 ^{ns}
	Female	35.5	25.5	33.4	31.4		
Education level %	Illiterate	45.1	41.2	62.7	49.6	15.91	0.01*
	Primary	21.6	23.5	9.8	18.3		
	Secondary	17.7	25.5	17.6	20.3		
	Diploma & above	15.7	9.8	9.8	11.8		
Ages of respondents %	20-30	9.8	3.9	5.9	6.6	10.29	0.11 ^{ns}
	31-40	29.4	41.1	29.4	33.3		
	41-50	37.3	41.1	47.1	41.8		
	>50	23.5	13.7	17.6	18.3		
Marital status of respondents %	Married	74.5	84.3	76.4	78.4	7.65	0.10 ^{ns}
	Single	15.6	11.8	19.6	15.6		
	Widowed	9.8	3.9	3.9	6		
Household size %	1-4	43.2	41.2	33.4	39.2	6.03	0.19 ^{ns}
	5-8	37.3	47.1	45.1	43.2		
	9-12	19.6	11.7	21.5	17.6		

*Note: Statically significant at * p <0.01, ns = no significant,* χ^2*= chi square.*

4.1.2. General description enset farming in the study area

In the three study districts, most (60.8%) of the farmers were self-producers of their enset sucker and seedlings, while (18.9%) of farmers bought enset sucker and seedling from their neighbors. The rest (20.3%) of farmers were both self-producers and purchased enset during the planting season. In current result, most of respondent farmers' source of enset suckers and seedling were from their own enset field, which reduces the spread of the enset root mealybug The majority of farmers (50.4%) regularly weeded their enset field twice a year, while the remaining farmers (49.6%) weeded their enset farm three times a year. The weeding practice is significantly different in the district's (χ^2 *=12.6, p<0.01*), they practice their enset field based on the background experience and based on the season before, and after rain in their enset field. The frequency of weeding practice adopted by farmers on their enset farm was used to reduce the enset root mealybug population.

In the study area, 45%) of the farmers reported that they harvest enset between 6-7 years, 34% in 2-5 years and 21.6% in eight years. The decision on the time of harvest is based on the need and experience. The maturity year for harvest is not significantly different between three district's (χ^2 *=10.9, p>0.01*).

About 71%) of the farmers cultivated enset for home consumption, while 19%) as source of income and the rest (11%) for animal feed and other purposes. The purpose of the enset was not significantly different between district's (p>0.01). The result showed that enset plays roles of home consumption, source of income and other purposes in the study area.

Table 4 Farming of enset plant in the study area

Variable	Description	Assessed districts			Mean	χ^2	P = value
		Mareka	Mari Manisa	Tocha			
Source of sucker and seedling	Self	60.8	53	68.6	60.8	5.5	0.23^{ns}
	Purchase	17.7	23.5	15.7	18.9		
	Both	21.6	23.5	15.6	20.3		
Transplanting year of seedling to main field	Two year	33.4	53	51	45.8	9.3	0.009*
	Three year	66.7	47	49	54.2		
Frequency of weeding per year	2 times	37.3	51	62.8	50.4	12.6	0.001*
	3 times	62.7	49	37.2	49.6		
Maturity year for harvesting	2-5 year	35.3	35.3	31.4	33.9	10.9	0.02^{ns}
	6-7 year	41.2	53	39.2	44.5		
	> 8 year	23.5	11.8	29.4	21.6		

Purpose of enset production	Consumption	80.4	60.8	70.6	70.6	10.5	0.03[sn]
	Source of income	13.7	25.5	17.6	18.9		
	Animal feed & others	5.9	13.7	11.8	10.5		

*Note: Statically significant at * p <0.01, ns = no significant, χ^2 = chi square*

4.1.3. Constraint of the enset plant production in the study area

The constraints of the enset plant in the study area are presented in (Table 5). According to the survey results, about 33% of the farmers indicated that bacterial wilt is the main problem of enset plant production in the study area. In addition, 24.2% of farmers reported that the enset root mealybug causes damage to enset. About (12%) mentioned other pests including mole rat and porcupines as constraints of enset production, and other farmers indicated that replied that climate change(9.1%), and soil infertility problems (7.8 %) as the main constraints of the enset in the three districts.

Table 5. Enset plant production constraint in the study area

Variable	Assessed districts			Mean	χ^2	P = value
	Mareka (N=51)	Mari Manisa (N=51)	Tocha (N=51)			
Bacterial wilt	33.4	33.4	31.4	32.7	4.58	0.91[ns]
Enset root mealybug	23.5	25.5	23.6	24.2		
Smallest use of agricultural practices	15.7	15.7	11.7	14.4		
Mole rate and porcupine	9.8	13.7	11.8	12		
Climate change	7.8	13.7	5.9	9.1		
Soil infertility	5.8	9.9	7.9	7.8		

Note: ns = no significant, χ^2 = chi square

4.1.4. Farmers knowledge of enset root mealy

Farmers' awareness level of the enset root mealy bug was shown in (Table 6). Among the surveyed farmers in the three districts, most (98%) of the farmers have no information of enset root mealybug. The remaining (2 %) respondents were able to describe the enset root mealybug. The result is lined report (Erenso *et al.,* 2022). There is no significant difference in the knowledge of enset root mealybug between three districts (χ^2 = *4.08, p= 0.12*).

4.1.5. Farmers knowledge of enset root mealybug problem and the level of problem in their enset field in the study area.

According to the survey result, the majority of the respondents (86.3%) of the survey reported have noticed the problem of P. *ensete* on their enset farms (Table 6).

Furthermore, the majority (66%) farmers' enset fields had a high level of enset root mealybug problem, while the problem was moderate on 20%) of the farmers, while the remaining (14%) of the farms low level of enset root mealybug *damage.*. There is no significant difference of enset root mealybug problem (χ^2 = *2.13, p= 0.3*) and level of problem (χ^2 = *3.17, p= 0.7*) between the districts (Table.6).

Table 6.Farmer's knowledge, problem and level of enset root mealybug problem in the study area.

Variable	Description	Assessed districts			Mean	χ^2	P= value
		Mareka (N=51)	Mari Manisa (N=51)	Tocha (N=51)			
Do you Know enset root mealy bug?	Yes	0	2	4	2	4.08	0.12 ^{ns}
	No	100	98	96	98		
Do you have enset root mealybug problem on your enset farm?	Yes	90.2	84.3	84.3	86.3	2.13	0.3^{ns}
	No	9.8	15.7	15.7	13.7		
Level of enset root mealybug problem	High	68.6	64.7	64.7	66	3.17	0.7^{ns}
	Moderate	21.6	17.6	21.6	20.3		
	Minor	9.8	17.7	13.7	13.7		

Note = ns = no significant , χ^2 = chi square

4.1.6. Farmers' perception of the symptom of enset root mealybug damage in the study area

The results of farmers' knowledge of the damage symptoms caused by *P. ensete* were shown in (Table 7). According to the study results, about 21% if the farmers have seen the damage symptom produced by *C. ensete*. Farmers explained that their enset in their fields lacked strength and was deformed additionally about 19% of the farmers observed that the infested enset could not grow as fast as the healthy plants. Furthermore, 15% of the respondents observed the damage by the mealybugs during agronomic practices in their enset field, such as weeding and plowing. Additionally, (14.4%) of farmers reported damaged symptoms when the plants fail to stand up or fell to the ground. However, (12.4 %) of the respondents were not cognizant of the symptoms mealybug and did not associate such damages to *P. ensete.* Furthermore, 11.2% of the farmers observed the symptom when the corm yield of the enset crop was harvested, and these observations were mainly made by women respondents. The remaining farmers (7.2%) in the three districts identified the problem of the enset root mealybugs when they observed fewer roots while cultivating and transplanting of enset.

Farmers' knowledge of the symptoms of damage caused by C. ensete was not significantly different in the study area (χ^2 = *6.54, p= 0.88*) (Table.7).

Table 7. Farmers' perception of the enset root mealybug damage symptom in the study area

Variable	Assessed districts			Mean	χ^2	P = value
	Mareka (N=51)	Mari Manisa (N=51)	Tocha (N=51)		6.54	0.88^{ns}
Lacked strength and malformed %	23.5	21.6	17.6	20.9		
unable to stand up or fell into the enset field %	13.7	11.8	17.7	14.4		
Reduced yield of corm%	9.8	13.7	9.8	11.2		
Observed during farm practices %	15.7	13.8	15.7	15		
Slowed growing (%)	19.6	21.6	15.6	18.9		
Never seen (%)	11.7	9.8	15.7	12.4		
Low root number (%)	5.9	7.8	7.8	7.2		

Note: *ns = no significant,* χ^2= *chi square*

4.1.7. Farmers knowledge of the means of dispersal of *P. ensete* in the study area

The results regarding awareness among the enset-producing farmers about methods of means of spreading of enset root mealybug are presented in (Table 8).

The majority (30.7%) of the survey respondents believed that the enset root mealybug spreads through infected enset seedlings and corms. When exchanging already-infested enset seedlings and use infected mother enset plants to propagate corms for the production of sucker, they unintentionally share from other farms According to 26% of the farmers, enset root mealybug spread through the use of traditional tools and enset planting equipment because farmers borrow tools from each other throughout the operations of enset production and processing. The report is lined (Karar *et al*., 2021).

In the study area, (19%) of the farmers, believed that the mealybugs are dispersed to new fields and plants during cultivation and transplanting of enset seedlings from temporary to permanent enset fields. About 13.1% of the farmers believe that the close spacing between enset plants makes it easier for the dispersal of enset root mealybug to adjacent plants. Farmers are growing enset in their personal gardens, where there is acute shortage of land. As a result, they do not maintain the proper space between seedlings and neighboring plants. The result is agreed report of (Haider *al*., 2021).

As a result, the roots of adjacent enset plants are connected to each other and the mealybugs easily spread from one enset plant to the other. About 11.2% of the respondents believed that the ensete root mealybug spread through farm laborers. As respondent believe, *P. ensete* is transported through their cloth, disposable wares and shoes, during harvesting and cultivation time, when laborers had to make frequent travels from one farm to the next enset (Table 8). No significant differences in the dispersal means were observed among the three districts ($\chi^2 = 3.82, p = 0.87$). The result lines as report of (Beyene & Mekonnen, 2014).

Table 8. Means of dispersal of enset root mealy bug in the study area.

Variable	Assessed districts			Mean	χ^2	P= value
	Mareka	Mari Manisa	Tocha		3.82	0.87^{ns}
Infected seedling %	31.4	33.4	27.4	30.7		
un cleaned enset planting equipment %	25.5	23.5	29.4	26.1		
During cultivation & Transplanting time %	17.6	17.6	21.5	18.9		
improper spacing b/n enset %	11.8	15.7	11.8	13.1		
Farm Workers %	13.7	9.8	9.9	11.2		

Note: Statically significant at $p < 0.01$, ns = no significant, χ^2 = chi square

4.1.8. Management practices adopted by farmers for control *P. ensete*

The results of the management practice adopted by the respondent farmers to a control enset root mealybug population in the study area were presented in (Table.9).

Even if, most of enset producing farmers have no information about enset root mealybug, they use their own management practices , due to having yield loss and damages on enset plant.

In the three study districts, majority (66%) of farmers use various combinations of traditional cultural practices to control the root mealybug. Among the respondents (22.9%) of the farmers adopted farming procedures, such as frequent plowing and pruning, weeding two or three times per year, plowing to expose insects to sunshine, and maintaining enset field hygiene The result is agreed the reports (Walton, 2000).

Additionally, (17%) of farmers manage enset root mealybug by applying wood ash and farmyard manure and compost. The farmers reported that enset plants develop more quickly when farmyard manure and wood ash are applied during planting and farm cultivation. They also believed that root mealybugs do not harm that enset. Similar reports were made by), Anonymous, (2002); and Gemu *et al*., (2010). Furthermore, (12%) of the farmers use cleaned planting equipment; they remove dirt from their equipment after plowing and store it in a dry place. The report is lined report of (Ameyaw *et al*.,2014).

Moreover, (9.7%) of the farmers they indicated that cultivars they plant are tolerant to enset root mealybug. The result is in line with Kefelegn *et al.*, (2014). The remaining (7.9%) reported that they employ quarantine techniques. They did not exchange or purchase enset seedlings or suckers from their neighbors to avoid movement of the pest from one field to the other field.

However, (15.7%) of the farmers did not use any management practices against the enset root mealybug, due to lack of information on the pest The management methods adopted by the farmers were not significantly different *(χ^2 = 2.59, p = 0.99)* in the three districts (Table 9).). The management practices adopted by farmers of enset root mealybug was agreed with the report of (Karar *et al.*,2021 ; Habtamu & Dadi, 2022).

Table 9. Management practices of enset root mealybug in the study area

Control measures	Assessed districts			Mean	χ^2	P= value
	Mareka (N=51)	Mari Manisa (N=51)	Tocha (N=51)			
Cultural practice (%)					2.59	0.99^{ns}
Frequently farm practices, weeding and repeated ploughing %	25.5	23.5	19.6	22.9		
Using FYM and wood ash %	15.7	17.7	17.6	17		
Sit selection & Establish new fields %	11.8	15.7	15.7	14.4		
Using cleaned planting equipment %	11.7	11.7	11.8	11.7		
Using tolerances local variety of enset %	9.7	9.8	11.7	10.4		
Quarantine%	7.9	7.8	7.9	7.9		
Can't use any management %	17.7	13.8	15.7	15.7		

Note: ns = no significant, χ^2 = chi square

4.2. The infestation of enset root mealybug in the enset plant in the study area

The results of enset root mealybug infestations on enset plants assessed in three districts were shown in (Figure 8). Among the total of enset sampled at the study site, the highest (41.6%) percentage of infestation was recorded Mari Manisa followed by Mareka district (33.4%), while the lowest percentage of infestation was in Tocha district (25%) (Fig.8)

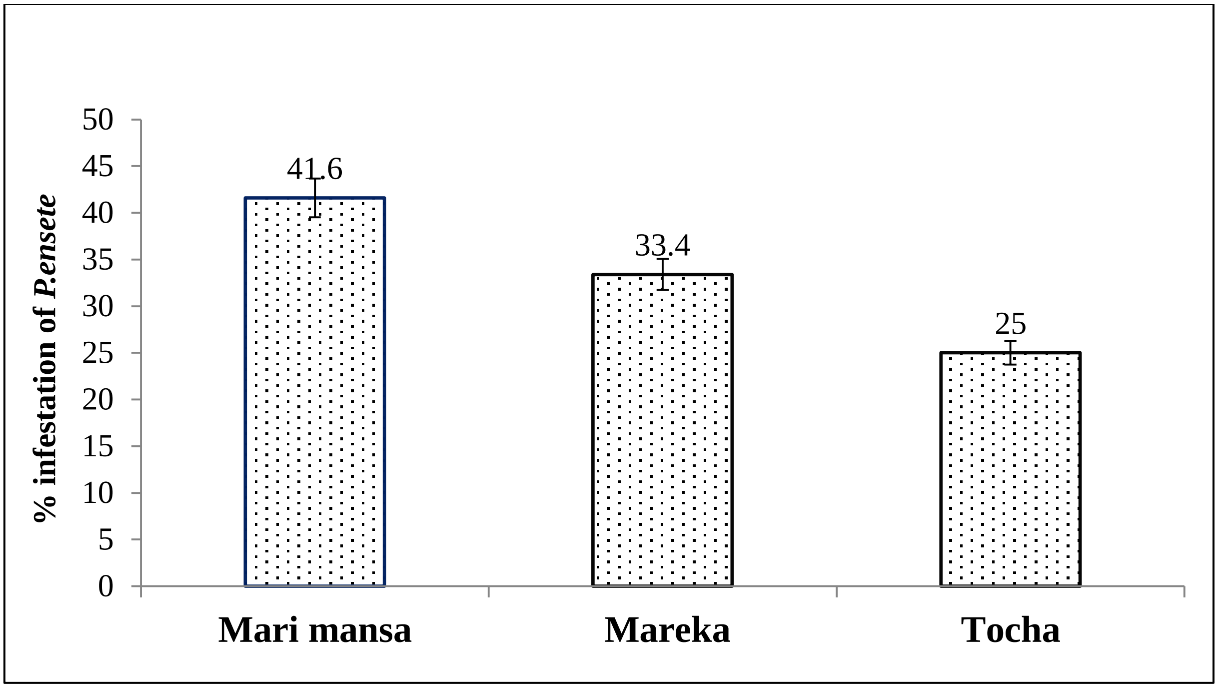


Figure 8 Infestation of the enset root mealybug between districts.

4.2.1. Age and infestation frequency of infested enset plant in the study area

The age of the infested enset and the frequency of the infestation are shown in (Figure 9)

Among the infested ensets in the three districts, the highest infestations of enset root mealybug were frequently found at the age of three years. On the other hand, the five-year growth stages showed the lowest frequency of infestations. At the age of three years, the highest frequency of infestation (10) was observed at Mari Manisa district followed by Mareka districts (8). Tocha district had the lowest frequency of infestation.

At five years of age, the highest infestation frequency (three) was found in Mareka and Mari Manisa, while the Tocha districts had the lowest infestation frequencies (1). The result is in agreement with the report of (Addis et al., 2010b)

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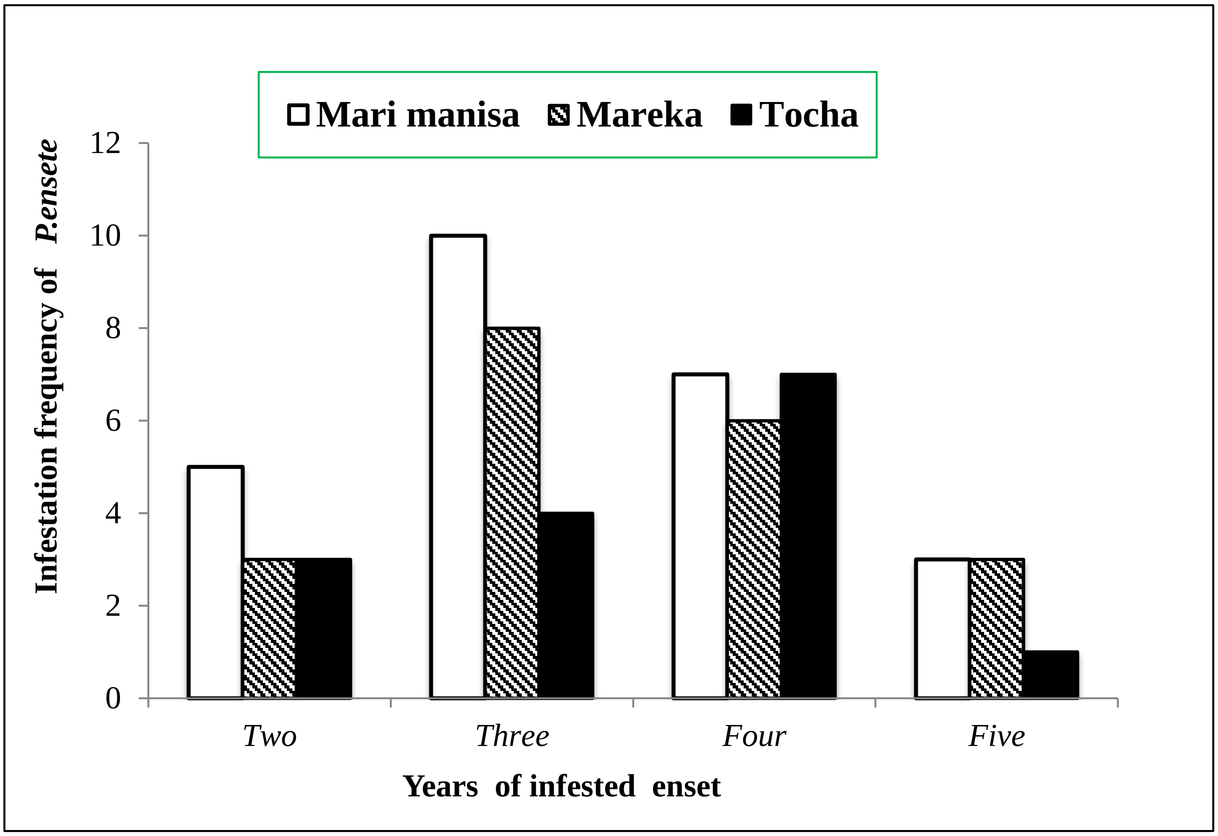

Figure 9 Infestation frequently of enset root mealybug with enset age in the study area

4.2.2. Population of Enset root mealy bug in study areas.

The results of enset root mealybug populations counted under the roots and corms of infested parts of enset in three districts were shown in (Figure 10). The highest population enset root mealybug were counted from the roots (44.5) and corms (178) of sampled enset in Mari Mansa district followed by from the Mareka districts, 158 on the roots and 39.5 on corms. However, lower populations' densities of *P ensete*, 30.75 on roots and123 on corms of enset plant, were recorded in Tocha district. The population of enset mealybugs was significantly (<0.01) higher in the root than corms of enset plant parts (Figure 9). The majority of the enset root mealybug population 388 (84.5%) was recorded from infested roots compared to corms in the three districts. The corm of the enset had the lowest population density (71) and proportion (15.5%) of the enset root mealybug.

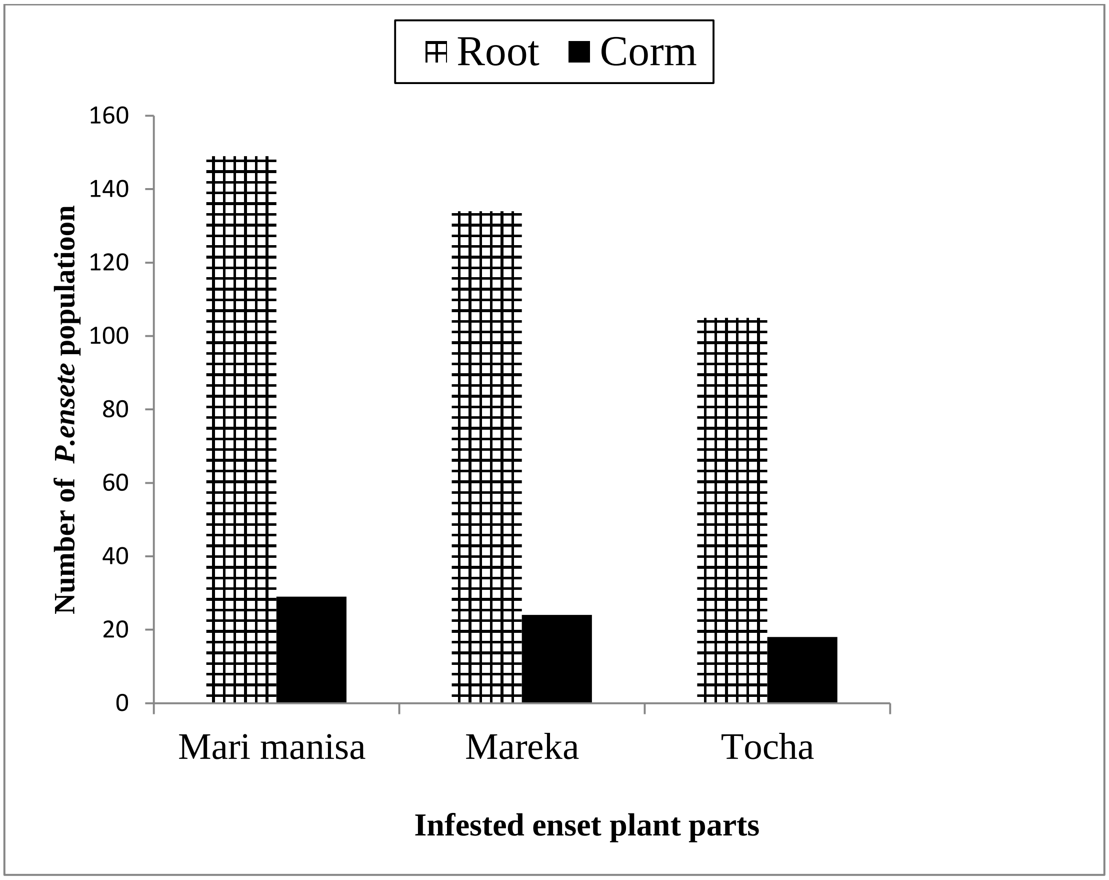

Figure 10.The distribution of enset root mealybug in the root and corm of the enset plant in the study area.

4.2.3. Effect of altitude on the incidence of enset root mealybugs

The enset root mealybug distribution was observed between 1200 to 2900 m.a.s.l. The infestation was found to be serious in the elevation between 1300-2900 m.a.s.l. As indicated in figure 11, the highest infestation was recorded in the elevation between 1300-1500 m.a.s.l. conversely, the infestation were not recorded at >1500 m.a.s.l. this influence be liked to lower temperature of the soil that might not suitable to the enset root mealybug. Furthermore, the enset root mealybugs were not recorded in 1200-1300 m.a.s.l (figure 11).

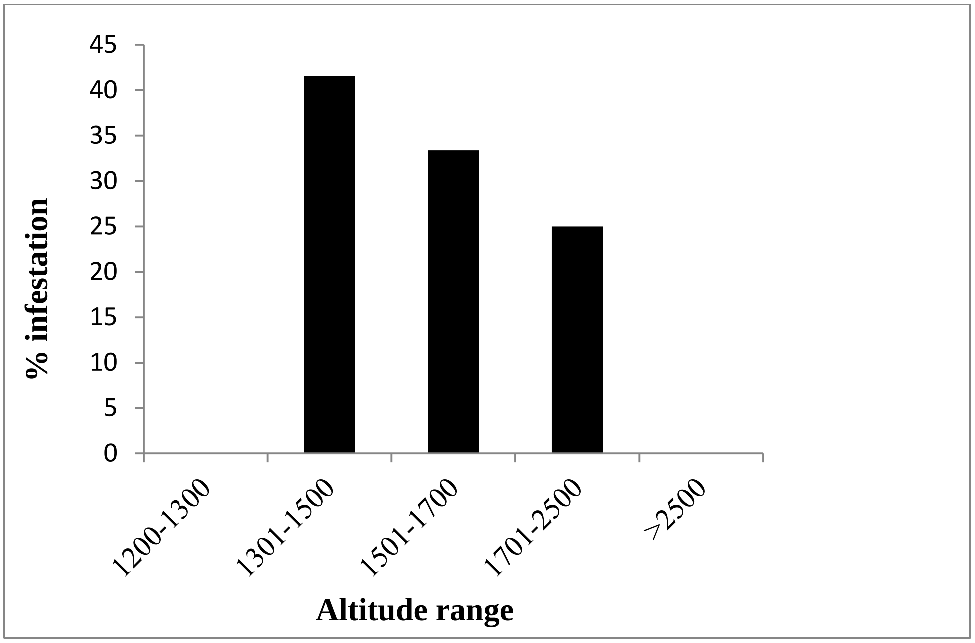

Figure 11 Incidence of enset root mealybugs at different altitude

4.3. Evaluation of botanical efficacy against the second instar nymph of P. *ensete*

4.3.1. Laboratory bioassay

The bioassay result indicated that, botanicals, concentration, and their interaction (botanical × concentration ×Time) with in 24hr intervals had significant effect *(p<.001)* on mortality of the second instar nymphs compared to the control. In addition, the interaction of concentration had a significant impact on the morality of second instar nymphs for all the botanical extracts. The botanicals *Z. officinale, A. sativum* and *E. globulus* applied at 5% concentration caused 20% mean mortality on the second instar nymph followed by with *M. oleifera* extracts (16.6%). At 10% concentration the botanical extracts of Z. *officinale* extracts causes 23.4% mean morality. Furthermore, *A. sativum* and Z. *officinale* extract at 15% caused 26.7% mortality and by 23.3% with *E, globulus* extract.

At 48 hours, when dipped in 15% concentrations, the mean percentage mortality of the second instar nymphs *by A. sativum, E. globulus, Z. officinale, D. stramonium, M. oleifera and P. betle* were 60.0%, 56.7%, 56.6%, 53.3%, and 46.6%, respectively. *Eucalyptus globulus* at 10% caused 50% mortality on second instar nymphs. The highest mean mortality of the mealybug after 72 hr of application with 10% concentration was caused by *A. sativum* (86.7%) and followed by with *D. stramonium* (83.4%). *Allium sativum* extracts caused (100%) mortality of the second instar nymphs at15%, followed by 93%) from *Z. officinale, D.*

stramonium, respectively. *Piper betle* caused the lowest mortality (77%). **@** 5% (73.4%) 2^{nd} instar mortality was recorded with *A. sativum and Z. officinale* extracts. The result is lined with (Muthulingam, 2014). There was a significant effect of botanical, concentration, time and their interaction that caused mortality to second instar nymphs (*p<.001*) at 24h, 48h and 72 h exposure, respectively (Table 10).

Table 10. Mean (Percentage ±SE) mortality of second instar nymphs' of enset root mealybug treated with different botanical extracts under laboratory

Treatments	Conc	Means (%) mortality against 2^{nd} instar nymphs of enset root mealybug hr after exposure		
		24hr	48hr	72hr
Allium sativum	5	20.0 ± 0.00^{ab}	46.7 ± 3.33^{abc}	73.4 ± 6.66^{bcd}
	10	23.4 ± 3.33^{ab}	53.3 ± 3.33^{abc}	86.7 ± 3.33^{abcd}
	15	26.7 ± 5.77^{a}	60.0 ± 0.00^{a}	100.0 ± 0.00^{a}
Eucalyptus globulus	5	20.0 ± 0.00^{ab}	46.6 ± 3.33^{abc}	70.0 ± 5.77^{cde}
	10	23.3 ± 3.33^{ab}	50.0 ± 0.00^{abc}	76.7 ± 3.33^{bcd}
	15	23.4 ± 3.33^{ab}	56.7 ± 3.33^{ab}	90.0 ± 00^{abc}
Zingiber officinale	5	20.0 ± 0.00^{ab}	43.3 ± 6.66^{e}	73.3 ± 6.66^{bcd}
	10	23.3 ± 3.33^{bac}	53.3 ± 3.33^{abc}	83.3 ± 8.8^{abcd}
	15	26.6 ± 5.77^{a}	56.7 ± 3.33^{ab}	93.4 ± 3.33^{ab}
Datura stramonium	5	13.4 ± 3.33^{bc}	40.0 ± 0.00^{bcd}	70.0 ± 0.00^{cde}
	10	20.0 ± 0.00^{ab}	50.0 ± 0.00^{abc}	83.4 ± 3.33^{abcd}
	15	23.4 ± 3.33^{ab}	56.6 ± 3.33^{ab}	$93.3 \pm 3.3.33^{ab}$
Moringa oleifera	5	16.7 ± 3.33^{abc}	40.0 ± 5.77^{bcd}	66.7 ± 8.88^{de}
	10	20.0 ± 0.00^{ab}	50.0 ± 0.00^{abc}	83.3 ± 3.33^{abcd}
	15	23.3 ± 3.33^{ab}	53.3 ± 3.33^{abc}	90.0 ± 0.00^{bac}
Piper betle	5	6.7 ± 3.33^{cd}	23.3 ± 3.33^{d}	50.0 ± 5.77^{e}
	10	16.7 ± 3.33^{abc}	36.6 ± 3.33^{cd}	66.6 ± 3.33^{de}
	15	23.3 ± 3.33^{ab}	46.6 ± 3.33^{abc}	76.6 ± 3.33^{bcd}
Control		0^{f}	0^{f}	0^{f}
CV		26.7	15.01	11.90
LSD (0.05%)		7.23	11.31	14.86
P – value		<.001	<.001	<.001

Note = CV; Coefficient of variance, LSD = Least significant difference, Con = Concentration. Means within the same column with the same letter are not significantly different according to Turkey's (HSD) test at P>0.05.

4.3.1.1. Concentrations Response Bioassay under Laboratory Conditions

The LC_{50} and LC_{90} value that kill 50% and 90% of the second instar nymph population exposed after three days were presented in (Table.11).

The minimum value (23.76) and (89.26) required to kill 50% and 90% of the second instar nymphs of enset root mealybug population at 95% fiducial limits were recorded from the extract of *A. sativum.* Whereas, the maximum (49.14) value was recorded from *P. betle* for the mortality of the second instar nymphs. The botanical extract with the lowest values of LC_{50} and LC_{90} was considered to show the highest efficacy at the lowest dose. Although the highest value has the lowest efficacy against the second instar nymphs of enset root mealybug morality.

Table 11. Lethal concentration value for extracted botanicals against the second instar nymph of enset root mealybug after three days post-treatment

Botanicals	LC_{50} (mg/ ml) (95%FL)	LC_{90}(mg/ml) (95 % FL)
Allium sativum	23.76(13.68-32.17)	89.26 (80.60-102.13)
Eucalyptus globulus	28.26(18.52-36.22)	144.46 (120.55-193.43)
Zingiber officinale	33.13 (26.38-38.60)	131.48 (109.83-176.84)
Datura stramonium	28.81(19.60-36.34)	130.43 (111.02-167.35)
Moringa oleifera	30.1(20.43- 37.93)	152.06 (126.44- 204.53)
Piper betle	49.14 (37.84- 58.1)	357.44 (255.87- 638.40)

Note= FL; fiducial limit, LC_{50}; lethal concentration of 50%, $LC_{90;}$ lethal concentration of 90%.

4.3.1.2. Effect of botanical extracts on 2nd instar at different times-LT50 and LT90

The LT_{50} and LT_{90} value at each botanical were presented in (Table 12). The *A. sativum* botanical extract had a minimum LT_{50} and $LT_{90)}$ (1.39) ,(2.77) value used to kill 50% and 90% respectively at 15% of concentration, against the 2nd instar nymphs population with 95% fiducial lower and upper limit. The lethal result indicated that the minimum values have the highest efficacy than the maximum value in both the lower and upper fiducial limit LT_{50} and LT_{90} (Table 12).

Table 12 Lethal time value for botanicals extracted against the second instar nymph of enset root mealybug three days after treatment.

Treatment	LT_{50} (Days) (95% FL)	LT_{90}(Days) (95% FL)
Allium sativum	1.39(1.26-1.53)	2.77(2.43-3.33)
Eucalyptus globulus	1.51(1.35-1.66)	3.25 (2.80-4.05)
Zingiber officinale	1.59 (1.43-1.74)	3.29 (2.86-4.05
Datura stramonium	1.59(1.43-1.74)	3.29 (2.86-4.05
Moringa oleifera	1.65(1.48-1.82)	3.64 (3.10-4.63
Piper betle	1.88 (1.66-2.13)	5.36 (4.17-8.26

Note= FL; 95%= fiducial limit, LT_{50}*; lethal time of 50%, LT90; lethal time for 90%*

4.3.2. Potted Experiments

The results obtained in the potted experiment with selected botanicals efficacy are shown in (Figure 12).

E. globulus applied two times caused the highest mortality (91.8%) of the second instar nymph followed by extracts of *A. sativum* (83.9%). However, *D. stramonium* showed the lowest (64%) mortality.10 days after treatment. The highest population mortality (65.3%) of the second instar nymph were caused from *A. sativum* extracts in a potted enset seedling followed by (61.4%) and (53.9%) of *E. globulus* and *Z. officinale* extracts after ten days with in single drenching (Fig. 12),. While the lowest (46.1%) mortality was caused *by D. stramonium* extract, after ten day of treatment. The most effective botanicals were those that were drenched twice as frequently until ten days in potted enset seedling.

However, a single application of 60% drenched diazinon EC resulted in 100% mortality of the second instar nymph's population. While, the efficacy of botanicals against second instar nymph mortality was lower than that of the drenched insecticide of diazinon (Figure 12).

There is significant difference b/n twice and single drenched botanical and insecticide in potted experiment ($p>0.001$).

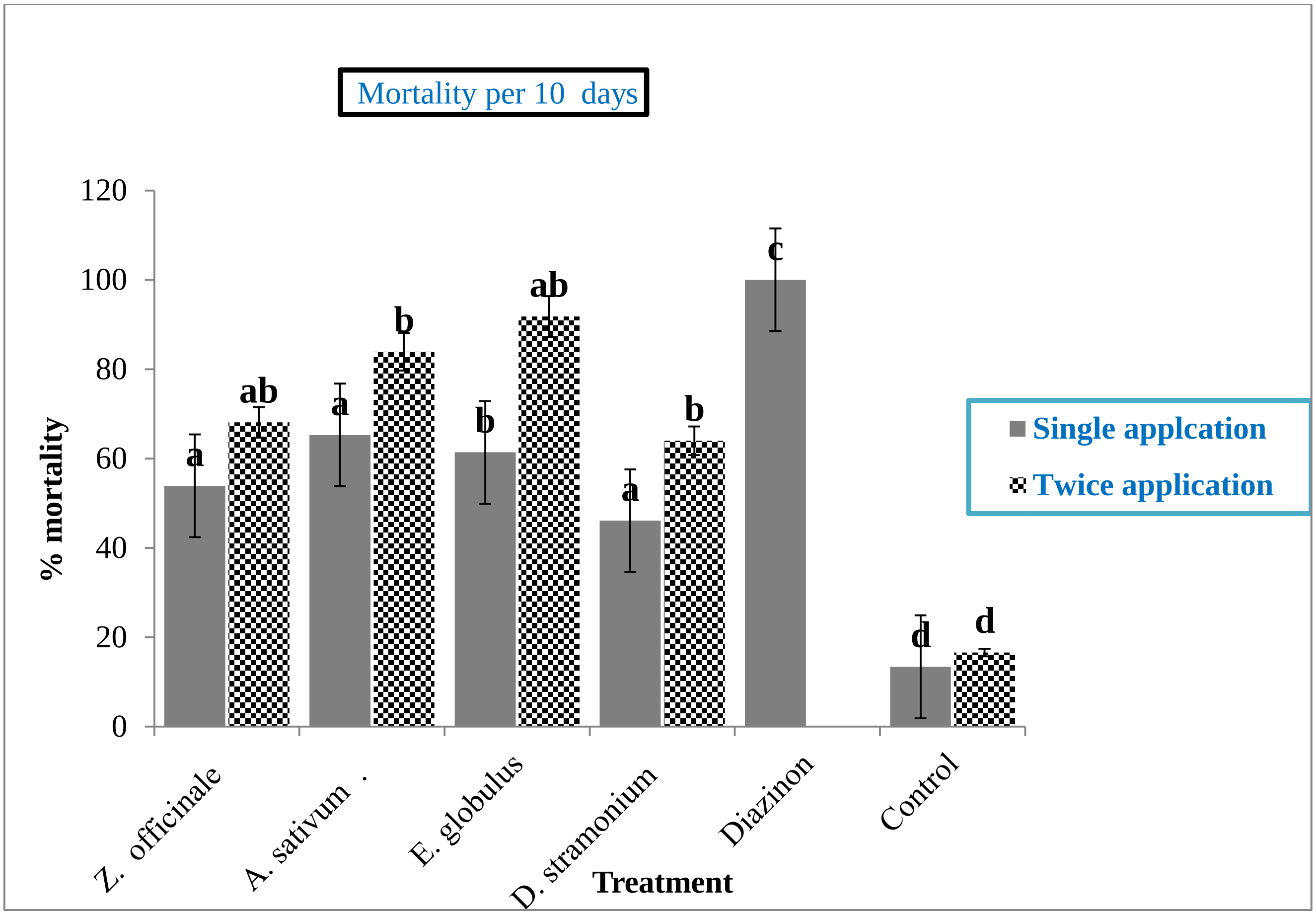

Figure 12. Efficacy of botanical to 2nd instars nymphs' enset root mealybug in potted enset seeding

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusions

The study delivers observations of household characteristics in to three districts in Dawuro Zone, south western of Ethiopia. According to the present study, the enset plantation is infested by enset root mealybug in the study area. The study confirmed that most farmers lack information, and are unable to identify the enset root mealybug on their enset fields. Farmers indicated that infested ensets with enset root mealybug are deformed, lack strength and are unable to remain in erect position in the enset field.

Furthermore, the enset root mealybug infestation reduced yield of corm which grew slowly and had few roots when transplanted. Spreads with infested enset roots and corms, planting equipment, and farm laborers, and close spacing's during planting were found to be the main means of dispersal of the enset root mealybugs. In the current study, farmers used mainly cultural practices, use of clean planting materials, and tolerant enset cultivars. The respondents disclosed that they do not use pesticides or botanicals against enset root mealybug.

The present study revealed that, infestations of enset root mealybug was present in all the study sites. Among the assessed districts, the highest infestations were recorded from Mari Manisa, while the lowest in Tocha. Farmers were the opinion that the infestation and dissemination of enset root mealybug was mainly by enset seedling. The study showed that, the infestations of enset root mealybug were observed on young growth ages of enset. Most infestations were found when the enset was three years old. At this stage, its roots and soft corms are easily sucked by the mealybugs. The present finding revealed that, most (84.5%) of the enset root mealybugs were found on the roots, while (15.5%) were in the corms of the infested plants.

The current bioassay result revealed that, the concentration and frequency of application at 24 hr, 48 hr and 72 hr of exposure had a significant interaction on the morality of enset root mealybug population for all botanical extracts. The mortality response was concentration and time dependent; it increased along with concentration of botanical extracts with different time exposure. The present findings showed that, *A. sativum*, *E. globules*, *Z. officinale,* and *D.*

stronmoum had highest efficacy against second instar nymphs of *P.ensete,* when compared to the rest of the botanicals bio assayed.

Furthermore, compared to 10% and 5% concentration for all the treatments, the 15% concentration demonstrated the highest efficacy. However, the extract of *A. sativum* was the most effective and showed significantly higher mortality than the other botanical extracts. *A. sativum* had the lowest LC_{50} and LC_{90} values three days application. The mortality of the second instar nymphs' mortality increased with the length of exposure of treatment.

In a potted experiment, twice drenching with *E. globulus* and *A. sativum* botanical extracts induced the highest reduction against the second instar of the *P. ensete* population ten days after application. In a single drenching, *A. sativum* caused the highest mortality on the second instar enset root mealybug nymphs. However, 100% mortality of the enset root mealybug was recorded with diazinon 60% EC applied one time.

5.2. Recommendation

- The findings of present study suggested that A. *sativum* and *E, globulus* extract can be used as safe control of enset root mealybug (*P.ensete).* However, further study should be needed on other botanical at twice drenching is needed for enset root mealybug management.
- It should be required from agricultural experts and stakeholders in order to demonstrate farmers about the distribution, and management practices of the *P.ensete* in their enset farm and farmers training center. Assessing of infestation of the *P. ensete* on root and corm of enset during transplanting enset seedling from temporary to the main field will be needed.
- Additionally, promoting the use of plant and their product in mealybug infested area and conducting furthers successful IPM control methods to improve the preparation of affordable local management skills with the importance of cultural and prevention will be needed for production and productivity in the enset growing area.
- Finally, awareness raising activities should be conducted with agricultural experts and stakeholders, enset-producing farmers with government programs, nongovernmental organizations (NGOs), and agricultural research findings etc. emphasizing the advantages of botanical plants and promoting participatory enset root mealybug management . In the study area, I hope to see sustainable production of enset plants to improve food security.

6. REFERENCES

Abbott, W. (1925). A method of computing the effectiveness of an insecticide. *Journal of economic entomology, 18*(10), 256–267.

Abdella K. (2016). *"Traditional medicinal use of Ensete ventricosum (Welw.) cheesman in gedebano gutazer Welene district, Gurage zone, S NNP region, Ethiopia," M.Sc. th esis, Addis Ababa University, Addis Ababa, Ethiopia, 2016.*

ADDIS, TEMESGEN, F. A., & BLOMME2, and G. (2008). *Density and distribution of enset root mealybugs on enset*. *16*(1), 67–74.

Addis T, Azerefegne F, B. G. and K. K. (2008). *Biology of the Enset Root Mealybug Cataenococcus ensete and its Geographical Distribution in Southern Ethiopia*. *January 2015*.

Addis, T. (2005). *In Partial Fulfillment of the Requirements for the Degree of*. *April*.

Addis, T., Azerefegne, F., Blomme, G., & Kanaujia, K. (2008). Biology of the Enset Root Mealybug, Cataenococcus ensete and its Geographical Distribution in Southern Ethiopia. *Journal of Applied Biosciences*, *8*(1), 251–260. www.biosciences.elewa.org

Addis, T., Gmbh, B. C., & Azerefegne, F. (2010a). *Density And Distribution Of Enset Root Mealybugs On Enset*. *May*. https://doi.org/10.4314/acsj.v16i1.54344

Addis, T., Gmbh, B. C., & Azerefegne, F. (2010b). *Density And Distribution Of Enset Root Mealybugs On Enset*. *May 2014*. https://doi.org/10.4314/acsj.v16i1.54344

Addis T. (2005). *Biology of Enset root mealy bug (Cataenococcus ensete Williams and Matile Ferrero) (Homoptera: Pseudococcidae) and its geographical distribution in southern Ethiopia. M. Sc. Thesis. Alemaya University, Ethiopia, 81 pp.*

Agize, M., Demissew, S., & Asfaw, Z. (2013). *Indigenous Knowledge On Management Of Home Gardens And Plants In Loma And Gena Bosa Districts (Weredas) Of Dawro Zone , Southern Ethiopia : Plant Biodiversity Conservation , Sustainable Utilization And Environmental Protection*. *10*, 63–99.

Ameyaw GA, Dzahini-Obiatey HK, D. O. (2014). *Perspectives on cocoa swollen shoot virus disease (CSSVD) management in Ghana. Crop Protection. 65*, 64–70.

Anonymous. (2000). *Awassa Agricultural Research Center Progress Report for the period 1999. Awassa, Ethiopia.*

Anonymous. (2002). *Awassa Agricultural Research Center progress report of plant protection research division for the year 2001. Awassa, Ethiopia.*

Asfaw Amamo, A. (2018). The Role of Women in EnsetMarkt Chain the Cause of Dawuro Zone, Southern Nations Nationalities and Peoples Regional State, Ethiopia. *International*

Journal of Current Research and Academic Review, *6*(4), 36–47. https://doi.org/10.20546/ijcrar.2018.604.006

Asfawu Amamao, . A. (2018). *and Academic Review The Role of Women in Enset Markt Chain the Cause of Dawuro Zone , Southern*. *6*(4), 36–47.

Asnake Boyana Kefelegn Getahun2, A. M. and M. A., & 1Department. (2018). *International Journal of Current Research Suitability Analysis for Enset (Ensete ventricosum Cheesman (Welw)) Cultivation in*. *March*. https://doi.org/10.20546/ijcrar.2018.603.007

Avila, V., Achim, F., Brito, V. D., Aguilar, R., & Pizzolitto, R. P. (2023). Insecticidal Activity of Essential Oils against Mealybug Pests. *Avila, M.d.V.; Achimón, F.; Brito, V.D.; Aguilar, R.; Pizzolitto, R.P.; Zunino, M.P.; Peschiutta, M.L*.

Ayele, A., & Sahu, O. (2014). Extension of Enset Plant Product for Rural Development in Ethiopia. *Journal of Agricultural Economics*, *2*(3), 31–40.

Aytenfsu, M., & Haile, B. (2020). Distribution and Management of Bacterial Wilt (Xanthomonas Campestris pv. Musacearum) of Enset (Ensete Ventricosum) in Ethiopia: a Review. *Online) International Journal of Research in Agriculture and Forestry*, *7*, 40–53.

Azerefegne, Temesgen Addis, Tameru Alemu, Sisay Lemawork, Eyob Tadesse, M. G. and G. B. (2014). *An IPM guide for Enset root mealybug (Cataenococcus ensete) in Enset production*. *March 2014*.

Azerefegne F, Addis T, Alemu T, Lemawork S, Tadesse E, Gemu M, B. G. (2009). *An IPM guide for enset root mealy bug (Cataenococcus ensete) in enset production. In: Johnson V (Ed) Biodiversity International, Uganda and France Offices,18 pp*.

Bala, K., B, A. G. R., & Arivudainambi, S. (2019). *Efficacy of certain botanicals against cotton mealybug Phenacoccus solenopsis L . (Pseudococcidae : Hemiptera) on Okra*. *8*(5), 1586–1591.

Bekele, J. (2002). *Evaluation of the toxicity potential of Millettia ferruginea (Hochest) Barker against Sitophilus zeamais (Motsch.). International Journal of Pest Management 48*. *48*(1), 29–32.

Bekele, T. (2001). *Insecticidal screening against enset root mealybug Paraputo spp. AgriTopia. Newsletter,Addis Ababa, Ethiopi*. *16*(2), 2–3.

Belmain, S.R., Neal, G. E., Ray, D.E. and Golop, P. (2001). *Insecticidal and vertebrate toxicity associated with ethno botanicals used as postharvest protectants in Ghana. Food Chem. Toxicol. 39*, 287–291.

Beyene, T. M., & Mekonnen, T. W. (2014). *Farmers indigenous knowledge and assessment of enset (Ensete ventricosum Welw . Cheesman) cultivars for major insect pests in Ojojia water shade Kembata- tembaro zone , South Ethiopia*. *July*.

Birmeta, G. (2016). *Genetic variability and biotechnological studies for the conservation and improvement of Ensete ventricosum Genetic Variability and Biotechnological Studies for the Conservation and Improvement of Ensete ventricosum Genet Birmeta Swedish University of Agr* (Issue January 2004).

Bizuayehu T. (2002). *Studies on land races Diversity, in vivo and in vitro Rege- neration of enset (Ensete ventricosum (Welw.) PhD dissertation, Humboldt Universitat zu Berlin, 127 pp*.

Blomme, G., Dita, M., Jacobsen, K. S., Vicente, L. P., Molina, A., Ocimati, W., Poussier, S., Prior, P., Studholme, D. J., & Grant, M. (2017). *Bacterial Diseases of Bananas and Enset : Current State of Knowledge and Integrated Approaches Toward Sustainable Management*. *8*(July), 1–25. https://doi.org/10.3389/fpls.2017.01290

Blumberg, D. and R. G. V. D. (2001). *Encapsulation rates of three encyrtid parasitoids by three mealybugs species (Homoptera: Pseudococcidae) found commonly as pests in commercial green house. Biological control 22:* 191–199.

BoFED-SNNPRS-. (2012). *Bureau of finance and economic development," Tech. Rep. Hawassa, Ethiopia,*. 2011–2012.

Bonso, A. B., Jabessa, G. M., & Negeri, B. G. (2022). Does enset (Ensete Ventricosum) production upshot smallholder farmers food security and income : Evidence from Dedo Woreda , Jimma. *Journal of Agriculture and Food Research*, *10*(January), 100349. https://doi.org/10.1016/j.jafr.2022.100349

Borrell, J. S., Biswas, M. K., Goodwin, M., Blomme, G., Schwarzacher, T., Heslop-harrison, J. S. P., Wendawek, A. M., Berhanu, A., Kallow, S., & Janssens, S. (2019). *Enset in Ethiopia : a poorly characterized but resilient starch staple*. 747–766. https://doi.org/10.1093/aob/mcy214

Borrell, J. S., Goodwin, M., Blomme, G., Jacobsen, K., Wendawek, A. M., Gashu, D., Lulekal, E., Asfaw, Z., Demissew, S., Wilkin, P., & Gardens, R. B. (2020). *Enset-based agricultural systems in Ethiopia : A systematic review of production trends , agronomy , processing and the wider food security applications of a neglected banana relative*. *May 2019*, 212–228. https://doi.org/10.1002/ppp3.10084

Brandt, S. (1996). *A model for the origin and evolution of enset food production. In: Enset-Based Sustainable Agriculture in Ethiopia, (Tsedeke Abate, Steven, C.H., Brandt, A. and Seifu Gebremariam, Eds.). Proceedings from the International Workshop on Enset held i*. 36–46.

Castellani E. (1939). *Su un marciume dell'ensete. L'Agricoltura Coloniale, Firenze, 33,* (pp. 297–300).

Cheesman EE. (1947). *Classification of the Bananas. The genus Musa L. Kew Bull,2(2):* (pp. 106–117).

Cocco A, Pacheco da Silva VC, B. G. (2021). *Sustainable management of the vine mealy bug in organic vineyards. 94*, 153–185.

CSA (Central Statistical Agency). (2021). *Report on Area and Production of Crops. The Federal Democratic Republic of Ethiopia Central Statistical Agency, Report No 1. April 2018.*

Daane, K. M., Almeida, R. P. P., Bell, V. A., Walker, J. T. S., Botton, M., Fallahzadeh, M., Mani, M., Miano, J. L., Sforza, R., Walton, V. M., & Zaviezo, T. (2012). *Biology and Management of Mealybugs in Vineyards*. https://doi.org/10.1007/978-94-007-4032-7

Degefa, D. E. (2018). *Indigenous Knowledge on cultivation and consumption of Enset (Enset ventricosum) in Kercha District; West Guji Zone, Oromia Region of Ethiopia. J Plant Breed Genet 6:87 – 94. 6*, 87–94.

Delvin, J. F. and Zettel, T.(1999). *Eco agriculture: Initiatives in Eastern and Southern Africa. Weaver Press, Harare.*

Desalegn R, Addis S. (2015). *Enset (Ensete ventricosum (Welw.) bacterial wilt survey in Borena Midaltitude. Int. Inv. J. Agric. Soil Sci. 3*(2), 9–12.

Díaz Arzola, C. G. (2014). *Revisión anotada sobre la taxonomía de Pseudococcidae (Hemiptera: Coccoidea) en Puerto Rico. MSc Thesis.Protección de Cultivos. Universidad de Puerto Rico- Recinto Universitario de Mayaguez. 275 pp.*

Dilebo, T., Feyissa, T., Asfaw, Z., & Zewdu, A. (2023). On-farm diversity, use pattern, and conservation of enset (Ensete ventricosum) genetic resources in southern Ethiopia. *Journal of Ethnobiology and Ethnomedicine*, *19*(1), 1–18. https://doi.org/10.1186/s13002-022-00569-x

Dougoud, J., Toepfer, S., Bateman, M., Jenner, W. H., Dougoud, J., Toepfer, S., Bateman, M., & Jenner, W. H. (2020). *Efficacy of homemade botanical insecticides based on traditional knowledge . A review To cite this version : HAL Id : hal-02877034 knowledge . A review*.

DZAD. (2021). *DZAD Annual report of Dawuro Zone Agricultural Department 2021*.

Earecho, M. K. (2015). *Demonstration of Effective Management Option for Mole Rat of Enset in Kafa Zone*. *17*, 1–4.

El-Ashram, D.; Abd El-Mageed, S.A.M. and Shaaban, A.-R. (2020). *Egyptian Journal of Plant Protection Research Institute*. *3*, 794–803.

El-masry, G., & Saleh, F. M. (2017). *MORINGA PLANT, Moringa oleifera LAM., AS A source of biopesticide*. *6*(3), 285–292. https://doi.org/10.21608/sinjas.2017.78836

Erenso, F., Blomme, G., Goergen, G., Muanenda, M., Kearsley, E., & Addis, T. (2023). First report of the enset root mealybug Paraputo ensete (Williams & Matile - Ferrero) (Hem

.: Pseudococcidae) on banana in Ethiopia. *International Journal of Tropical Insect Science, 2022*. https://doi.org/10.1007/s42690-023-01003-9

Erenso, F., Blomme, G., Muanenda, M., Kearsley, E., & Goergen, G. (2022). *Assessing the host status of banana and other plant species to the enset root mealybug Paraputo ensete in Ethiopia*. *18*(12), 1023–1036. https://doi.org/10.5897/AJAR2022.16205

Farms, I. (2020). *Integrated Pest Management , Department of Food and the Marine An Roinn Talmhaionchta Bia agus Mara*.

Ferdu Azerefegne, Temesgen Addis, Tameru Alemu, Sisay Lemawork, Eyob Tadesse, M. G. and G. B. (2009). *An IPM guide for Enset root mealybug (Cataenococcus ensete) in Enset production*. 15–18.

Finney, D. . (1971). *Probit Analysis. Cambridge University Press.*

Forsido, S.F., Rupasinghe, H.P.V. and Astatkie, T. (2013). *"Antioxidant capacity, total phenolics and nutritional content in selected Ethiopian staple food ingredients", International Journal of Food Sciences and Nutrition,*. *64*(8), 915–920.

Garedew, B., & Ayiza, A. (2018). *Research Article Major Constraints of Enset (Ensete ventricosum) Production and Management in Masha District , Southwest Ethiopia*. *13*(2), 87–94. https://doi.org/10.3923/ijar.2018.87.94

Garedew, B., Ayiza, A., Haile, B., & Kasaye, H. (2017). *Indigenous Knowledge of Enset (Ensete ventricosum (Welw .) Cheesman) Cultivation and Management Practice by Shekicho People , Southwest Ethiopia*. *5*(1), 6–18. https://doi.org/10.11648/j.jps.20170501.12

Gebre-Mariam, T. (2016). *Industrial applications of enset starch and its modifcations: from native starch to nanoparticles. In International Workshop on Enset (Ensete ventricosum) for Sustainable Development (pp. 19 – 21).*

Gebriel, Y. J. (2020). *Assessing the indigenous knowledge of enset cultivation and management practices among sidama people, Southern Ethiopia assessing the indigenous knowledge of enset cultivation and management practices among sidama people, southern Ethiopia.*

Gemu, M., Ngangbam, A. K., & Blomme, G. (2010). *Effect of wood ash, tagetus minut a extract and hot water treatment of enset sucker for the control of enset root treatment mealy bug (cataenococcus ensete) mealy bug*. *44*(4), 300–305.

Genet Birmeta, G. (2004). *Genetic Variability and Biotechnological Studies for the Conservation and Improvement of Ensete ventricosum. Doctoral thesis ISSN.*

Gessesse, A. (2016). *Industrial uses of enset: Application in the food, animal feed, paper, textile, and brewery industries. In International Workshop on Enset (Ensete Ventricosum) for Sustainable Development (pp. 18).*

Gezahagn Kudama, T. T. and L. G. (2022). Good farm practices and improved processing technology of enset for sustainable hunger solution in Ethiopia. *Journal of Innovation and Entrepreneurship*. https://doi.org/10.1186/s13731-022-00210-x

Gezahegn, G., & Mekbib, F. (2016). *Evaluation of Enset (Ensete ventricosum (Welw .) Cheesman) Clone Suckers to Bacterial Wilt Disease Pathogen under Greenhouse Condition*. 51–56.

Gullan, P. J. (2000). *Identification of the immature instars of mealybugs (Hemiptera: Pseudococcidae) found on citrus in Australia. Aus. J. Entomol. 39*, 160–166.

Gupa, M. A., & Zira, B. D. (2023). *Assessment of Insect Infestation on Moringa Based Agroforestry Farm at Fune LGA*. 58–65.

Habtamu G.M,. & Dadi, T. L. (2022). *Integrated Major Pest Management Systems of Enset (Ensete ventricosum (Welw.) Cheesman) in Ethiopia. American Journal of Entomology*. *6*(2), 14–21. https://doi.org/10.11648/j.aje.20220602.11

Haider Karar', Muhammad Amjad Bashir' Reem Atalla Alajini , Dina M. Metwally' Muneeba Haider, N. H. (2021). *Farmers knowledge, perception and management of mango mealy bug, Drosicha mangiferae C.reen (Hemiptera: Monophlebidae), on Mangifera indica in Pun.jab, Pakistan*. https://doi.org/10.1016/j.sjbs.2021.03.061

Haile, A., Megerssa, B., & Negash, R. (2020). *Enset (Ensete Ventricosoum) Value Chain in Dawuro Zone ,. 6*, 126–150.

Hara, A. H., Nino-Duponte, R. Y. and Jacobsen, C. M. (2001). *Root mealybugs of quarantine significance in Hawaii. Cooperative Extension Service, CTAHR, university of Hawaii, Manoa. 4 pp*.

Hara, A.H., Niino-DuPonte, R.Y., Jacobsen, C. M. (2001). *Root mealybugs of quarantine significance in Hawaii. In: Insect Pests (Cooperative Extension Service, College of Tropical Agriculture & Human Resources, University of Hawaii at Manoa) , 4 pp.*

Hincapié Ll, C. A., López P, G. E., & Torres Ch, R. (2008). Comparison and Characterization of Garlic (Allium sativum L.) Bulbs Extracts and Their Effect on Mortality and Repellency of Tetranychus urticae Koch (Acari: Tetranychidae). *Chilean Journal of Agricultural Research*, *68*(4), 317–327.

Jacobsen, K., Blomme, G., Tawle, K., Muzemil, S., & Yemataw, Z. (2018). (2018). *Dietary diversity associated with different enset [Ensete ventricosum (Welw.) Cheesman]-based production systems in Ethiopia. Fruits International Journal of Tropical and Subtropical Horticulture*. *73*(6), 356–364.

Jacobsen, Z., Bekele, A., Blomme, G., Muzemil, S., Tesfaye, K., & Jacobsen, K. (2018). *A review of enset [Ensete ventricosum (Welw .) Cheesman] diversity and its use in Ethiopia*. *73*(6), 301–309.

Jahn GC, B. J. and G.-H. H. (2003). *A review of the association of ants with mealy bug wilt disease of pineapple. Proceedings of the Hawaiian Entomological Society*. *36*, 9–28.

Jana, H. (2017). *Plant protection measures to control insect*. *12*(1). www.researchjournal.co.in

Karar, H., Amjad, M., Atalla, R., Metwally, D. M., & Haider, M. (2021a). *-Farmers knowledge perception mango mealybug Saudi Journal of Biological Sciences Farmers ' knowledge , perception and management of mango mealy bug , Drosicha mangiferae Green (Hemiptera : Monophlebidae), on Mangifera indica in Punjab , Pakistan. Saudi*. *28*(7), 3936–3942.

Karar, H., Amjad, M., Atalla, R., Metwally, D. M., & Haider, M. (2021b). *Farmers knowledge perception mango mealybug Saudi Journal of Biological Sciences Farmers ' knowledge , perception and management of mango mealy bug , Drosicha mangiferae Green (Hemiptera : Monophlebidae), on Mangifera indica in Punjab , Pakistan. Saudi* . *28*(7), 3936–3942.

Kefelegn, H., Tilahun, B., and Girma, F. (2014). *Indigenous Management of Enset Root Mealy bug (Cataenococcus ensete) Williams and Matile-Ferrero (Homoptera: Pseudococcidae) in Gedeo Zone, Ethiopia. International Journal of Life Sciences. 3*(4), 131–136.

Kudama, G., Tolera, T., & Gebeyehu, L. (2022). Good farm practices and improved processing technology of enset for sustainable hunger solution in Ethiopia. *Journal of Innovation and Entrepreneurship*. https://doi.org/10.1186/s13731-022-00210-x

Kusse, K., Ermias, G., & Darch, D. (2021). *Enset Production , Its Challenges and Controlling Methods in South Omo Zone , Southern Ethiopia*. *9*(3).

Lacey L.A., Frutos R., Kaya H.K., V. P. (2001). *Insect pathogens as biological control agents: do they have a future? Biological Control,*. *21*, 230–248.

MaguleT. Bizuayehu Tesfaye, Catellani, M. and E. P. M. (2014). (2014). *Indigenous knowledge, use and on-farm management of enset (Ensete ventricosum (Welw.) Cheesman) diversity in Wolaita, Southern Ethiopia. J. Ethnobiol. Ethnomed. 10:41*. https://doi.org/10.1186/1746-4269-10-41.

Majeed, Muhammad Zeeshan, Muhammad Irfan Nawaz2, Rashad Rasool Khan3, U. F. and C.-S. M. (2018). *Insecticidal effect of some plant extracts on citrus mealybug Planococcus citri (Risso) (Hemiptera: Pseudococcidae)*. *21*, 421–430. https://doi.org/10.1603/ice.2016.110728

Malsch AKF, Kaufman E, vHeckroth HP, Williams DJ, M. M. and U. M. (2001). *Continuous transfer of subterranean mealy bugs (Hemiptera: Pseudococcidae) by Pseudolasius spp. (Hymenoptera: Formicidae) during colony fission.Insects Soc*. *48*, 333-341.47.

Mamoon-ur-Rasheed, Bushra, S. 1, M. T. (2021). *Use And Impact of Insecticides IN*. *May*.

Mani, M., & Shivaraju, C. (2016). *Mealybugs and their Management in Agricultural and Horticultural crops*.

Mani, M., & Ummer, N. (2017). *Root mealybugs and their management in horticultural crops in India Root mealybugs and their management in horticultural crops in India*. *July*.

MANI1, M., & M. S. SMITHA and U. NAJITHA. (2016). *Root mealybugs and their management in horticultural crops in India Root mealybugs and their management in horticultural crops in India*. *22*(July), 103–113.

McKnight, C. (2013). *Integrated Management of Bacterial Wilt of Enset (Ensete ventricosum (Welw.) Cheesman) caused by Xanthomonas campestris pv. Musacearum in Ethiopia. Annual report 11/2012–10/2013, 73 pp.*

Meenakshi Sharmaa, Vikas Kumar Singhb, Deepti Chaturvedib, Anil Kumar Deltaa*, M. M. S. and P. K. (2023). *Insecticidal Effects of Datura Species against Major Agricultural Pests*. 1–22.

Megersa, H. G., Lemma, D. T., & Banjaw, D. T. (2022). *Integrated Pest Management System of Enset (Ensete ventricosum (Welw .) Cheesman) in Ethiopia : A Review*. *13*(9), 19–27. https://doi.org/10.7176/JNSR/13-9-03

Mekuria W, Ayalew A, C. A. (2016). *Assessment of bacterial wilt (Xanthomonas campestris pv. musacearum) of enset in Southern Ethiopia. Afr J Agric Res,*. *11*(19), 1724–1733.

Meriga, B., Mopuri, R., & MuraliKrishna, T. (2012). Insecticidal, antimicrobial and antioxidant activities of bulb extracts of Allium sativum. *Asian Pacific Journal of Tropical Medicine*, *5*(5), 391–395. https://doi.org/10.1016/S1995-7645(12)60065-0

Mesele, T., Dibaba, K., & Mendesil, E. (2019). *Farmers ' Perceptions of Mexican Bean Weevil , Zabrotes subfasciatus (Boheman), and Pest Management Practices in Southern Ethiopia*. *2019*.

Mikias Y, Yemataw Z, Muzemil S, Ayalew A, Negash F, Michael K, Bekele A, Chindi A, Gebre TF, M. D. (2011). *Registration of enset [Ensete ventricosum (Welw.) Cheesman] varieties Yanbule, Gewada, Endale, Kelisa, Zerita and Mesena. Ethiop J Agric Sci, 21,*. *21*, 147.

Miller DR, Miller GL, W. G. (2002). *Invasive species of mealy bugs (Hemiptera: Pseudococcidae) and their threat to U.S. agriculture. Proc Entomology Soc Wash*. *104*, 825–836.

Mohammed, B., G. Martin, and M. K. L. (2013). *"Nutritive values of the drought tolerant food and fodder crop enset," African Journal of Agricultural Research,*. *8*(20), 2326–2333.

Muthulingam, P. (2014). *Efficacy of some selected botanical extracts against the Cotton mealybug Phenacoccus solenopsis (Tinsley) (Hemiptera: Pseudococcidae)*. *March*.

Negash, A. (2001). *STELLINGEN belonging to the thesis Diversity and Conservation ofEnset (Ensete ventricosum Welw. Cheesman) and its Relation to Household Food and Livelihood Security in South-western Ethiopia*.

Negash, T., & , Tamirat Wato, Atinafu Mengesha, A. A. (2023). *Enset Bacterial Wilt (Xanthomonas campestris pv. Musacearum): Effects and Management Strategies Deployed in Ethiopia*. *5*(1), 104–110. https://doi.org/10.36959/394/632

Olango, T. M., Tesfaye, B., Pagnotta, M. A., Pè, M. E., & Catellani, M. (2015). *Development of SSR markers and genetic diversity analysis in enset (Ensete ventricosum (Welw.) Cheesman), an orphan food security crop from Southern Ethiopia. BMC Genetics.*

Pai, S. G. (2020). *Diversity of root mealy bugs of kerala*.

Pande, P.C.; Chauhan, J. (2011). *Screening of in vitro antifungal activity of plant extract of Datura stramonium, Solanum nigrum and Withania somnifera. J. Plant Dev*. *3*, 315–316.

Pundt L. (2003). *Managing mealybugs in the green house. Integrated Pest Management. The University of Connecticut*.

Quimio J. (1992). *Enset team support project Sidamo Gamo Gofa. Annual report of the plant pathologist: July 17,*.

Rajendra. (2020). *Role and mechanism of botanicals in pest management*. *1*(2).

Reddy, K., & Seetharama, H. G. (2020). *Efficacy studies of insecticides against root mealybug, planococcus lilacinus (homoptera : pseudococcidae) infesting coffee*. *10*(2), 96–98.

Refera, S., Mehare, A., & Aman, M. (2023). *Enset Product Market Chain Analysis : The Case of Wonchi District , South West Shoa Zone , Oromia National Regional State , Ethiopia*. *February 2023*.

Riyaz, S. M. and Kathiravan, K. (2019). *Integrated Pest Management Approaches. Geminiviruses,*. 219–235.

Sandford and kefale alemu, S. (1991). *Enset in north omo region*. *December*.

Senbeta, A. F., Sime, G., & Struik, P. (2022). Enset farming system – a resilient , climate-robust production system in South and South-Western Ethiopia Enset farming system – a resilient , climate-robust production system in South and South-Western. *Cogent Food & Agriculture*, *8*(1).

Shumbulo A, Gecho Y, T. M. (2012). *Diversity, Challenges and Potentials of Enset (Ensete ventricosum) Production : In Case of Offa Woreda, Wolaita Zone, Southern Ethiopia. Food Sci Qual Manage,*. *7*(1974), 24–32.

Sirany, T., Tadele, E., Hibistu, T., Kefalew, A., & Reta, H. (2022). *Economic Viability and*

Use Dynamics of the Enset Food System in Ethiopia : Its Implications for Food Security. 2022.

Smitha, M. S., Mathew, M. P., Thomas, J., Ushakumari, R., and Nair, S. 2005. (2005). *Root mealybug, Geococcus citrinus: A threat to banana cultivation in Kerala. Insect Environ*. *11*(3), 112–113.

Sreerag, R. S, Jayaprakas, C. A. and N. K. S., & Central. (2014). *Biology of the mealy bug , Rhizoecus amorphophalli infesting tubers of major aroids*. *6*(6), 80–89. https://doi.org/10.5897/JEN2014.0097

Tadesse, A. (2009). *Increasing Crop Production T hrough Improved Plant Protection Volume II*.

Tadesse, E., Azerefegne, F., Alemu, T., Addis, T., & Blomme, G. (2010). *Studies on the Efficacy of Some Selected Botanicals against Enset Root Mealybug (Cataenococcus ensete) Williams and Matile-Fererro (Homptera : Pseudococcidae)*.

Tadesse M, A. E. and G. E. (2003). *Enset-based farming systems of Masha woreda, Sheka zone. EARO Research report No. 51. Addis Ababa Ethiopia. 25 pp. 51*.

Tadesse Tilahun, Nigussie Dechassa2, Wondimu Bayu3, S. G. (2013). *Effects of Farmyard Manure and Inorganic Fertilizer Application on Soil Physico-Chemical Properties and Nutrient Balance in Rain-Fed Lowland Rice Ecosystem*. *2013*(February), 309–316.

Tafesse, K., Berhanu, T., Meseret, M., Fekede, G., Tolosa, S., Debebe, N., & Shewarega, M. (2021). *On-Farm Management , Processing and Post- Harvest Handling of the Indigenous Enset (Ensete ventricosum (Welw) Cheesman) in*. *31*(2), 73–85.

Tewodros M, Tesfaye W, . (2014). *Farmers indigenous knowledge and assessment of enset (Ensete ventricosum (Welw.) Cheesman] cultivars for major insect pests in Ojojia water shade KembataTembaro Zone , South Ethiopia. Sky J Agric Res,*. *3*(6), 112–119.

Thwaites R. (2000). *Diseases caused by bacteria. In: Diseases of Banana, Abacá and Enset. Oxon, GB: CAB International.* 213–239.

Totin, E. (2022). *Modelling potential range expansion of an underutilised food security crop in Sub-Saharan Africa Modelling potential range expansion of an underutilised food security crop in Sub-Saharan Africa*. *17*, 014022.

Tsedeke, A. (1988). *Insect and Mite Pests of Horticultural and Miscellaneous Plants in Ethiopia. Handbook Addis Ababa, Ethiopia.*

Tsehaye Y, K. F. (2006). *Diversity and cultural use of Enset (Enset ventricosum (Welw.) Cheesman) in Bonga in-situ conservation site, Ethiopia. Ethno bot Res Appl 4:147. .*

Tushemereirwe W, Kangire A, Ssekiwoko F, Offord L, Crozier J, Boa E, Rutherford M, S. J. (2004). *First report of Xanthomonas campestris pv. Musacearum on banana in Uganda.*

Plant Pathol,. 53(6), 802–802.

Walton V. M. (2000). *Mealy bug: Biology and control strategies. Wynboer. A technical guide for wine producers. 9pp*.

Williams D. J. and Matile-Ferrero D. (1999). *A new species of the mealybug genus Cataenococcus ferris from Ethiopia on Ensete ventricosum, a plant infected by a virus (Hemiptera: Pseudococcidae; Musaceae). Revue frncaise d'Entomologie (N.S.)*. *21*(4), 145–149.

Workneh, S., & Satheesh, N. (2019). *A review on nutritional profile of the food from enset: A staple diet for more than 25 per cent population in Ethiopia. Nutrition & Food Science*. *49*(5), 824–843.

Yamane, T. (1967). *Statistics: An Introductory Analysis. 2nd Edition. Harper and Row, New York,*. 919.

Yemataw, Z., Blomme, G., International, B., Muzemil, S., & Tesfaye, K. (2018). *A review of enset [Ensete ventricosum (Welw .) Cheesman] diversity and its use in Ethiopia*. *December*. https://doi.org/10.17660/th2018/73.6.1

Yemataw, Z., Borrell, J. S., Biswas, M. K., & White, O. (2020). *The Distribution of Enset Pests and Pathogens and a Genomic Survey of Enset Xanthomonas Wilt*. 1–38.

Yirgou D, B. J. (1968). *Bacterial wilt of Enset (Enset ventricosum) incited by Xanthomonas musacearum sp.n. Phytopathology,. 58*, 111–112.

Zerfu, A., Gebre, S. L., Berecha, G., & Getahun, K. (2018). Assessment of spatial distribution of enset plant diversity and enset bacteria wilt using geostatistical techniques in Yem special district ,. *Environmental Systems Research*. https://doi.org/10.1186/s40068-018-0126-9.

7. APPENDIXES

Appendix A

Questioners to be completed by Farmer House hold heads for survey and FGD study area

College of Agriculture and veterinary medicine

Department of plant science and Horticulture

Dear respondent:

My Name is Ermias Elias; I came from Jimma University for fulfillment of master's degree in Agricultural entomology.

The research questionnaires was to collect the research data from households for the objective of MSc thesis work on Distribution and management practice of enset root mealybug in your area. I would like to assure you that, the information that you are giving have great role for this study Therefore, you are kindly requested to give genuine information.

Name of District________________ Peasant Association_______________________

Altitude_____________________________Rainfall____________________________

Longitude__________________________ Latitude__________________________

Average__________daily__________Temperature————————Relative humidity_________________________

Totally, Enset producing farmers number in PAs ———— Male——Female———

A. Back ground information about the respondent

1. Gender of respondent. A, Male B, Female
2. Ages of respondent A, 20-30 B, 31-40 C, 41-50 D >50
3. Education levels , A, Illiterate B , Primary C, Secondary D , Diploma and above
4. Marital status of respondents A, single B, married C, Windowed
5. Respondent house hold size number. A, 1-4 B, 5-8 C, 9-12 D, above 12

B .Questionnaires related to agronomic practices of Enset plant

1. Enset sucker Transplanting from nursery to main field A, 1 year B, 2 year C, 3 year
2. The frequency of Enset weeding per year A, 2 times B. 3 times, C, 4 times
3. When you harvest enset plant /Maturity year for harvest

   A, 2-5 year B, 6-7 year C, > 8 year

4. Year of mother plant for corm multiplication

A, 2-4 years B, 3-5year C, above 5 year

5. Enset Corn planting month per year

   A, September B, October C, November D, December

6. Enset sucker planting month per year

   A, March B, April C, May

7. What is the purpose of enset production for you? A, Consumption A, Sell C, Both
8. Source of enset sucker for planting

   A, self/own sucker B, neighbors farmer/ buying C, from both

9. What are the main constraints of Enset plant in your enset farm?

   A, Bacterial wilt B, Enset root mealybug C, Mole rate and porcupine

   D, Soil infertility E**,** Smallest use of agricultural practices F, Climate change

D. questionaries' related to enset root mealybug

1. The means of spreading of Enset root mealybug

   A, infected seedling and corm B, un cleaned enset planting equipment

   C, During Cultivation & Transplanting time

   D, Inappropriately planting space b/n enset plant E, Farm Laborers F, other

2. Damage symptom of enset root mealybug on enset plant

A, Weaken and lacked strength B, Slowed growth C, reduced yield of corm

D, Observed during transplanting & harvesting time E, Unable to stand in position

F, Low root number G Never seen

3. Farmer's management practices to control enset root mealybug your kebele

A. Cultural control methods**.** B. Local tolerance Variety selection

C, Quarantining D. Can't use any management Practices

4. Do you know enset root mealybug? A, yes, B, No

5. Do you identify these enset root mealybug? A, yes, B, No

6. Farmers' knowledge level on enset root mealybug A, High B, Medium C, Low

7. Do you have enset root mealybug problem in your enset farm? A, yes B, no

8. Problem Levels of enset root mealybug in your enset field.

A, high B, Moderate C, minor

9. More damaging year of the enset root mealybug after Enset planting?

A, Seedling stage B, 2 year C, 3 year D, year E, 4 year F, above 5 year

10. When the enset root mealybug first seen in on enset plant?

A, transplanting B, harvesting

11. Other enset plant pests you may know that damage your enset plant

A, Animals B, mole rat C, other

12. In your view which plant parts is more attack by enset root mealy root

A, corm B, stem C, root

13. How does the enset root mealybug affect you?

A, Loss of income from sell of estimated amount of enset in Birr

B, Shortage of enset for home consumptions

C, Shortage of sucker for planting D, All

14. Have you received any training about enset root mealybug management practice?

A, Yes B, No if yes, what type of control practices that have you used?

A, Chemical insecticides B, Cultural practices

14. In which year after planting of enset, the enset root mealybug attacks the enset corm and root? A, 1 year B, 2 year C, 3 year D, 4, Year.

Interview questions for District agricultural experts

District Name ———————

1. Name of respondent —————————— position ———————————?

2. Can you tell me the current enset coverage in your district level (in hectare) ——————?

3. What are the factors that hinder the sustainability of enset plant productivity in the district list them ——————————————————————————?

4. What are the enset plant damaging pests in the district ——————————————? List them ——————————————————————————————?

5. Do you know enset root mealybug? Yes No

6. Which part of enset root mealybug damages the enset plant ————————————?

7. What are the management methods of enset root mealy ————————————?

8. The enset root mealybug reduces the product and productivity on enset plant by percentage A, 1-30% B, 31-50% C, 51- 75% D, 100%

9. What are the dispersal methods of root mealybug ——————————————?

10. Traditionally Management practices of the root mealy ——————————————?

11. How can agricultural experts overcome those constraints/challenges of pets in enset the district?———————————————————?

12. is there Strengthening extension program about the distribution and management practices of enset Root mealybug—————————— ——————————————?

13. Do you think that substantial research and development activities carried out on enset plant pest ——————————————?

14. How many identified enset variety in the district ——————————————?

15. Which variety is more susceptible to enset root mealybug——————————————?

16. Which variety is resistance these root mealybug ——————————————?

<u>Interview questions for kebele agricultural experts(DA)</u>

District ———————— Kebele————————————

1. Name of respondent ——————————— position ———————

2. Enset producing farmers in kebele Male ——Female——Total———

4. What are the constraints of enset cultivation still now at farmers in your kebele —————?

List some of them you know ——————————————————————————?

5. The main damage enset pest in your kebele —————————————————————?

6. Do you know enset root mealybug insect pest? A, Yes —— B, No——

7. Does the farmer know root mealybug insect pest? A, yes —— B No ——

8. Which part of root mealybug damages the enset plant? A, corm B, root

9. What are the spreading methods of root mealybug from one enset to other ———————?

10. What are the Management practices of the enset root mealybug?

A, cultural, B, chemical. Among these, which methods are essential for managements?

11. The enset root mealybug reduces the product and productivity of enset plant

A, 1-30% B, 31-50% C, 51-75% D, 100%

12. How can you overcome those constraints/challenges of these root mealybug in enset plant in Kebele of farmers' field ————————————————————————?

13. Do you think that substantial research and development activities carried out on enset pest in Kebele level ——————— ———————————————————————?

14. How can household heads overcome those constraints/challenges of root mealy of enset in their farms ——————————————————?

Guide questions for focus Group Discussion

1. What are the main challenges of enset production and productivity————?
2. Discuss the distribution of enset root mealybug and the main attacking parts in enset plant——————————————————?
3. Deliberate the main Prevention means of the root mealybug ——————————?
4. How many variety of enset grow in your field do you know ——————————?
5. Name them you know —————————————————————————————?
6. Which local variety does more susceptible to enset root mealybug ————————?
7. Which local varieties of enset are resistant to enset root mealybug————————?
8. Mention the damage symptom of enset plant when attacked by enset root mealybug through visually on above ground parts ——————————————————?
9. What are the dispersal methods of enset root mealybug——————————?
10. Discuss the management Practices of enset root mealybug seasons ————————?
11. Describe the cultural management practice of these pests to sustain enset plant production——————————————————?
12. Is there Strengthening extension program about the distribution and management practices of mealybug in the kebele ——————————————?
13. What should be done for sustain the enset cultivation and management practice from the pest? /list and order ————————————————————————?

***Thank you**, for your cooperation to respond to these questions*

Appendix figure 1. Household interviews in study area

Appendix table 1. Local name and ages of infested enset plant in study area.

PAs	Mari Manisa district infested Local variety name of enset	Ages of infested enset
	Agina	3
	Erantiya	4
	Argama	4
	Kekeriya	3
	Tuzuma	5
	Locingiya	2
	Bozaa	3
Daka	Budntsa	2
Ocha	Hoindya	3
	Shododinya	2
	Bozaa	4
	Buduntsuwa	5
	Bozaa	4
	Quruwa	3
	Argama	3
Deshi	Hoindiya	4
	kuruwa	3
	Shododinya	3
	shedhiya	2
	Kuruwaa	4
	Bozaa	3
	Ziraa	4
	Locingiya	2
	Geenaa	5
	Shododinya	3

Appendix table 2. The main effect of the enset root mealy bug on enset production in the study area

Variable	Assessed districts			Mean	X^2	P- value
	Mareka	Mari Manisa	Tocha		4.63	0.32
Loss of income sell of enset from expected amount in Birr	13.7	23.5	21.5	19.6		
Shortage of enset for home consumptions	64.7	55	53	57.6		
Shortage of enset sucker for planting	21.6	21.5	25.5	22.8		

PAs	Tocha district infested Local name of enset	Ages of infested enset
Gebira	Buk'uniya	3
	Elotiya	4
	Arkiya	3
	k'arttiya	2
Gani	Aamiya	4
	Shododinya	3
	Hoindiya	4
	Shasha	2
	Muassuwa	4
	Kuruwa	3
Botor	Bangabaala	4
	Barijjiya	2
	Arkiya	4
	Argamaa	5
	shamara	4

PAs	Mareka district Local name infested of enset	Ages of infested enset
Maydi	Hoindiya	2
	Argamma	3
	Shododdinya	4
	Maziya	5
	Bozaa	3
	Sheddiya	4
Gozo	Shododinya	3
	Booza	2
	Aamiya	4
	yak'aa	4
	Elotiya	3
	Geena	4
	Arikiya	3
	Argama	5
	Bozaa	3
Eyesus	Hoindiya	2
	Shedhiya	4
	Bozaa	3
	Yaqaa	5
	Elotiya	3

Appendix figure 2.Adult enset root mealy bug

Appendix figure 3 .The infestation of *C. ensete* on root and corms on young enset plant parts

Source, own survey assessment, 20204.

Appendix figure 4. Collected botanical parts

Diazinon 60% EC

Appendix figure 5. Botanical extraction and preparation

Appendix table 3. Factorial analysis of variance ANOVA regarding mortality of 2nd instar nymphs due to different botanical extract and concentrations for 24hr

Source	DF	SS	MS	F	P-value
Botanical	5	294.44	58.89	3.53	0.001
Concentration	3	6227.78	2075.93	124.56	0.000
Time	2	19.44	9.72	0.46	0.033
Botanical ×Conce× Time	30	272.22	18.15	1.09	0.010
Error	72	800.00	16.67		
Total	112	7613.88			
CV			26.72		

Appendix table 4 . Factorial analysis of variance ANOVA regarding mortality of 2nd instar nymphs due to different botanical extract and concentrations for 48hr

Source	DF	SS	MS	F	P-value
Botanical	5	1373.6	274.7	9.42	0.001
Concentration	3	333101.2	11034.7	378.33	0.000
Time	2	452.8	226.4	4.94	0.0103
Botanical ×Conc ×time	30	654.2	43.6	1.50	0.014
Error	72	1400.0	29.2		
Total	112	336981.8			
CV			15.01		

Appendix table 5 . Factorial analysis of variance ANOVA regarding mortality of 2nd instar nymphs due to different botanical extract and concentrations for 72hr

Source	DF	SS	MS	F	P-value
Botanical	5	22027.8	405.6	8.11	0.001
Concentration	3	89722.2	29907.4	598.15	0.000
Time	2	752.8	376.4	5.33	0.0074
Botanical ×Conc ×time	30	827	55.2	1.10	0.013
Error	72	2400.0	50.0	50	
Total	112	115729.8			
CV			11.90		

Appendix table 6 . Means mortality of second instar nymphs of *P.ensete* at different botanicals and concentration during preliminary observation.

Treatment	Concentration	Percentage (%) mortality hr *P. ensete* after treatment		
		24hr	**48hr**	**72hr**
Allium sativum	2%	6.66 ±3.33^{a}	40.0±0.00^{bcd}	70.0±5.77^{cd}
	5%	20.0±0.00^{ab}	46.6±3.33^{abc}	73.33±6.66^{cd}
	8%	20.0±0.00^{ab}	50.0±0.00^{abc}	80.0±0.00^{abcd}
	10%	26.66±3.33^{ab}	53.3±3.33^{abc}	90.0±0.00^{bac}
	12%	26.6±6.66^{ab}	50.0±0.00^{abc}	93.3±3.33^{bac}
	15%	30.0±0.00^{c}	60.0±0.00^{b}	100.0±0.00^{a}
Eucalyptus globulus	2%	10.0±0.00^{bc}	50.0±0.00^{abc}	60.0±0.00^{dc}
	5%	16.6±3.33^{abc}	43.3±6.66^{bcd}	70.0±00.00^{cd}
	8%	20.0±0.00^{ab}	50.0±0.00^{abc}	76.66±3.33^{cd}
	10%	23.3±3.33^{ab}	50.00±0.00^{abc}	80.0±0.00^{abcd}
	12%	20.0±0.00^{ab}	50.0±0.00^{abc}	83.3±3.33^{abcd}
	15%	23.4±3.33^{ab}	66.6±3.33^{ab}	90.0±0.00^{bac}
Zingiber officinale	2%	10.0±0.00^{bc}	30.0±0.00^{cd}	66.6±3.33^{ab}
	5%	16.6± 3.33^{abc}	50.0±0.00^{abc}	60.0±0.00^{dc}
	8%	16.66±3.33^{ab}	50.0±0.00^{abc}	73.33±6.66^{cd}
	10%	20.0 ±0.00^{ab}	53.3±3.32^{abc}	80.0±0.00^{abcd}
	12%	20.0±0.00^{ab}	56.67±3.33^{abc}	83.4±3.33^{abcd}
	15%	26.6±5.77^{ab}	60.0±0.00^{a}	93.3±3.33^{bac}
Datura strontium	2%	3.33±3.33^{a}	40.0±0.00^{cd}	70.0±0.00^{cd}
	5%	10.00±0.00^{bc}	40.0±5.77^{cd}	70.0±0.00^{cd}
	8%	16.77±3.33^{abc}	40.0±0.00^{cd}	70.0±0.00^{cd}
	10%	20.00±0.00^{ab}	50.0±0.00^{abc}	73.3±3.33^{cd}
	12%	20.00±0.00^{ab}	53.34±3.33^{abc}	80.0±0.00^{abcd}
	15%	23.3±3.3^{ab}	56.66±3.33^{abc}	90.0±0.00^{bac}
Piper betle	2%	3.3±3.33^{a}	10.0±0.00^{ab}	90.0±0.00^{bac}
	5%	3.33± 3.33^{a}	20.0±0.00^{ab}	40.0±0.00^{d}
	8%	6.67±3.33^{a}	20.0±0.00^{ab}	50.0±0.00^{dca}
	10%	13.33^{bc}	36.6±3.33^{cd}	60.0±0.00^{dc}
	12%	16.0±3.33^{ab}	40.0±0.00^{cd}	66.6.±3.33^{ab}
	15%	20.0 ±0.00^{ab}	46.6±3.33^{cd}	70.0±0.00^{cd}
Moringa oleifera	2%	10.0±0.00^{bc}	30.0±0.00^{cd}	50.0±0.00^{ca}
	5%	16.7±3.33^{abc}	40.0±0.00^{cd}	66.6±8.88^{ab}
	8%	16.6± 6.66^{abc}	50.0±0.00^{abc}	70.0±0.00^{cd}
	10%	20.00± 0.00^{ab}	56.6±3.33^{abc}	83.3±3.33^{abcd}
	12%	20.00±0.00^{ab}	60.0±0.00^{b}	90.0±0.00^{bac}
	15%	20.0±0.00^{ab}	50.0±0.00^{abc}	93.3±3.33^{bac}
Control		0^{e}	0^{e}	0^{e}
CV		18.10	13.61	10.79
P - value		<.0001	<.0001	<.0001

Note = CV; Coefficient of variance. Means within the same column with the same letter are not significantly different according to Turkey's (HSD) test at P>0.05.