



**ASSESSMENT OF MANGO YIELD LOSS AND FRUIT FLY (DIPTERA,  
TEPHRITIDAE) MANAGEMENT PRACTICES OF MANGO PRODUCING  
FARMERS IN ARBAMINCH ZURIA WOREDA, ETHIOPIA**

**MSc. THESIS**

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**HAWASSA UNIVERSITY**

**HAWASSA, ETHIOPIA**

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**A THESIS SUBMITTED TO THE DEPARTMENT OF PLANT AND  
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## STATEMENT OF AUTHOR

I hereby declare that this MSc. thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

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## **BIOGRAPHICAL SKETCH**

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## **LIST OF ABBREVIATIONS AND ACRONYMS**

ANOVA	Analysis of Variance
CSA	Central statistics agency of Ethiopia
FAO	Food and Agricultural Organization
FAOSTAT	Food and Agriculture Organization of the united nations Corporate Statistical Database
FTD	Flies per Trap per Day
HSD	Honest Significant Difference
Icipie	International Center of Insect Physiology and Ecology
IPM	Integrated Pest Management
MAT	Male Annihilation Technique
Mt	Million Tones
SD	Standard Deviation
SE	Standard Error
SNNPR	Southern Nations, Nationalities, and People's Region
SNV	Sanitary Napkin Vendor
SPSS	Statistical Package for the Social Science

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**Assessment of mango yield loss and fruit fly (Diptera, Tephritidae) management practices of mango producing farmers in Arbaminch Zuria woreda, Ethiopia**

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**ABSTRACT**

*Mango (Mangifera indica L.) is a valuable food and cash crop that contributes to agricultural development agents. This study was conducted to assess mango fruit yield loss due to fruit flies (Diptera, Tephritidae) and management approaches by farmers in Arbaminch, Zuria Woreda. Three administrative kebeles, viz., "Chano mile," "Lante," and "Kolla shele," were purposively selected from the Arbaminch Zuria Woreda. Both survey and assessments were collected. Sixty respondents were interviewed using semi-structured questionnaires. Mango variety, mango pests and their economic importance, abundance, infestation, yield loss estimation, management practices applied for fruit flies and farmers' willingness to pay for the best management options were assessed. The results were analyzed using SPSS software and presented using descriptive statistics; and the variables were tested by chi-square test. Farmers in Arbaminch Zuria produced five types of mango varieties, with local mango varieties being the most common. All the respondent farmers (100%) had the local mango variety. Common mango fruit pests like fruit flies, white mango scales, mealybug, grivet monkeys, speckled birds, and weaver ants as an indirect pest which may interfere with natural enemies were recognized. The fruit fly species *Bactrocera invadens* was trapped in the field with the abundance of 43 flies per trap per day (FTD). Fruit flies caused  $94.28 \pm 10.21$  Kg and 29.84% of loss in fruit yield per tree. The mean monetary loss value was estimated to  $471,412.3 \pm 51010.9$  birr/ha/year. The highest infestation was recorded in the peak harvest time (February) which was 40.78%. To overcome the fruit fly damage, mango producers applied different management methods. Of these methods, Methyl Eugenol trapping, field sanitation, burying infested fruits, and smoking the field were the most common. It was concluded that mango fruit flies are the most economically important insect pests of mango in the Arbaminch Zuria Woreda. The study recommends the evaluation and release of less susceptible mango varieties to fruit fly infestation, white mango scale, and other pests and diseases, evaluate the farmers' practices. And new methods of management to develop a holistic integrated pest management system.*

**Keywords:** *Mango, infestation, fruit fly, yield loss, yield estimation, management, pest.*

# 1 INTRODUCTION

## 1.1 Background and Justification

Mango (*Mangifera indica* L.) is one of the most important and widely cultivated fruits of the tropical world. The mango tree is considered indigenous to southern Asia, especially Myanmar and Assam state of India, and numerous cultivars have been developed (Yadav and Singh, 2017). The trees grow to 40m in height, with a crown radius of 10–15m and the trees are long-lived, some specimens fruit after 300 years (Asif et al., 2002; Sennhenn et al., 2014). Mango is one of the 73 genera of the family *Anacardiaceae* and order *Sapindales*. It belongs to the genus *Mangifera* and there are at least 62 species within the genus and 15 of these bear edible fruits (Ahmed and Mohamed, 2015). This fruit tree has noticeable differences in size, shape, appearance and physiological characteristics depending on the variety of mango species. The mango fruit is a fleshy drupe, containing skin (epicarp) and edible flesh (mesocarp) surrounding a fibrous, hard stone (endocarp) containing a single seed (Sennhenn et al., 2014).

Mango fruit is ordered as a key food and cash crop and plays an important role in agricultural development. The crop is a highly prized exotic fruit on the European market and one of the important fruit crops grown in tropical and sub-Saharan Africa (Lux et al., 2003). Mango is native to south Asian countries more likely in the Burma-Malaysia region from where it was distributed worldwide and becomes one of the most cultivated fruit crops in the tropical and subtropical world (Yadav and Singh, 2017). Mango is widely consumed as fresh fruit and the ripe fruit is eaten for dessert, or used for making juices, jams and other preserves (Hussen and Yimer, 2013). Apart from its nutritional benefits, mango has also an economic advantage for the rural smallholder farmers and traders as a source of income generation, sources of employment and food security, which is considered a king of fruits (Asif et al., 2002; Fita, 2014).

Mango is one of the most widely cultivated and globally traded tropical and subtropical fruit trees in the world. A total of 1,337,049.26 quintals<sup>1</sup> of mango was produced in the 2018/19 production season with a productivity level of 68.57 quintals per ha (CSA, 2019). Among the regions of Ethiopia, Harari, west and east Oromia, Southern Nations, Nationalities, and People's Region (SNNPR) and Amhara are the main mangoes producing regions (Banjaw, 2017). South Nation Nationality Peoples' Region (SNNPR) is famous for its mango production with its 47% share of total production in the country (CSA, 2020).

Mango production and productivity have been influenced by various biotic and abiotic factors. The diseases and insect pests are biotic stresses which could bring problems by suffering the fruit trees and can cause fruit rot, tree dieback, anthracnose attack, malformation of the fruit, necrosis of the leaf, spots on fruit and leaf, and mildew attack on the inflorescence (Fita, 2014; Melese, 2019). Fruit flies that infest mango fruit are the most important and widespread pest, followed by scale insects, mealy bugs, thrips, mites and stem borers in India (Ansari., et al 2019). Mango is considered the primary host of *Bactrocera invadens* (Cohen, 2007; Mwatawala et al., 2009). Climate change and the increase in the international crop trade and ornamental plants have promoted the emergence, introduction and establishment of some of these pests. Among them, the white mango scale, and fruit fly are currently considered two of the most damaging pests of mango groves worldwide, in tropical and subtropical regions, where their control is difficult and causes important economic losses.

Mango post-harvest losses, both in quantity and quality happen at many stages throughout the handling chain. Premature color changes and weight loss are the other nature of losses. Fruit flies are economically important because many representatives of this family attack and severely damage important fruit crops, especially mangos, in tropical regions. *Bactrocera invadens* has

become the most important fruit fly species attacking mango since its first detection in the African continent and without control, the loss will range from 30% to 100% depending on the fruit maturity stage, variety, location and the season (Ekési et al., 2006; Mwatawala et al., 2009). Therefore, this study was initiated to assess on the improvement of mango yield in Southern Ethiopia with better understanding of farmers' production practices, economic losses, and pest management practices. Attempt to evaluate the major ideas regarding knowledge and management practices exercised by the mango producers. Other aspects such as fruit fly abundance, mango varieties under production, fruit flies infestation level and yield loss due to fruit flies.

## **1.2 Statement of the Problem**

Mango is the second potential fruit crop produced in Ethiopia next to banana (CSA 2022). Mango is widely consumed as fresh fruit, eaten for dessert, or processed juicy products (Hussen and Yimer, 2013). Mango has also an economic benefit for rural smallholder growers and traders as a source of income generation, sources of employment and food security (Asif et al., 2002; Fita, 2014). The production and marketing of mango are affected by a variety of factors, of which pests and diseases are regarded to be the major constraints. Among the insect pests, fruit flies are known to be the most disreputable (Chay et al., 2019; Hagos et al., 2020). Fruit flies are ranked first on the list of the top mango pests by mango farmers (Isabirye et al., 2015; Tewodros et al., 2019). The biological nature of fruit flies; wide distribution, fast proliferation, high populations, polyphagous nature and the difficulty to control those using insecticides cause high yield losses in fruit and vegetable crops (Abdullahi et al., 2011).

The reduction of the quality and quantity of marketable mango fruit due to fruit fly infestation impacts farmers negatively through yield losses (Wangithi et al., 2021). However, in Ethiopia

little is known about the degree and yield value of losses incurred at the farm level as a result of fruit fly infestation (Tewodros et al., 2019). This is because empirical evidence on yield estimates has not yet to be gathered. A few studies were conducted on the infestation and economic importance of fruit flies. The government of Ethiopia has recently introduced improved mango varieties (CSA 2022). However, most of the studies focused on the processes and limitations (lack of appropriate postharvest handling, transportation constraints, lack of appropriate management practices, and lack of resistant variety) of mango production and productivity in Ethiopia. In addition, it is important to study the losses sustained by the existing mango and their resistance to pests and diseases.

Minimal studies have been conducted on the infestation and economic importance of fruit flies to mango fruit in Ethiopia. In Arbaminch Zuria woreda, there were no studies conducted on yield loss assessment at the field and the post-harvest level at once, and this study was designed to have a better understanding of fruit flies infestation level on mango yield loss caused by fruit flies and farmers' management practices practiced and need to be practiced in the Zuria woreda.

### **1.3 Objectives**

#### **1.3.1 General objective**

To improve the yield of mango in Southern Ethiopia with better understanding of farmers' production practices, assessment of economic losses, and pest management.

#### **1.3.2 Specific objectives**

- ✓ To assess the farmers' knowledge of mango production, mango pests and the management practices due to fruit flies
- ✓ To determine the extent of fruit fly infestation and loss of mango in Arbaminch area
- ✓ To evaluate the willingness of farmers to pay for fruit fly management

#### **1.4 Hypotheses**

- i. There are many pests with different status infesting mango in Arbaminch area
- ii. There are significant differences in fruit fly infestations related to harvesting time in the study area
- iii. Infestations of fruit flies on mango cause high mango fruit and economic loss
- iv. Farmers already have general knowledge of IPM management practices of fruit flies on mango fruit.
- v. Farmers are receptive and pay for the management methods to combat fruit flies

#### **1.5 Scope and Limitation of the Study**

This study was based on the farmers' knowledge of yield loss of mango due to fruit flies and pest management options practiced at Arbaminch Zuria Woreda, where mango is widely produced. This study was focused on mango varieties, infestation, yield loss, and farmers' management activities at Arbaminch Zuria woreda. Since it is educational research with limited resources and time, the research did not assess the details of other sites on the farmers' knowledge, yield loss of mango due to fruit fly and pest management options used.

## 2 LITERATURE REVIEW

### 2.1 Mango Production Status in Ethiopia

Mango (*Mangifera indica* L.) is a widely produced and addressed fruit and is referred to as the "King of Fruits" due to its broad adaptability, excellent taste, unique flavor, exceptional nutritious content, many varieties, attractive color and appearance, and extensive popularity. Mango is a fleshy stone fruit, consisting of numerous tropical fruiting trees in the flowering plant family of *Anacardiaceae* (Luo et al., 2021). Mango is a perennial tree which can live more than fifty years and it is also the leading fruit produced in most parts of eastern and southwestern Ethiopia both in area coverage and quantities produced.

Mango ranked 2<sup>nd</sup> and 3<sup>rd</sup> in total production and area coverage among fruit crops grown in Ethiopia respectively (Tewodros et al., 2019). From 2003/4 to 2013/14, both its area coverage and total production increased by 208.4% and 247%, respectively. The average proportion of mango production of household characteristics by mango market outlets accessed by the local collector, wholesaler, retailer and consumer market outlet was 32, 41, 22 and 26 quintals of mango per hectare was accessed, respectively (Ermias D. 2021). According to CSA (2019), annual mango production in Ethiopia is 133,704.93 tons with a land coverage of 19,497.92 ha and its production is 6.86 tons/ha which accounts for 0.18% of the world production (FAOSTAT 2020). Likewise, CSA (2020/21) report indicates the total area coverage under mango production in Ethiopia is around 23,818.6 hectares (20,783.1 ha by private peasant holdings and 3,035.5ha by large and medium-scale commercial farms). In the same year, the average productivity of mango was 7.3 t/ha and 8.9 t/ha in the respective order.

According to FAOSTAT (2010), the total cultivated area for mango in Ethiopia is not more than 12,000 hectares. The highest annual production estimate in five years is 180,000 Mt and more

area coverage is expected in the southwestern and other parts of the country due to more conducive climatic and edaphic factors. According to Honja (2014), even if the farmer's livelihood is highly supplemented by the income from their mango trees, there is a declining trend in the yield and quality of mango due to old age, poor management and the seedling-originated nature of the trees. However, there are exceptionally good-yielding trees with the best quality fruits. Apart from its economic importance, it is forest and environmentally friendly to fight against drought, and use as shade and firewood. CSA (2013) showed as mango is one of the second potential fruit crops produced in Ethiopia next to banana which is the first fruit crop produced in large quantity.

The mango industry in Ethiopia is in its infant stage. Even though the large potential for fruit production in the country, their contribution to the total output has been extremely low (Chay et al., 2019; Hagos et al., 2020; Tewodros et al., 2019). The national research system has developed several varieties but is not widely spread. Experiences from other countries in growing this crop, therefore, contribute to the success and widespread of this fruit. There are also ample garden mango trees in different parts of the country at farmer's holdings. The livelihood of most of these farmers is highly supplemented by the sale of mango fruits. The area coverage under mango in eastern Ethiopia has reached about 35% of the total acreage allotted for fruit production (Chay et al., 2019). The reasons include lack of market-oriented production which is too traditional; excessive margin mainly due to inefficient and costly transport; absence of fruit market information; and absence of market regulations and legislations and its marketing activity is principally attributed to poor actors' skill.

## 2.2 Common Varieties of Mango

Several main mango cultivars are used in the commercial production of fruit. These cultivars are described as either poly embryonic or mono embryonic. Poly embryonic varieties can be grown from seed and produce trees that are true to type. Mono embryonic cultivars contain one embryo that has genes from both parents and produces a hybrid tree (mix of both parents), and therefore, must be reproduced vegetatively by grafting onto a root stock (Abou-Ellail et al., 2014). Rymbai et al, (2014) stated that thousands of mango genetic varieties are grown all over the world; the greatest numbers are in India. The commercial industries of the world rely on a handful of improved varieties supplemented with local varieties that are less suited to the export trade. The following are some of the mango varieties.

**“Apple”:** This variety originated from the Kenya coastline, most probably around the Malinda area. It is a chance seedling and its parentage is unknown ( Upadhyay et al., 2013). The fruits are medium to large, nearly round in shape and have a rich yellow/orange to red color the skin is smooth and thin, and the juicy yellow flesh has excellent flavor.

**“Kent”:** This variety originated from Florida and USA, The fruits are large & ovate with greenish-yellow skin, red or crimson blush shoulders and a rounded base shape The skin is thick and tough with small numerous yellow lenticels; the flesh is juicy, melting, deep yellow, fibreless and of a rich flavor melting texture virtually free from fibre ( Upadhyay et al., 2013).

**“Tommy Atkins”:** The fruits are medium to large, oval to oblong longer than broad, orange/yellow with a heavy red blush, numerous white lenticels and broadly rounded. Base Resistant to anthracnose and powdery mildew the smooth skin is tough and thick (Upadhyay et al., 2013).

**“Ngowe”:** The fruits are large, slender, and oblong longer than broad with a very prominent hook-like beak at the apex the deep yellow flesh is of excellent quality, virtually fibreless, melting, and carries no turpentine taste ( Upadhyay et al., 2013).

Table 1. Mango varieties and their unique characteristics

Mango variety	Characteristics of each variety						
	Origin	Shape	Size	Skin color	Av. Length by width	Av. Weight	Advantages
<b>Apple</b>	Kenya coastline	nearly round	medium to large	smooth and thin	9.7cm X 11cm	397g medium/large	An early cultivar of excellent fruit quality
<b>Kent</b>	Florida & USA	rounded base	large & ovate	greenish-yellow	12.4cm X 9.7 cm	545g (Large)	late maturing, fibreless and of excellent internal quality
<b>Tommy Atkins</b>	Florida & USA	oval to oblong longer than broad,	medium to large	orange/yellow with a heavy red blush	12.6cm X 9.9cm	522 g (Large)	excellent shipping and shelf-life qualities,
<b>Ngowe</b>	Kenya	oblong longer than broad	Large	deep yellow flesh	14cm X 9.5cm	523 g (Large)	Good to excellent fruit quality, Excellent for processing
<b>Keitt</b>	S. Florida	ovate & plumb, rounded base	Large	Green to yellowish	11.7 cm X 9.2 cm	456g (Large).	Late maturity, good marketing qualities and productivity
<b>Van Dyke</b>	S. Florida	Ovate	Large	bright yellow ground	10.5 cm by 7.9 cm	280g (Small/Medium)	Good resistance to Anthracnose and Powdery Mildew, regular bearer
<b>Sensation</b>	S. Florida	Oval/oblique		deep yellow	10.8 cm by 7.8 cm	307g (Medium)	The beautifully colored late cultivar, none to scanty fibres, heavy yielder
<b>Sabine</b>	Kenya	Elongated		bright yellow	14.2 cm by 6.6 cm	435g (Medium/large)	Only slightly affected by Anthracnose
<b>Haden</b>	Florida, United States			Bright yellow with deep red blush	10 cm by 8 cm	431g (Medium/large)	Excellent fruit quality, good shipper
<b>Maya</b>	India	Ovate and plumb		yellow color with a reddish blush	10.3 cm by 7.8 cm	295g (Medium).	good to excellent eating quality

Source: (<https://www.jica.go.jp/project/english/kenya/015/materials/c8h0vm0000f7o8cj-att/materials12.pdf>)

### **2.3 Constraints of Mango Production**

Production constraints are factors that restrict farmers' potential to acquire their work goal as greatly viable (Begna, 2020). Following development strategies, overcoming those constraints is dependent on the right expertise on the issues and the results of those constraints on agricultural output. Certain mango managerial skills and technical knowledge are required to bring together the various elements of production and coordinate them from year to year to achieve economic results (Dessalegn et al., 2014).

Mangos grown under different agro-climatic conditions are exposed to various biotic and abiotic stresses that limit mango production and productivity, affecting the economic situation of mango farmers.

The major constraints in mango production in Ethiopia are both biotic and abiotic situations. The unavailability of affordable agricultural inputs, improved varieties, marketing of fruits and low agriculture extension services were the major blocks to the mango growers in Ethiopia (Dessalegn et al., 2014; Tewodros et al. 2019). Yigezu (2021), also states the major issue restraining the development of the mango industry in Ethiopia was a lack of organization or cooperation among mango growers. Due to the highly seasonal nature of the mango crop, and also the tendency to prioritize food security with grain crops, mango growing is not the main income activity for most farmers, and is generally considered a complementary activity to other farming methods (Ssemwanga et al., 2008). Honja (2014) stated that irrigation water scarcity, pest and disease and technology limitations are the major factors influencing the production of mango in Ethiopia.

According to James et al, (2008) the key challenges to developing a fruit processing sector in

Ethiopia lack technical knowledge in processing, a low level of technical maintenance support, and a low capital base from which to invest many low-priced mango juice imports. The major Constraints of mango production in Ethiopia include a lack of knowledge; skill and facility limitations in production, harvesting and post-harvest handling; Limited mango varieties, and limited capacity in extension services to promote improved and marketable mango varieties introduction; Prevalence of mango fruit diseases and pests (Fita, 2014; Hagos et al., 2020; Tewodros et al., 2019; Yigezu, 2021).

## **2.4 Mango Products Loss**

The types of losses associated with mango are both quantitative and qualitative. The critical loss points were based on whether mangoes were marketed as table ripe or as a value-added product (WIFAD, 2018). Quality losses include those that affect the nutrient composition, the acceptability and the edibility of a given product. Quantity losses refer to those that result in the loss of the amount of a product (WIFAD, 2018). Africa's mango production is considered to be below its potential as a result of the ever-increasing production costs and the reduction of the quality and quantity of marketable production due to insect pests (Sebstad and Snodgrass, 2004). Biotic constraints include; seasonal over-production, disease attacks and heavy infestations by a range of insect pests (Muhammad and Kiilu, 2004). The major abiotic constraints include; limited access to markets, unavailability of quality planting materials, limited access to technological information on husbandry practices, poor infrastructure, high input costs, inadequate post-harvest handling techniques and facilities as well as limited access to information on value addition technologies (Bekele, 2016).

In Ethiopia major causes of mango product losses are birds, wind, wounding, microorganisms and maturity stage. The birds are more challenging during the maturity stage, the wind is so problematic starting from the fruiting to the harvesting stage of the product (Hussen and Yimer, 2013). Major loss of mango occurs during harvesting and before harvesting time, because of harvesting methods and maturity stage and also wind and birds. Loss of mango products also occurs during harvesting and storage because of the use of inappropriate harvesting materials and the inadequacy of the storage facility.

## 2.5 Main pests associated with mango production systems

Pests are the main factors that can impact sustainable mango fruit production in the tropics and subtropics worldwide. Peña et al. (2009) reported that approximately 492 species of insects, 17 species of mites, and 26 species of nematodes have been found to infest mango-producing systems. However, the majority of pests fall into the category of minor pests since they cause less damage to the crop. Reddy et al. (2018) claim that commercial mango farming, which is characterized by growth into new areas, replacement of varieties, altered crop management, and greater chemical interventions has drastically changed the composition of the pest community. Additionally, the worldwide trade in mangos has facilitated the movement of pests between countries, and climate change has caused the establishment of new pests. Because of this, several pests that were once thought to be minor or secondary problems have recently become major ones (Jayanthi et al., 2014).

The primary pests of mango in the world are mango scale (*Aulacaspis tubercularis*), mango tipborer (*Chlumetia euthysticha*), mango shoot caterpillar (*Penicillaria jocosatrix*), mango cecid flies (*Procontarinia mangivora*), mango seed weevil (*Sternochetus mangiferae*), mango pulp weevil (*Sternochetus frigidus*), mango red-banded caterpillar (*Deanolis sublimbalis*), mango fruit borer/citripestis (*Citripestis euthraphera*), pink wax scale (*Ceratoplastes rubens*), mango mealybug (*Rastrococcus*), mango plant-hopper (*Colgaroides acuminata*), mango leafhoppers, tea red spider mite (*Oligonychus coffeae*), tea mosquito bug (*Helopeltis* spp.), coconut bug (*Pseudotheraptus wayi*), mango bud mite (*Aceria mangiferae*), red-banded thrips (*Selenothrips rubricinctus*), mango shoot/flower caterpillars (*Penicillaria jocosatrix*), fruit-spotting bug (*Amblypelta lutescens* and *A. nítida*), and different species of fruit flies (*Bactrocera* spp.,

*Ceratitis* spp. and *Anastrepha* spp.) (De Faveri, 2018; Drew et al., 2005). The several pests that damage mangoes are described above without distinction of the parts they impact.

Peña et al. (2009) and Reddy et al. (2018) reported that the primary pests of mango fruit; are flies, seed and pulp weevils, *Aulacaspis tubercularis*, and *Procontarinia frugivora*. About 60 different fruit fly species most importantly belonging to the genera *Anastrepha*, *Bactrocera* and *Ceratitis* affect mango and related species. Thus about 33 species of the genus *Bactrocera* affect mango in Africa, Asia and Australia (Peña et al., 2009).

## **2.6 Biology of Fruit flies**

Fruit flies belong to the huge family Tephritidae, which has roughly 4,500 known species and above 500 genera. The pest species of fruit flies in Africa are classified into indigenous and invasive species, which belong mostly to four genera: *Bactrocera*, *Ceratitis*, *Trirhithrum*, and *Dacus* (De Meyer et al., 2012). Pests are multivoltine tropical and subtropical species that feed on a variety of pulpy fruits. In Sub-Saharan Africa, mango is highly infested by fruit flies. In most species, females locate, recognize and accept host plants for oviposition, eggs hatch on the host plants, and larvae develop to the adult stage by consuming various parts of the host plants (Gripenberg et al., 2010). The link between female preference and larval performance varies with the degree of diet specialization and depends on the taxonomic diversity of studied host plants (Gripenberg et al., 2010; Balagawi et al., 2013). Thus, the larval stage of fruit fly is of major importance since they live and feed on the stalks, leaves, fruit, flower heads, or seeds of fruits. Tephritid also attack other commercial crops and the flower heads of ornamental plants (Mwatawala et al., 2009).

The life cycle of fruit flies consists of the egg, larva (first instar, second instar and third instar larvae), pupa and adult. At room temperature, fruit flies can develop into adults within one to two weeks. The egg and larval stages span approximately eight days, while the pupal stage lasts six days. The adult fruit fly lives for several weeks (Faria et al., 2014). Fruit flies are distinguished by the female's long, extendible ovipositor, which is used to lay eggs beneath the skin of fruits and vegetables, which later serve as food for the larval stage. The egg color is usually glistening white to creamy-yellow, becoming slightly darker towards the time of closure; while the shape and size of eggs vary with species (Ferrar 1987).

The larvae that hatch initially are small and delicate first-instar larvae (Hobololo, 2004). They moult into slightly more robust second instar larvae, and these in turn moult into quite stout and tough third-instar larvae. When the third instars have finished feeding they leave the fruits, fall to the ground, and crawl away into the soil where they pupate. The larval skin becomes barrel-shaped, tanned brown and hard, and is known as the puparium. The true pupa is formed inside this puparium shell. The pupa turns into an adult fly, which escapes from the puparium by splitting open the anterior end and squeezing out. After the few days to a week or more required for the attainment of sexual maturity after the adult emerges, mating occurs, and a new cycle is begun (Papadopoulos et al., 1998). Emerging adults tend to crawl upward through the soil although not always vertically. Fruit flies also appear to take advantage of any cracks or crevices that might afford an outlet to the surface, especially when the soil is hard and compacted. Adult fruit flies are moderately large, with individual flies varying in body length from 1 to above 20 mm. The wings of most species are pictured with yellow, brown, or black stripes/spots, or a combination of both, in characteristic positions or with light or hyaline spots in a darker field (Headrick et al., 1998).

## 2.7 Economic Importance of Fruit flies in Mango Production

Among the insect pests as a constraint of mango, fruit flies are known to be the most notorious (Ekesi, et al., 2006; Isabirye et al., 2015; Hussien and Yimer, 2013). Fruit flies are belonging to two families: Tephritidae and Lonchaeidae (Uchôa, 2012). These two families of fruit flies have great economic importance because they are considered the key pests that most adversely affect the production and marketing of fruits and vegetables around the world. The fruit fly genera *Ceratitis*, *Dacus* and *Trirhithrum* are known to be indigenous to Africa and the *Bactrocera* are native to Asia. Mangos are attacked by five native fruit fly species in Eastern and Southern Africa: *Ceratitis cosyra*, *Ceratitis fasciventris*, *Ceratitis rosa*, *Ceratitis anonae*, and *Ceratitis capitata* (Sunday and Billah, 2006).

The *Bactrocera invadens* fruit fly species were discovered for the first time in India, making it the country that first hosted these species before they spread throughout the world and became a serious economic threat (Mwatawala et al., 2004). *Bactrocera invadens* and *Ceratitis cosyra* species of fruit fly were found for the first time in Africa in 2005 (Drew et al., 2005). These two invasive species are now the major fly species encountered in Africa. Female fruit flies that lay eggs under the skin of the fruits cause direct losses. The eggs hatch into larvae that feed on the decaying flesh of the crop. Infested fruit rot quickly and become inedible or drop to the ground. Besides the direct damage to fruit, indirect losses are associated with quarantine restrictions, because infestation and sometimes the only presence of the flies in a particular country could restrict the trade and export of fruit to markets abroad (Ndlela et al., 2022).

Tephritid fruit flies cause direct damage to important export crops such as mango, avocado and cucurbits, leading to losses of 40% to 80%, depending on locality, variety and season (Ndlela et al., 2022).

Several surveys across Eastern and Southern Africa showed a 30-70% yield loss in mango due to fruit flies, depending on the locality, variety and season (Lux et al., 2003; Ekesi et al., 2006). However, since the invasion by *Bactrocera invadens* in East Africa, damage to mango has increased to over 80% (Ndlela et al., 2022). Thus, the mango fruit fly pest causes a reduction in efficiency and yield of farmers due to a decrease in the quality and quantity of mango in the mango field and store (due to burying mango fruit in the soil and piling the mango on the field for ripening purpose); it causes beating decay of mango fruit; so this study creates the way how mango farmers and merchants handle mango to ripen. Mwatawala et al. (2009) report without control, direct damage in Zimbabwe has been from 30-80% depending on the fruit, variety, location and fruit season.

## **2.8 Management Practices of Fruit Flies**

There are different management practices of mango fruit flies among those male annihilation technique, Bait Application Technique (BAT), Biological control agents, Cultural management approaches and IPM practices

### **2.8.1 Male Annihilation Technique (MAT)**

The male Annihilation Technique exploits the attraction of male fruit flies to para-pheromones and eradicates males so that flies cannot reproduce. It uses fruit fly traps that contain a male lure in liquid form (i.e. Methyl Eugenol) that is combined with a toxic insecticide. The technique aims to reduce the male fruit fly population to such a low level or to eliminate them so that no mating occurs (Allwood et al., 2002; Manoukis et al., 2019). In the process, small whip are soaked in an attractant such as Methyl Eugenol poisoned with a less toxic insecticide and placed

in traps hung on trees. Repeated fruit fly monitoring data have revealed that if Methyl Eugenol traps are combined with bait sprays, fungal pathogens, parasitoids and orchard sanitation, they are extremely effective to trap and kill male fruit flies thereby achieving a reduction in the percent infestation of fruits significantly within the growing season. MAT also meets the requirements for use in an integrated control programme since it has characteristics of a pheromone which specifically targets male fruit flies and is not toxic to other beneficial insects (Ekesi et al., 2016).

### **2.8.2 Bait Application Technique (BAT)**

The protein-baiting technique is based on the use of proteinaceous food baits combined with an insecticide, applied to localized spots of one square meter in the canopy of each tree in the orchard when fruits are 1.3cm in size. Spraying is done weekly until the very end of harvest. The proteinaceous substance attracts adult fruit flies, mainly females, from a distance to the bait spray droplets. The fruit flies ingest the bait, along with a toxic dose of insecticide, killing them before they infest the fruit (Prokopy et al., 2009).

### **2.8.3 Cultural management approaches**

Cultural management techniques often rely on crop cleanliness and orchard sanitation, which aim to disrupt the target pests' typical life cycles (Reddy et al., 2020). The method comprise the collection and destruction of all the infested fruits either they are present on the trees or fallen on the ground. Destruction of fruits can be done by crushing them in a grinder followed by burying them under the soil surface at least >50cm depth. As a result, fruit fly populations can considerably reduce. The activities are very labor intensive but can be very effective if practiced on regular basis. Collection and destruction of infested and fallen fruits is very strongly

recommended to minimize the populations of fruit flies in farms/orchards. Putting infected fruits in black plastic bags, fastening the bag, and exposing the fruits to the sun for a few days until the fruits are rotting and all the maggots within the bags are dead is another cultural control strategy against fruit flies (Mohamed and El-Wakkad, 2003).

Cultural controls modify production practices and/or the crop environment to reduce pest populations and damage. Creating asynchrony between insect incidence and fruit ripening as well as keeping bugs from fruit to limit infestation are techniques to minimize pest damage, which is an overarching goal of IPM. Planting cultivars that mature earlier or are less susceptible lowers the risk of fruit fly infection when populations increase in the later part of the season. These strategies may not be practical in all production systems since they need careful planning, frequent fruit sampling, and an initial financial investment (Schöneberg et al., 2021).

#### **2.8.3.1 Orchard sanitation**

Field sanitation is the cultural method used to prevent fruit fly build-up. It entails regular collection and destruction of all fallen fruits on the ground during the entire season, especially those containing fruit fly maggots. Field sanitation is basic because poorly managed or abandoned farms result in a buildup of fruit fly populations. The method also includes the collection of infested fruit found on the trees or fallen on the ground and depositing them in an augmentorium (De Meyer et al., 2010; Ekesi et al., 2016, Vargas et al., 2008, Vargas et al., 2015). Population dynamics studies undertaken by Peña, (2002) found that there was a strong correlation between the densities of fruit flies in fruits lying on the ground and those in fruits from the tree, thereby establishing field sanitation is important. The collected fruits should be disposed of by burying them in a deep hole. They can also be deposited in an augmentorium,

while at the same time conserving their natural enemies (parasitoids) by allowing them to escape from the structure through a fine mesh at the top of the tent.

Fruit bagging involves protecting fruit with a brown or clear paper bag during the prematurity stage preferably one month before harvest. Early harvesting of some fruits such as papaya and banana while still green helps protect them from fruit fly damage but for mango, this practice is not very effective because fruit fly species like *B. invadens* and *C. cosyra* are capable of infesting green mangoes and causing immature fruit dropping. In countries like South Africa, post-harvest hot water treatment has proven to be effective in killing all the maggots in mangoes though it is yet to be tried in Kenya (Vargas et al., 2015).

#### **2.8.4 Biological control agents**

In natural environments, biological control can keep pests low in a population (Murillo et al., 2015). The presence of biological control agents, such as *Oecophylla longinoda* (red ants), *Fopius arisanus* (parasitoid wasps), and *Metarhizium* (fungal pathogens) reduces fruit fly infestation by predating adult fruit flies and third-stage larvae, destroying pupa in the soil, and having a repulsive effect on fruits through the "pheromones" left by the ants so that fruit (Ekesi et al., 2016). The use of parasitoids has several advantages; the persistence and activity of the introduced natural enemy do not need farmer intervention and preserve itself in the environment at no extra cost to the farmer. Moreover, it is safe for the farmer, the consumer, as well as the environment and the fruit flies do not become resistant to the parasitoids. Nonetheless, if pesticide cover sprays have to be used, mango farmers are advised to use safer (less toxic) pesticides recommended for IPM regimes in their orchards to avoid destroying the parasitoids (Mohamed et al., 2010). Soil inoculation with fungal pathogens creates a hostile environment

for adult fruit flies or their larval and pupae developmental stages. However, it is non-toxic to beneficial parasitoids and since it can persist in the soil for over a year, it is applied only once in a season.

### **2.8.5 IPM Practices of Mango Fruit flies**

The management practices of mango fruit flies are mostly by integrated management practices (IPM). IPM is a diverse mix of approaches to manage pests and keep them below damaging levels, using control options that range from cultural practices to chemical pesticides (Korir et al., 2015). The fruit fly IPM package is a combination of various fruit fly management techniques; including the use of the male annihilation technique (MAT), the application of protein bait spray, the use of fungus-based bio-pesticide, releases of exotic parasitoids, and orchard sanitation that encompasses the use of augmentorium (Korir et al., 2015). In Kenya, the commonly used method of controlling fruit flies by many farmers is intensive insecticide cover sprays. This is not only highly costly for the growers, but also damaging to the health of the farmer workers, the environment and non-target beneficial organisms.

Internationally coordinated research, development, and innovation initiatives will be needed to combat mango pests to find efficient treatments for current pests and also to be ready for emerging threats. This should involve choosing varieties that are tolerant of or resistant to pests; up until now, these varieties have been developed through conventional breeding and selection programs and growers' empirical selection, but new biotechnological approaches will undoubtedly hasten this process in the future. Effective mango pest and disease management should ideally include a variety of management techniques with stringent regulatory controls

that should be implemented for fruit and plant materials at entrance points of nations where mango is grown to avoid the spread of harmful organisms (Pena et al., 2002).

### 3 MATERIALS AND METHODS

#### 3.1 Description of the Study Area

##### 3.1.1 Location

The study was conducted at Arbaminch Zuria district of Gamo Zone located in the Southern Nations and Nationalities Peoples' Regional State (SNNPR) of Ethiopia. The Zone has fourteen districts and four town administrations. The study was conducted on three farmers' kebeles (Lante, Chano mile, and Kolla shale).

Arbaminch Zuria woreda is found about 500 km south of Addis Ababa, the capital city of Ethiopia. The Geographic location of the study region is bounded by a latitude of 5°51'23" – 6°20'05" N and a longitude of 37°19'16" – 37°43'31" E and covers a total area of 51.4km<sup>2</sup> (Figure 1).

The mean monthly temperature is 23.9°C varying between 22.7 (July) to 25.7°C (March). Rainfall distribution in the study area is bimodal with a long rainy season from the beginning of March to the end of May with maximum rainfall around the month of April (228 mm), and a short rainy season from mid-August to mid-October. The minimum rainfall is recorded in January (18 mm) (FAO, 2010). The 25 years maximum average temperature trends of the study area were displayed (1987-1999 and 2000-2011), average maximum temperature difference in the years were 30.3 and 30.6°C, respectively. The minimum temperature trends showed variation before and after 1996.

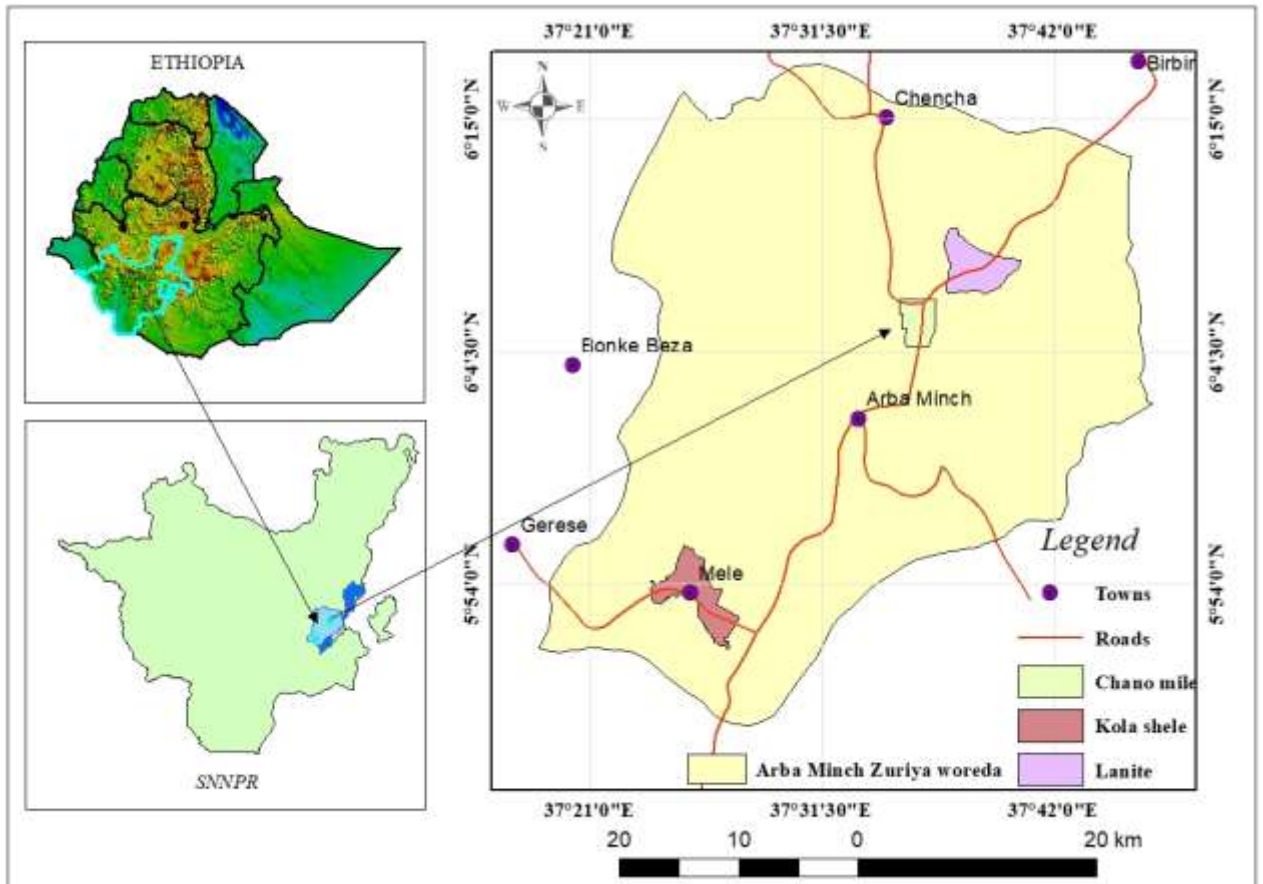


Figure 1. Location map of the study area

### 3.2 Sampling Procedure

Multi-stage sampling techniques were used to select the representative sites from SNNP. Arbaminch Zuria woreda was selected, from Arbaminch Zuria woreda three kebeles (Kolla shele, Lante and Chano mile) were selected purposively based on production potential, and experience, and level of fruit flies infestation level. Reconnaissance survey was carried out to get first-hand information about the areas in which fruit flies infest mango fruit mostly. Before starting data collection, a preliminary survey was conducted in July 2021 to ascertain, and a first discussion was conducted with the agricultural development agent experts. A uniform number of respondents (20) were taken from each kebeles for survey data collection, a total of three

kebeles, 60 households, who have at least local mango variety were chosen for interviews, and for mango fruits for fruit fly infestation assessment.

During assessment, the data were collected from mango farms that have local mango variety. Three mango trees were randomly selected from each farm and 7–10 mango fruits (~2kg) were randomly sampled, considering the availability of mango fruit on the branches and tree crown. Three round samples of mango fruit were collected. Consequently, 210 mango fruits were collected from each site in each round (early, peak, and late harvest). The total samples were 180 mango trees and 1260 mango fruits (3\_harvest time X 3\_site X 210\_fruit).

### **3.3 Data Collection**

#### **3.3.1 Procedure in survey data collection**

Semi-structured questionnaires with both open and close-ended questions were prepared to interview farmers and key informants (developmental agent experts and plant health clinic professionals). By the help of extension agents twenty respondents (mango producers) in each kebele were interviewed. Mango producers who had better production experience and knowledge about fruit pests were selected based on the information given by development agents. The questionnaires' included the number of mango trees each respondent had, the mango variety grown, the time of susceptibility for fruit flies, the level of infestation, the type of pests attacking mango fruit, the farmers' management methods, economically important pests of mango, and their willingness to accept / pay for management methods. The questionnaires were prepared in English and translated into the Amharic language for ease of understanding by the respondents.

Knowledge of pest identification among farmers was assessed by requesting farmers to enumerate the pests they know that are known by the farmers in their daily work during field-

level pest identification. They were also asked about the occurrence of the pest in their mango fields in previous experience.

### **3.3.2 Data collection procedures in assessments**

**Mango insect pest type identification:** Insect pest samples were collected from the Chano mile nursery and mango producers' orchards of the three locations. Pests were collected from ripe and unripe mango fruits. The collected insect pests were examined under a stereomicroscope and morphologically identified with the use of different books, identification catalogues and keys. The fruit fly was identified with a guideline and standard keys by International Center for Inset Ecology and Physiology (icipe,). The expert staff of the Arbaminch plant health clinic laboratory also participated in the identification process and additional reference books were used (Lux et al., 2003; Musasa et al., 2019; Mwatawala et al., 2009; Peña et al., 2009).

**Fruit fly abundance:** trapping was conducted to calculate the average number of flies per trap per day (FTD) and determine the fruit fly species. Samples were collected from mature mango fruit using traps with para-pheromone lures (methyl Eugenol). The para-pheromone traps were placed on the branch of mango trees 2-3 meters from the ground, and the traps were placed on visible parts of the mango branch but not exposed to direct sunlight, strong wind, or dust (makes it to be expired). The traps were kept on mango branches for about 7-10 days during the fruiting period of mango. Fruit flies from each trap were sorted, counted, and the average number of flies per trap per day was calculated.



Figure 2. Traps with para-pheromone in Kolla shele, Chano mile and Lante (picture was taken at Arbaminch, Ethiopia. February, 2022)

The total number of fruit flies collected was counted and (FTD) was calculated using the formula;

Fruit fly abundance (FTD)

$$= \frac{\text{Total number of flies Collected}}{\text{number of serviced trap} \times \text{Average number of days trap was exposed}}$$

**Rearing of fruit flies;** Fruits were collected from each site three times from January to March to rear fruit flies and estimate fruit flies per kg of fruit. The sampled fruits were counted, weighed and kept in a small plastic container with a net lid and bottom sand layer for a larvae to develop to puparia. The sand layer was kept moistened by adding a small amount of water. The plastic container was covered by a screened tight-fitting net to allow air circulation but keep the emerging flies inside the container. Mango fruits collected from each site were kept separately. The fruits were left in the plastic container for 18 to 22 days. The fruits in the containers were checked once a week for puparia. They were sieved from the sand and counted; abundance was compared to

each other (site and round). The fruit fly species were identified using morphological characteristics and published guides.

**Infestation indices;** From the total mango fruit harvested, 50 mangoes (approximately 9 kg) i.e. one kg from each site and each harvest time (3 sites x 3 harvest time) were used to determine the infestation indices, and the remaining for the level of infestation after harvest.

**Fruit fly infestation after harvest:** Twenty farms, each with three mango trees were used to estimate the development of fruit infestations after-harvest. From each respondent farmer 7-10 (approx. 2kg) mango fruits were sampled with a total of 210 (44.73kg) mango fruits per site per harvest time. The fruits were taken to the laboratory, washed with tap water and air dried. The fruits were kept in plastic buckets, which have a bottom sand layer for the pupation of the flies. The sand layer was kept moistened by adding a small amount of water. The bucket was covered tight screen net to allow air circulation but keep the emerging flies inside the container and ripening in the plastic bucket. The samples were kept for 8 days and dissected to check the presence or absence of fruit fly larvae. A fruit was considered damaged when at least one fruit fly larva was observed inside the fruit (Vayssieres et al., 2009). The percent infestations of mango fruits were calculated using the formula below.

$$\text{Infestation after harvest (\%)} = \frac{\text{Number of infested fruit}}{\text{Total number of fruit sampled}} \times 100$$

### **Estimation of yield and yield loss**

Yield and yield loss estimation for the sampled mango farm was performed over three harvest times (January-March) of assessments. The yield and yield loss of mango in the Arbaminch Zuria woreda was estimated by selecting 180 mango trees and assessing the mango fruits during three harvest times, early, peak and late fruiting period. The average weight of one mango fruit and the average annual yield of mango per tree were calculated and weighed; the annual yield per hectare was estimated by using average number of trees per hectare in the area (100 trees per ha); The estimate of average number of trees per hectare (100 trees) used to calculate the annual yield loss per tree and hectare was a figure obtained by consulting farmers, and extension workers.

The post-harvest loss of mango at each locality was determined multiplying the average mango fruit yield per tree and yield per hectare by the percent infestation.

$$\text{yield loss after harvest (Kg)} = \text{Average yield} \times \text{percent of infestation}$$

Field-level fruit yield loss was determined on a tree and hectare basis. The sampled mango trees were from different ages, heights, thicknesses, crown canopies and yield potential. Mango fruits were sampled during the three harvest time to estimate the average yield per tree for each site. The samples were taken while farmers were harvesting mangos. Yield per tree and hectare were calculated using the average weight of mango fruit per tree. The yield and yield loss estimates were calculated from a total of 180 mango trees.

Fruit yield loss (Kg) per hectare was estimated by using the percent damaged fruit and fruit yield per hectare.

The monetary loss was estimated based on the price of mango in kilogram at the time of the study. The Average farm-gate price was 50 Birr/kg of mango fruit

$$\text{Infestation at the field (\%)} = \frac{\text{Total infested fruit by fruit fly (kg)}}{\text{Total fruit harvested (kg)}} \times 100$$

$$\text{Yield loss (Kg)} = \text{Total yield} \times \text{percent of infestation}$$

Yield loss at field per hectare: The average number of infested fruits per tree  $\times$  Average fruit weight  $\times$  Average tree density per hectare

### **3.4 Data Analysis**

The data obtained from the survey were summarized using descriptive statistics with SPSS software (SPSS version22). The analysis related the dependent variable to the explanatory variables, and the output was given as descriptive statistics. The relationships of the explanatory variables socioeconomic and demographic variables and the dependent variable the farmers' interest in accepting or buying the best management options if offered were investigated using a binary logistic regression model. In the bivariate setup, the chi-square test was performed to assess the unadjusted effect of the selected explanatory variables on farmers buying/accepting in the study area. Furthermore, fruit fly abundance, indices and infestation were calculated for analysis of differences across the locations. Analysis was employed for a decision regarding cultivars, infestation rates and yield loss. Cross-tabulation analyses using chi-square tests were undertaken to assess differences among Sites, experience, and Variety types concerning mango production.

## 4 RESULTS AND DISCUSSION

### 4.1 Socioeconomic Characteristics of Mango Producers in Arbaminch

Table 2. Socio-demographic variables of mango producing farmers at Arbaminch, Ethiopia, 2022 (N=60)

variables	N	The proportion of respondents (%)				
		Kolla Shele	Lante	Chano Mile	Mean	$\chi^2$ – test
<b>Gender</b>						
Female	11	20.0	25.0	10.0	18.3	
Male	49	80.0	75.0	90.0	81.7	
<b>Age-group</b>						
below 25	3	5.0	5.0	5.0	5.0	47.50**
26-30	5	5.0	15.0	5.0	8.3	
30-35	6	20.0	0.0	10.0	10.0	
36-40	14	50.0	15.0	5.0	23.3	
Above 40	32	20.0	65.0	75.0	53.3	
<b>Educational level</b>						
Illiterate	13	25.0	25.0	15.0	21.7	22.53**
Elementary	30	45.0	45.0	60.0	50.0	
high school	12	20.0	25.0	15.0	20.0	
College	5	10.0	5.0	10.0	8.3	
<b>Farming experience</b>						
Below 10	5	5.0	10.0	10.0	8.3	11.60**
10 to 20	14	25.0	35.0	10.0	23.3	
20 to 30	18	35.0	20.0	35.0	30.0	
Above 30	23	35.0	35.0	45.0	38.3	
<b>Source of advisory knowledge</b>						
sFamily(Ancestors)	20	20.0	50.0	30.0	33.3	8.10*
Own experience	11	10.0	25.0	20.0	18.3	
Extension agent	29	70.0	25.0	50.0	48.3	
<b>Purpose of production</b>						
Income generation	34	65.0	35.0	70.0	56.7	14.80**
In-home consumption	14	20.0	35.0	15.0	23.3	
Shade of farmland	12	15.0	30.0	15.0	20.0	

\*\*significant at  $p \leq 0.01$ ; significant at  $p \leq 0.05$ ; ns = not significant

The majority of respondents were male farmers (81.7%) indicating men's households dominated mango production activities in the study area. Regarding the age-group, most of the respondents

(53.3%) were age-class above 40. A small number of respondents (5.0 %) were under the age of 25 years. The respondent farmers had been producing mango for several years in Arbaminch Zuria Woreda. Accordingly, the proportion of farmers' experience used for the interview was significantly higher at ( $\chi^2$  – test = 47.50,  $p \leq 0.01$ ).

The educational status of respondents varied significantly in production and management approaches ( $\chi^2$  – test = 22.53,  $p \leq 0.01$ ). The highest proportion of respondents (50%) attended elementary schools and the few (8.3%) attended college/undergraduate school, and those who attended high school and who didn't attend formal classes were 20% and 21.7%, respectively. Education is the most important factor for farmers' skill development. The study showed that the majority of the interviewed farmers had completed at least elementary school.

The highest proportion of respondents (38.3%) had a farming experience of above 30 years and only 8.3% of the respondents had experience below 10 years.

There is a significant difference between respondents' farming experience ( $\chi^2=8.10$ ,  $p \leq 0.01$ ) in mango production. The majority of mango farmers (48.3%) interviewed acquired the knowledge on mango farming from agricultural extension agents, and a fair number (33.3%) obtained from families/ancestors, whereas a very small proportion of farmers obtained knowledge from their own experience by trial and error. On the contrary, Tewodros et al. (2019) reported that the highest scores of respondents obtained knowledge of mango cultivation from ancestors and neighbors rather than agricultural extension agents.

There is a significant difference between respondents' production purpose ( $\chi^2=14.80$ ,  $p \leq 0.01$ ) on mango production and management practices. The highest proportion (56.7%) of

respondents produce mango fruit for income generation and some of the respondents (23.3%) for consumption purposes. But the some of the respondents (20%) keep mango for the shade.

#### 4.2 Common Mango Varieties Grown in Arbaminch Area

A total of seven mango varieties were documented to be grown in Arbaminch area. But five mango varieties, namely, Halava, Hybrid Apple, Kent, Tommy Atkins, and Local mango were documented during the survey (Table 3). The two new mango varieties, Alphonso and Keitt were observed at the Arbaminch Chano mile nursery site but are not yet available to farmers (not released). Among the varieties all the interviewer farmers had local mango variety.

Table 3. Mango varieties grown by farmers in different localities around the Arbaminch, Southern Ethiopia, 2022

Mango varieties	Responses on proportion of mango distribution (%)			
	Chano mile	Lante	Kola-Shale	Mean
Halava	0	3.7	20.7	8.13
Hybrid apple	40.5	22.2	20.7	27.80
Kent	4.8	0	24.1	9.63
Tommy Atkins	7.1	0	0	2.37
Local mango	47.6	74.1	34.5	52.07
<b>Total (%)</b>	<b>100</b>	<b>100</b>	<b>100</b>	<b>100</b>

Farmers in the study are grow five mango varieties namely, Halava, Hybrid apple, Kent, Tommy Atkins and Local variety were grown by farmers in the Arbaminch Zuria woreda (Table 3). Farmers in all localities of Arbaminch probably produce local mango varieties (52.07%). Second widely cultivated (27.80%) was Hybrid Apples while, Tommy Atkins was produced only in Chano Mile. Farmers in Chano mile and Kolla shele had a better experience of growing improved mango varieties in addition to the local varieties which they had been producing for decades.

Similarly, Haile (2016) found that the Local mango variety is the most popular variety grown by mango producers in the Arbaminch area followed by Hybrid Apples. Bekele et al. (2020) also reported that the varieties reported in this study are commonly produced in Ethiopia. Similarly, Tewodros et al. (2019) stated that more than 31 mango varieties have been identified in Ethiopia and further noted that the same variety may have different local names in different production areas.

Table 4. The proportion of farmers growing one or more varieties in the Arbaminch, Ethiopia, 2022

Amount of variety owned	Frequency	Percentage
Farmers with one variety of mango	18	30.0
Farmers with two varieties of mango	25	41.7
Farmers with three varieties of mango	8	13.3
Farmers with four varieties of mango	9	15.0
<b>Total</b>	<b>60</b>	<b>100.0</b>

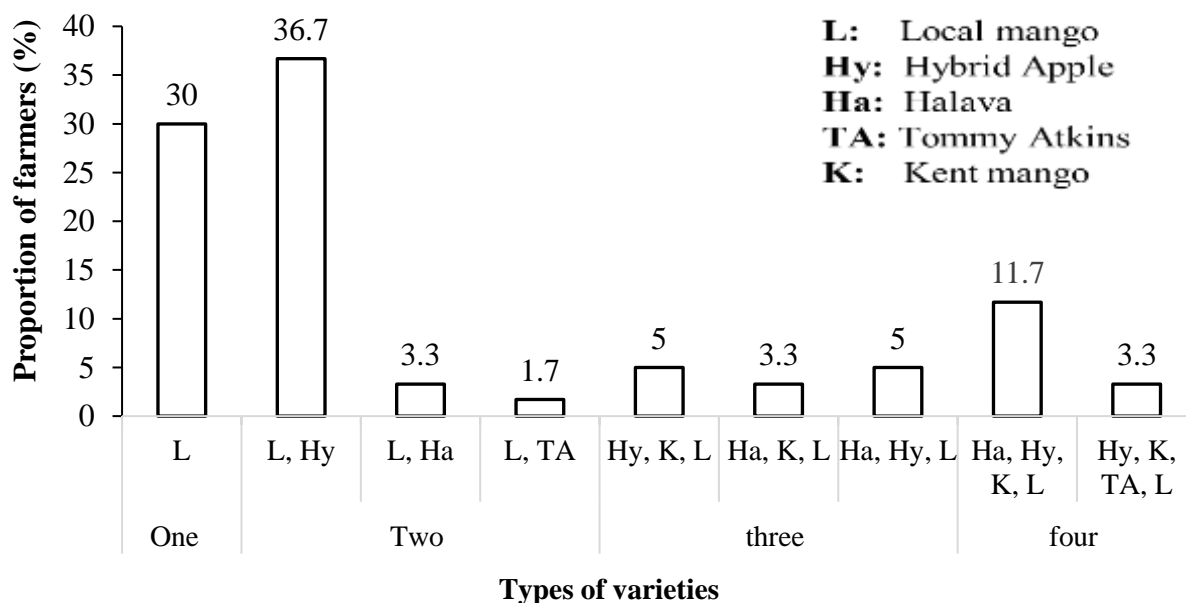


Figure 3. Proportion of farmers with different varieties of mango at Arbaminch, Ethiopia, 2022  
The mango producers in the study area had a limited number of mango varieties. The majority of farmers produce two varieties (41.7%), and 30% produce one which is only a local variety.

Others (15%) produce four varieties, and a small number (13.3%) produce three mango varieties (Table 4). Furthermore, the number of mango varieties owned per farmer indicates that; the majority (36.7%) of the farmers produce both Local and Hybrid Apple varieties followed by local mango 30% only, while only 1.7% of respondents produced Local and Tommy Atkins. Some farmers (5%), produced three mango varieties (Local, Hybrid Apple, Kent) and the other 5% produced Hybrid Apple, Local and Halava, and some (3.3%) of respondents produce (Local, Halava and Kent). Farmers producing Local, Halava, Kent and Hybrid Apple were 11.7%. (Figure 3).

According to the respondents, the fruiting season of the mango in the area starts in October with variable length of time to mature depending on the variety. The Local and Hybrid apple varieties were the early fruiting, whereas Kent, Halava and Tommy Atkins were late fruiting mango varieties.

#### **4.2.1 Susceptible mango variety and damage status to fruit fly**

Farmers characterized the susceptibility level of each mango variety and the fruit fly damage to the susceptible varieties. Although the extent of the damage varies with the season, the farmers indicated that the fruit fly (they call it “*mango-zimb*”) causes damage to mango fruit throughout the year.

Table 5. Farmers' evaluation on the severity and level of mango infestation and the susceptibility of mango varieties,

Variables	Proportion of respondents (%)				
	Kolla shele	Lante	Chano mile	Mean	$\chi^2 - \text{test}$
<b>The most susceptible mango</b>					
Halava mango	20.0	0.0	0.0	6.67	52.933**
Hybrid apple	30.0	30.0	15.0	25.00	
Kent mango	15	0.0	0.0	5.00	
Tommy Atkins	0.0	0.0	0.0	0.00	
Local mango	35.0	70.0	85.0	63.33	
<b>Period of high severity</b>					
Early harvest	95.0	35.0	100.0	76.67	53.200**
peak harvest	5.0	55.0	0.0	20.00	
late harvest	0.0	10.0	0.0	3.33	
<b>Level of fruit fly Infestation</b>					
Less	0.0	0.0	5.0	1.67	17.600**
Moderate	0.0	45.0	50.0	31.67	
High	10.0	40.0	45.0	31.67	
Extreme	90.0	15.0	0.0	35.00	

The majority (63.33%) of respondents stated that local mango as the most susceptible to fruit fly damage, but none of the farmers reported Tommy Atkins's susceptibility to fruit flies. The majority of farmers at Kolla shele (35%), Lante (85%), and Chano mile (70%) reported that the local mango as the most susceptible to fruit flies whereas they reported that Tommy Atkins is less attacked.

About (76.67%) of farmers reported that the severity of fruit fly damage is highest in the early harvesting time and the lowest (3.3%) in the late harvesting time. All the respondent farmers in Chano mile (100%), 35% in Lante, and about 95% in Kolla shele reported that the fruit fly damage severity was the highest during the first round of fruit maturity (early harvesting) which is from January.

Most respondents in the study area rated fruit fly infestation from high to extreme. The majority (35%) of mango growers reported the status to the extreme; a few (1.7%) of them rated the infestation status to low. There were statistically significant differences between the respondents' answers on the level of fruit fly infestation.

### **4.3 Mango Pests and Their Economic Importance**

#### **4.3.1 Mango pests associated with mango production and yield loss**

Mangoes are attacked by various pests at different times of their development. Eight common pests infesting ripen mango fruits were identified in the Arbaminch area. Mango fruit flies (*Bactrocera invadens*), White Mango Scale (*Aulacaspis tubercularis*), Speckled Mouse birds (*Colius striatus*), Weaver Ants (*Oecophylla longinoda* cf.), as indirect pests that disturbs the activities of workers while harvesting , Mealybugs (*unidentified*) “Gebre-gundan”, from vertebrates Grivet Monkeys (*Chlorocebus aethiops*) and unidentified caterpillars (fruit borers) were recognized as the most common insect pests damaging mango fruits in the study area. The mango mealybug (*Rastrococcus invadens* Williams) is an invasive pest spreading in Africa (Tanga 1991). It has been reported in many western and eastern African countries. The Mealybug detected in Arbaminch is not yet confirmed.

Weaver ants (*Oecophylla longinoda* cf)



White Mango Scale (*Aulacaspis tubercularis*)



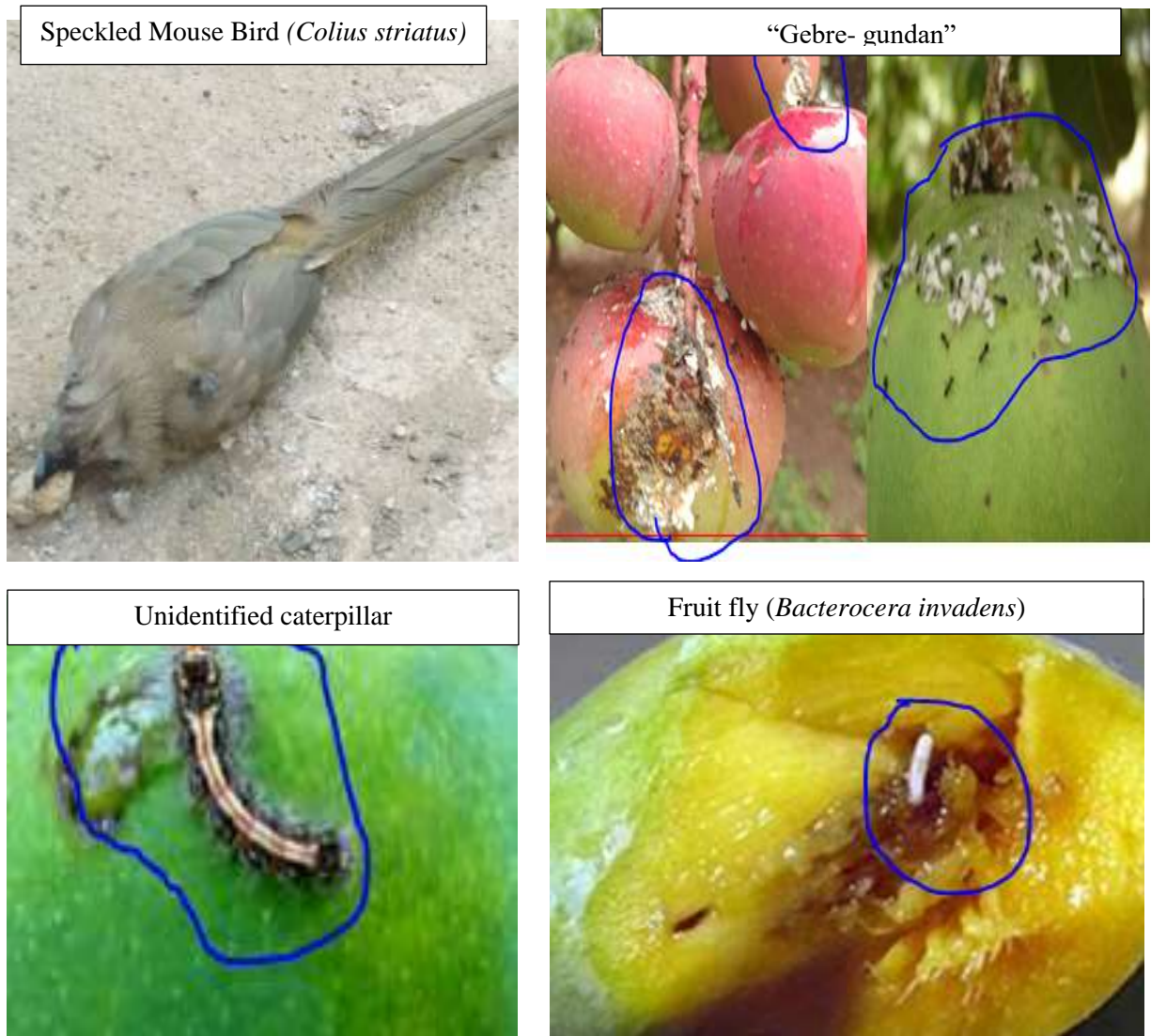


Figure 4. Insect pest types infesting ripen mango fruits at the Arbaminch area (Picture by the researcher, 2022)

A previous study by Kidanu et al. (2008) reported that the White Mango Scale and Fruit fly, as well as among Vertebrates, the Grivet Monkey, are the dominant pests of mango in the Southwestern mango growing region of Ethiopia.

### 4.3.2 Farmers' knowledge of identification of mango insect pests

Farmers classified them into main and minor pests according to the level of damage they cause (figure5).

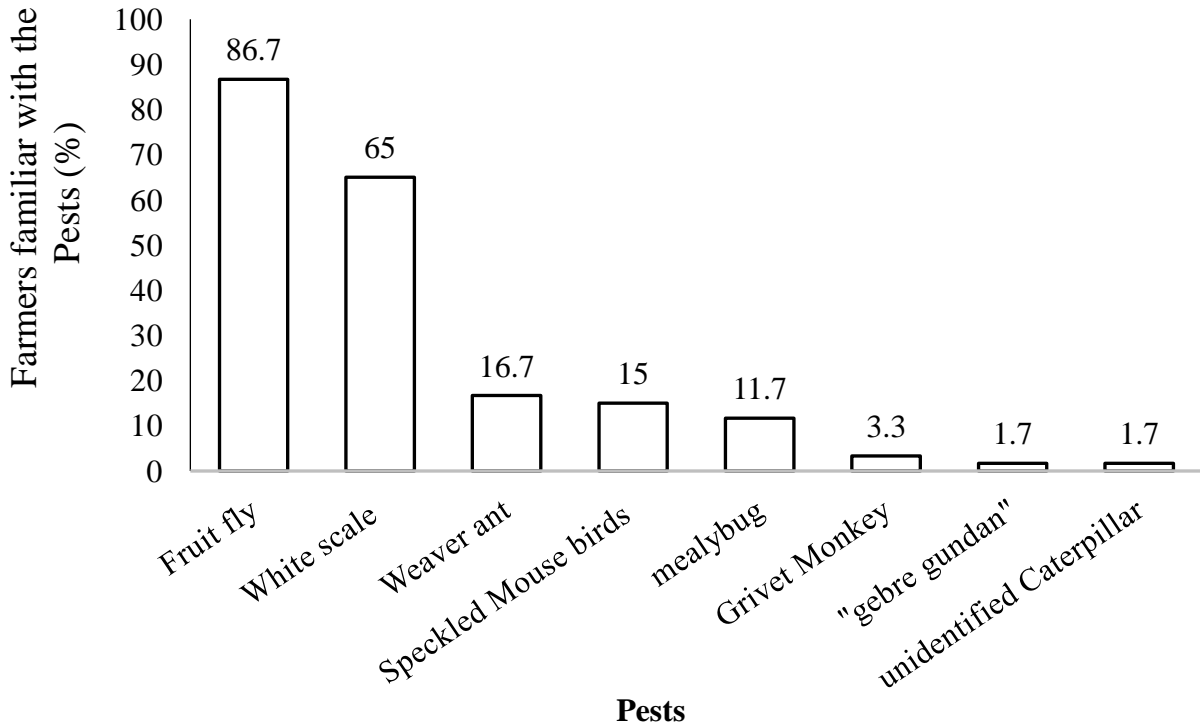


Figure 5. Common pests of mango recognized by farmers in the Arbaminch area, 2022

Farmers identified five main pests that cause problems to their mango. The majority of the farmers mentioned fruit flies (86.7%) and Mango White Scale (65%) as major pests. while some farmers identified weaver ants (16.7%), birds (15%), and mealybug (11.7%) as important pests of mango in the area. Farmers while Monkeys, “*gebre gundan*”, and unidentified caterpillar as minor pests. Peña (2002) identified about 400 species of insect pests are known to infest mango in different parts of the world, but the most abundant and destructive at the fruiting stage are mealybugs, fruit fly, mango stone weevil, and caterpillar pests.

Several studies in Ethiopia indicated that fruit flies and white mango scale are the major pests of mango (Fita, 2014; Hagos et al., 2020; Melese, 2019;; Tewodros et al., 2019).

### 4.3.3 Economic importance of mango pests

The majority of the respondents ranked fruit flies as the most important pest of mango followed by the white mango scale. Fruit flies are the most economically important pest of mango fruit, in all places of the world where mango is produced (Muriithi et al., 2020, Abdullahi et al. 2011). The finding confirmed that insect pests, primarily the recently introduced white mango scale and fruit flies are the most important economical pests of mango in Arbaminch area.

## 4.4 Infestation of Fruit fly on Mango Fruit

### 4.4.1 Fruit fly abundance

A total of 3156 fruit flies (936 from Kola Shele, 1135 from Lante, and 1085 from Chano Mile) were trapped from January to April. All the collected fruit flies were *B. Invadens* due to application of specific para pheromone hence there may be other species of mango fruit fly in the study area.

Table 6. Mean number of fruit flies collected per trap per day in the study area

Locations	Attractant type used	Total number of fruit flies	Mean number of days traps hanged	Flies/trap/day (FTD)
Kolla shele	Methyl Eugenol	936	8	39
Chano mile	Methyl Eugenol	1135	10	38
Lante	Methyl Eugenol	1085	7	52
<b>Total</b>		<b>3156</b>	<b>25</b>	<b>43</b>

The abundance of *B. invadens* was studied in three locations using traps with Methyl Eugenol as an attractant. The highest number of fruit flies/trap/day was at Lante (52), whereas the lowest

was at Chano mile (38). The mean number of fruit flies in the study area was calculated as 43 Flies/trap/day (Table 6).

The field-collected *B. invadens* flies using Methyl Eugenol as an attractant were high in the Arbaminch mango production areas. Attractant recommended for a survey of male *B. invadens*. Previous studies stated that *B. invadens* had dominated other species of fruit flies since its introduction to Africa and was highly invasive (Adzim et al., 2016; Lux et al., 2003; Mwatawala et al., 2009). Massebo and Tefera (2015) in their study conducted in the Arbaminch area stated that the number of fruit flies caught from May to June was low, which shows that the mango fruit fly in the Arbaminch area is the highest in the period from January to April.

#### 4.4.2 Infestation indices and pest species identified

Table 7. Mean number of fruit flies pupae per kg of fruit from three sites, three harvest times in Arbaminch, 2022 (N = 9kg)

locations	Number of pupae per kg			Mean $\pm$ SE per kilogram of fruit	Mean number of pupae $\pm$ SE per fruit
	early harvest	peak harvest	late harvest		
<b>Kolla shele</b>	15	19	17	17 $\pm$ 1.15	3.4 $\pm$ 0.40
<b>Chano mile</b>	17	22	18	19 $\pm$ 1.53	3.8 $\pm$ 0.37
<b>Lante</b>	26	28	27	27 $\pm$ 0.58	4.5 $\pm$ 0.76

The number of pupae retrieved from the mango fruits varied between the three locations. There were more number of pupae in Lante (27 $\pm$ 0.58 pupae/kg, and 4.5  $\pm$  0.76 per a fruit). Chano mile (19 $\pm$ 1.53 pupae/kg, 3.8  $\pm$  0.37 per a fruit) and Kolla shele (17 $\pm$ 1.15 pupae/kg and 3.4  $\pm$  0.40 per a fruit) had equivalent number of pupae.

Table 8. Extent of healthy looking mango fruit infestations by fruit flies in Arbaminch, Ethiopia, 2022 (N=210)

Locations	Infested mango fruits						Mean infestation (%)
	Early harvest		Peak-harvest		Late- harvest		
	N.	(%)	N.	%	N.	%	
Kolla shele	43	20.48	96	45.71	40	19.05	28.41±8.66
Chano mile	48	22.86	65	30.95	73	34.76	29.52±3.51
Lante	55	26.19	107	50.95	85	40.48	39.21±7.18

Fruit fly damage continued after harvest on good-looking fruits which harbored the fruit fly larvae. The mean infestation of fruit flies ranged from 28.41±8.66% to 39.21±7.18% and the lowest infestation was recorded from Kolla shele and the highest from Lante kebele (Table 8). The post-harvest infestation in Kolla shele was the highest (45.71%) during the Peak harvest and the lowest (19.05%) in Late-harvest. The infestation at Chano mile also showed the same trend with a low infestation (22.86 to 34.76%) at early harvest (January) and the highest at peak harvest (February). The infestation was the highest in Lante and ranged from 26.19% to 50.95%, but lowest in Kolla shele as the mean infestation was 28.41±8.66, the lowest infestation was 26.19% (early harvest), and the highest infestation was 50.95% (peak harvest data). The low level of fruit infestation during early harvest is due to low population of fruit flies during the off season when fruits were not available to feed on. Farmers claimed that fruit fly infestation is high at early harvest which was not supported by the assessments made on sampled fruits at different times of fruit harvesting.

#### **4.5 Estimation of Yield Losses on Mango Due to Fruit Fly**

The total number of trees recommended per hectare is 100 (i.e. 10x10m spacing recommended by experts); the average weight of a single mango fruit of local variety was  $200 \pm 13.75$  grams; the average number of mangoes per tree was about 1579.17; the average yield per tree was 315.91kg which totals to 31,591 kg yield per hectare. The average farm gate price per kg was 50 birr.

Table 9. Weight of healthy and infested fruit at different harvest times from three sites at Arbaminch, Ethiopia 2022.

Location	Fruit Harvest/tree and Field level fruit infestation						Annual harvest		Annual losses (%)
	Early harvest (kg/tree)		Peak harvest (kg/tree)		Late-harvest (kg/tree)		Infested	Clean	
	Infested	Clean	Infested	Clean	Infested	Clean			
Kolla shele	38.74	127.5	46.03	53.64	16	50.55	100.77	231.69	30.31%
Chano mile	45.53	155.87	37.4	83.44	24.87	55.69	107.8	295	26.76%
Lante	27.82	78.43	32.48	31.27	13.97	28.5	74.27	138.2	34.95%
<b>Mean harvest</b>	<b>37.37±5.15</b>	<b>120.6±22.62</b>	<b>38.64±3.96</b>	<b>56.12±15.11</b>	<b>18.28±3.35</b>	<b>44.91±8.34</b>	<b>94.28±10.21</b>	<b>221.63±46.77</b>	
<b>% of damage</b>	<b>23.66%</b>		<b>40.78%</b>		<b>28.93%</b>		<b>29.84%</b>		

Table 10. Estimated mango fruit losses by fruit flies at farm gate at Arbaminch, Ethiopia 2022.

Locations	Mean Annual yield per tree (kg)	Estimated mango yield ha (kg/ha)	Annually infested fruit per tree (%)	Yield loss (kg/tree)	Yield losses (kg/ha)	Monetary loss (birr/ha)
Kolla shele	332.5±13.2	33,250	30.31%	100.77	10,078.08	503,904
Chano mile	402.78±39.3	40,278	26.76%	107.8	10,778.39	538,919.5
Lante	212.54±29.1	21,254	34.95%	74.27	7,428.27	371,413.5
<b>Mean</b>	<b>315.91 ± 55.54</b>	<b>31591</b>	<b>29.84% ± 4.99</b>	<b>94.28±10.21</b>	<b>9428.3±1020.21</b>	<b>471,412.3±51010.9</b>

The mean infestation of mango at the three locations was low at early harvest in January. (23.66%) and high in peak harvest in February (40.78%) (Table 9). The mean annual yield loss was  $94.28 \pm 10.21$  kg per tree and the annual percentage loss of mango fruit per tree was 29.84%. At Kolla shele, high fruit loss was recorded during peak-harvest and annually 30.31% of mango fruit per tree was lost due to fruit flies. Similarly, in Lante infestation was high in peak harvest and 34.95% mean annual fruit loss was estimated. Therefore, the annual mango yield loss per tree was higher in Lante (34.95%); while it was less in Chano mile (26.76 %) (Table 10). A similar study on a yield loss assessment conducted in Southwestern Ethiopia by Kidanu et al. (2008) indicated that mango fruit losses caused by fruit flies ranged from 1.67% to 50.76%, with a total mean of 13.5%. The mango fruit yield loss was the lowest in early harvest and, highest in a peak-harvest season of the year (February) than other harvest times. Infestation levels of 24% mango fruit flies has been reported from mango trees in Kenya (Mugure, 2012); in Sudan, it was 31% (Ali et al., 2014); and in Uganda, it ranged from 33-83% (Nankinga et al., 2014). In Tanzania, severe damage (30–80%) to mango fruit by *B. invadens* was reported (Mwatawala et al., 2009). Also, studies from Ethiopia indicated fruit flies cause a serious reduction in mango production (Azerefege et al., 2009; Birtukan 2014; Tewodros et al., 2019).

The annual average yield of mango in Kolla shele was 332.5 kg/tree and the estimated yield was 33,250 kg/ha. Yield losses caused by fruit flies were 100.78 kg/tree and 10,078.08 kg/ha; as a result, producers lost 503,904 birr/ha/yr. In Chano mile, the annual yield was 402.78 kg per tree and 40,278 kg per hectare, also the loss amounted to 10,778.39 kg per hectare. Consequently, producers lost 538,919.5 birr per hectare. Similarly in Lante, the annual estimated mango yield was 212.54 kg per tree and 21,254 kg per hectare; yield losses per hectare were 7,428.27 kg. Mango producers lose 371,413.5 birr per hectare at Lante. The mean annual loss/tree was

29.84% ± 4.99; the mean of annual yield/tree was 315.94±55.54 and 31591±5553.82 was; the mean of estimated mango yield loss/ha was 9428.25±1020.219, and farmers lost 471,412.3±51010.9 birr per hectare. Similar studies reported that mango fruit loss because of fruit flies ranged from 55.57% - 67% in Western Ethiopia (Fikiru et al., 2018) and 30.4% in Eastern Ethiopia (Getahun et al., 2015). Therefore the sum total yield loss at field and after harvest is estimated to 56.28% Chano mille, 58.72% at Kolla shele, and 74.16% at Lante.

#### 4.6 Management Practices with Emphasis on Fruit Flies

A total of seven management options (monitoring and detection, mechanical control, and behavioural control) were identified by mango farmers in the study area, Farmers practice one or more of these options to minimize fruit fly damage on mango and the methods were applied either alone or as integrated management methods.

Table 11. Percentage of farmers using different management options against fruit in three locations at Arbaminch

Management Practices	Percent users of management methods			Total response (%)	$\chi^2$ – test
	Kolla shale	Lante	Chano mile		
Methyl Eugenol Trap	100.0	60.0	95.0	85.0	108.87**
Field sanitation	55.0	65.0	80.0	66.7	
Burying infected mango fruit	70.0	20.0	55.0	48.3	
Branch pruning	5.0	20.0	40.0	21.7	
Prompt mango harvesting	0.0	10.0	20.0	10.0	
Proper spacing of mango trees	15.0	15.0	45.0	25.0	
Field smoke	45.0	45.0	65.0	51.7	

Note; \*\* significance at  $P \leq 0.01$

Farmers in the Arbaminch area use different methods to reduce the infestation of mango by fruit flies and other pests and there were significant differences ( $\chi^2=108.87$ ,  $p \leq 0.01$ ) on the use of these management practices (Table 11). Using traps (para-pheromone lure) was the most commonly applied fruit fly management method in the area and all the respondents in Kolla shale and 95% in Chano mile have used this method. Field sanitation (66.7%) was the second in all the Arbaminch areas followed by field smoke (51.7%) and some of the farmers (48.3%) bury infested mango. The respondents indicated that smoking is an effective insect control method as the smoke produced chases away insect populations from the mango tree. Smoking methods are conducted by the burning of green aromatic leaves and any leaves found around. However, the effectiveness of this method is not verified. The farmers also indicated that they use pruning of branch (21.7%) and spacing/sparse planting (25%) for the management of pests. These methods are useful especially in the reduction of white mango scale and diseases, but not fruit flies. Fruit flies are known to be strong fliers. Early harvesting of fruits is known to reduce infestation by fruit flies. However, prompt harvesting of mango (10%) was the least used method of management for fruit fly infestation in the Arbaminch area. Most of the mango producers mentioned trapping as the primary approach used for the management of mango fruit flies, followed by field sanitation because of effectiveness of the method. The finding is in agreement with earlier work by Gitonga (2009) and Mugure (2012), which confirmed that compared to trapping, the use of pesticides is ineffective against fruit flies whose larvae develop inside the fruit tissue. Similar studies have reported that many developing countries have been using attractant traps as the most recommended and effective control method against mango fruit flies (Peña, 2002; Korir et al., 2015; Manoukisd et al., 2019).

#### 4.6.1 Implementations of multiple option management as IPM strategy

The integrated pest management (IPM) practices repetition varied among the growers in the study area.

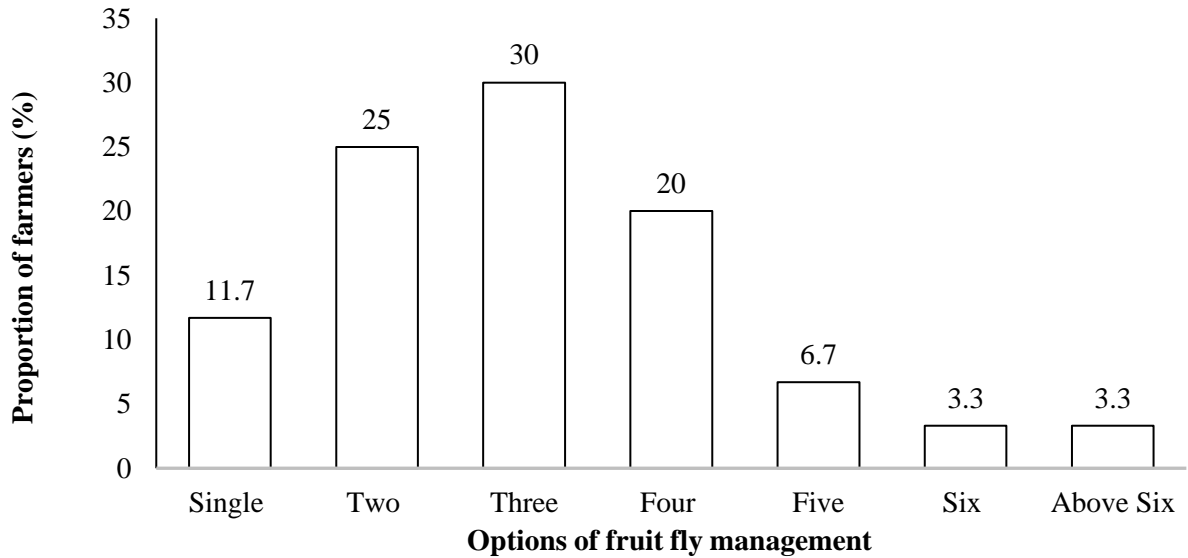


Figure 6. The implementation status of farmers among the seven IPM approaches

Seven different types of management approaches were used against fruit flies by mango producers in the Arbaminch area. More than 80% of the farmers applied more than two management approaches (two-to-all seven options) (Fig 6). In fruit fly management, the combinations of multiple methods are recommended because individual methods cannot completely control the pest. Therefore, it's important to evaluate the effectiveness of different approaches as a component of the IPM method. In agreement with this finding, Melese (2019) recommended IPM approach against mango fruit flies with the integration of cultural methods (fallen fruit destruction, branch pruning, and field/orchard sanitation), use of natural enemies, and trapping.

#### 4.6.2 Farmers' willingness to accept/buy if the best management option offered

A binomial logistic regression analysis was performed to ascertain the effects of gender, age, educational level, farming experience, source of advisory knowledge, production purpose, and amount of mango variety the farmers had on the likelihood of their interest in purchasing or accepting if the best management options are offered. About 60% of interviewed farmers were interested in accepting if the best management methods are offered in addition to currently applied methods (Appendix 3-6).

Table 12. Willingness of farmers to pay for fruit fly management

Predictor variables	B	S.E.	Wald	Df	Sig.	Exp(B)	95% CI for EXP(B)	
							Lower	Upper
Gender (Female)	1.758	2.010	.765	1	.382	5.801	.113	298.174
Education (illiterate)	3.157	1.524	4.290	1	.038	23.501	1.185	466.167
Age-group ( $\leq$ 35 yr.)	-1.689	1.548	1.190	1	.275	.185	.009	3.842
Farming exp. ( $\leq$ 20 yr.)	.521	1.640	.101	1	.751	1.684	.068	41.894
information source(informal)	1.356	1.695	.640	1	.424	3.882	.140	107.577
Production purpose (own use)	3.673	1.598	5.287	1	.021	39.388	1.720	902.093
Variety number owned (one)	.481	.975	.243	1	.622	1.617	.239	10.922
Constant	-6.040	2.886	4.381	1	.036	.002		

**B:** Regression coefficient in the binary logistic regression model. **S.E.:** Standard error. **Wald:** A Wald chi-square test used to determine whether the coefficients within the model are statistically significant **df:** Degree of freedom (for the Wald chi-square test. **Sig.:** p-values (in the column of Sig.). **Exp (B):** Odds ratio.

Gender of the farmers was not correlated with willingness to accept the best methods (B = 1.758; p = 0.382) indicating that both men and women are likely to accept the best management methods.

The age of farmers was not significantly correlated with willingness to accept ( $B = -1.698$ ;  $p = 0.275$ ; Wald statistics  $=0.185$ ). The educational level of the respondents was positively correlated with their interest in accepting if the best management is offered. The more they are educated the better they accept management methods.

Both farming experience of the respondents and the source of advice were correlated with interest in farmers' willingness. The farming experience of respondents was not correlated with the interest of farmers to accept better management methods, ( $B = 0.521$ ;  $P = 0.751$ ) and Wald statistics ( $1.684$ ) indicating that both farmers with many and few years' experience accept effective methods. The advisory source of the respondents was positively correlated with the farmers' willingness to accept if better management is offered. It was statistically significant at the 0.05 level ( $B=1.356$  and  $p =0.424$ ), and the Wald statistics ( $0.640$ ) also showed it has no significant relationship.

The production purpose of respondents was positively correlated with the farmers' willingness to accept if the best management is offered. It was statistically significant at the 0.05 level ( $B = 0.481$  and  $p = 0.021$ ), and the Wald statistics ( $5.287$ ) also showed a significant relationship. This result reveals farmers producing mango for marketing are more interested to accept than farmers who produce mango for household consumption. The number of varieties owned by respondents positively correlated with the farmers' willingness to accept if the best management is offered. It was statistically significant at the 0.05 level, and the Wald statistics ( $0.243$ ) also showed it hadn't a significant relationship.

## 5 CONCLUSION AND RECOMMENDATIONS

### 5.1 Conclusion

The study assessed mango varieties grown, mango fruit pests and their economic importance, fruit fly species and abundance, fruit fly infestation level, mango yield loss and yield, management practises of fruit flies, and mango growers' willingness to buy best management options for fruit flies. Local mango varieties, Halaba, Hybrid Apple, Kent, and Tommy Atkins are the main varieties produced in the study area.

Mango farmers in the Arbaminch are faced with a multitude of pest problems. There are many insect pests damaging mango fruit of which fruit flies and white mango scales are the major ones. Other vertebrate pests such as birds and grivet monkeys are causing great damage to mango in the area. *Bactrocera invadens* is the most important fruit fly species causing high damage to mango and a mean of 43 flies per trap per day were collected on average in mango farms in Arbaminch area. Mango fruit fly infestation and yield loss are high in Lante and low in Kolla shele. Currently, farmers are using the male annihilation technique ((MAT) using para pheromone methyl Eugenol and cultural methods to combat fruit flies. However, the level of infestation is still very high; on average 29.84% of fruit were infested in the field and 32.38% of the fruit was infested after harvest. Annual yield loss of mango fruit due to fruit flies is the sum total of infestation in the field (during harvest) and infestation after harvest and therefore annual yield loss was 62.22% as a result mango producers lost about 471,412.3±51010.9 birr per hectare per year. Farmers' educational level and purpose of mango production had a statistically significant association with farmers' interest to buy if a better management option is offered.

## **5.2 Recommendations**

Fruit fly infestations and yield losses are high in local mango varieties. Farmers are the backbone of the production and productivity of mango, based on the results and observations made during the survey and experiment it seems that production and management practices are inappropriate. Management practices using biological enemies are the best due to their merit of being economically important and environmentally friendly in addition to cultural practices. Technological-based knowledge and training should have to be given to farmers on production and fruit fly management. Understanding the period of mango fruiting and fruit flies and the life cycle, the intensity of infestation by farmers will help to adopt and implement better management practices. There are five varieties currently grown by farmers. There are mango varieties in the Chano mile nursery site which are not yet released. It is important to bring new varieties which are suitable to the area, market-accepted and less susceptible to major pests and diseases. There is a need to validate the pest management methods claimed to be effective for different pests. The use of traps is well accepted by the farmers and the only problem is its availability. Future studies should focus on the understanding of the mango production cycles, the introduction of suitable varieties and their susceptibility to major pests, evaluation of new methods of management to develop an Integrated Pest Management (IPM) system.

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## 7 APPENDICES

### Questionnaire to be completed by Respondent

Dear respondent, this questionnaire is designed to obtain reliable information on the **assessment of mango yield loss and pest management practices of mango-producing farmers in the Arbaminch area, Ethiopia: the case of fruit flies (Diptera, Tephritidae)**. The researcher came from Hawassa University to conduct research and the information obtained will be used only for academic purposes to complete the Master of Science study. For the success of the study; your responses will have a great contribution. Therefore, you are kindly requested to give genuine information.

1. Name of kebele \_\_\_\_\_

This section contains questions to obtain general information about you. The researcher believes that you are the right person to provide the required information regarding the farm's profile as you are the more informed person among the farmers.

<b>Gender</b>	Male			Female		
<b>Age-class</b>	20-25	26-30	31-35	36-40		Above 40
<b>Educational level</b>	Illiterate	Elementary	High School	College level	University level	
					1 <sup>st</sup> degree	2 <sup>nd</sup> degree

#### Questionnaires

1. Do you have a Mango tree?    A) Yes                    B) No

1.1. For the above question if your answer is “yes” list down the mango varieties (cultivars) you have in your mango farm \_\_\_\_\_

1.2. For how many years have you been producing mango?

A. Below 10 years

C. 20 – 30

B. 10 – 20

D. Above 30

1.3. How many mango trees do you have? (specify individually for each variety you grow)

\_\_\_\_\_



Appendix 1. Descriptive statistics result used in ANOVA analysis of the amount of variety owned per farmer by socio-economic variables

Socio-economic variables vz category	N	Mean	Std. Deviation	Std. Error	95% CI for Mean		min	Max
					lower bound	Upper Bound		
<b>Age-group</b>								
below 25	3	1.67	0.577	0.333	0.23	3.1	1	2
26-30	5	1.6	0.548	0.245	0.92	2.28	1	2
30-35	6	2.67	1.211	0.494	1.4	3.94	1	4
36-40	14	2.71	0.994	0.266	2.14	3.29	1	4
Above 40	32	1.91	0.963	0.17	1.56	2.25	1	4
Total	60	2.13	1.016	0.131	1.87	2.4	1	4
<b>Educational level</b>								
Illiterate	13	1.38	0.506	0.14	1.08	1.69	1	2
Elementary	30	2.1	0.923	0.168	1.76	2.44	1	4
high school	12	2.92	1.084	0.313	2.23	3.61	1	4
College	5	2.4	1.14	0.51	0.98	3.82	1	4
Total	60	2.13	1.016	0.131	1.87	2.4	1	4
<b>Farming experience</b>								
Below 10	5	1.6	0.894	0.4	0.49	2.71	1	3
10 to 20	14	1.93	0.73	0.195	1.51	2.35	1	3
20 to 30	18	2.44	1.149	0.271	1.87	3.02	1	4
Above 30	23	2.13	1.058	0.221	1.67	2.59	1	4
Total	60	2.13	1.016	0.131	1.87	2.4	1	4
<b>Source of advisory knowledge</b>								
Family(Ancestors)	20	1.65	0.587	0.131	1.38	1.92	1	3
own experience	11	1.45	0.934	0.282	0.83	2.08	1	4
extension agent	29	2.72	0.96	0.178	2.36	3.09	1	4
Total	60	2.13	1.016	0.131	1.87	2.4	1	4
<b>Purpose of production</b>								
Income generation	39	2.49	0.997	0.16	2.16	2.81	1	4
in-home consumption	15	1.53	0.743	0.192	1.12	1.94	1	3
shade of farmland	6	1.33	0.516	0.211	0.79	1.88	1	2
Total	60	2.13	1.016	0.131	1.87	2.4	1	4

Appendix 2. Mango variety and grower vs non-grower of each variety in Arba Minch Zuria Woreda

mango variety in farmers	Growing vs. not growing	Frequency	Percent	Valid Percent	Cumulative Percent
Halava mango variety	Yes	13	21.7	21.7	21.7
	No	47	78.3	78.3	100
	Total	60	100	100	
Hybrid apple mango variety	Yes	35	58.3	58.3	58.3
	No	25	41.7	41.7	100
	Total	60	100	100	
Kent mango variety	Yes	16	26.7	26.7	26.7
	No	44	73.3	73.3	100
	Total	60	100	100	
Tommy Atkins mango variety	Yes	3	5	5	5
	No	57	95	95	100
	Total	60	100	100	
Local mango variety	Yes	60	100	100	100

Appendix 3. Implemented vs. unimplemented Management practices used in the study area

Management types	user vs. non-user	Frequency	Percent	Valid Percent	C. Percent
Methyl Eugenol trap	yes	51	85	85	85
	no	9	15	15	100
	Total	60	100	100	
Field sanitation	yes	40	66.7	66.7	66.7
	no	20	33.3	33.3	100
	Total	60	100	100	
Burying infected mango 60cm hole	yes	29	48.3	48.3	48.3
	no	31	51.7	51.7	100
	Total	60	100	100	
Branch pruning	yes	13	21.7	21.7	21.7
	no	47	78.3	78.3	100
	Total	60	100	100	
Prompt harvesting	yes	6	10	10	10

	no	54	90	90	100
	Total	60	100	100	
Proper space planting	yes	15	25	25	25
	no	45	75	75	100
	Total	60	100	100	
Field smoke	yes	31	51.7	51.7	51.7
	no	29	48.3	48.3	100
	Total	60	100	100	

#### Appendix 4. Omnibus Tests of Model Coefficients

Step 1	$\chi^2$ - test	Df	Sig.
Step	54.693	7	.000
Block	54.693	7	.000
Model	54.693	7	.000

#### Appendix 5. Hosmer and Lemeshow Goodness of fit test

Step	$\chi^2$ - test	Df	Sig.
1	1.476	8	0.993

#### Step-3: model summary

Step	-2 Log likelihood	Cox & Snell R Square	Nage kerke R Square
1	26.069 <sup>a</sup>	0.598	0.809

#### Appendix 6. Model fitness Classification table

Observed		Predicted		
		interest-based DV		Percentage Correct
		no	Yes	
interest-based DV	No	22	2	91.7
	yes	4	32	88.9
Overall Percentage				90.0

#### Appendix 7. Proportion of interested farmers of buying if additional management is offered

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	no	24	40.0	40.0	40.0
	yes	36	60.0	60.0	100.0
	Total	60	100.0	100.0	



Figure in appendix 1: Rearing techniques to determine the pupae per kg of each site and round

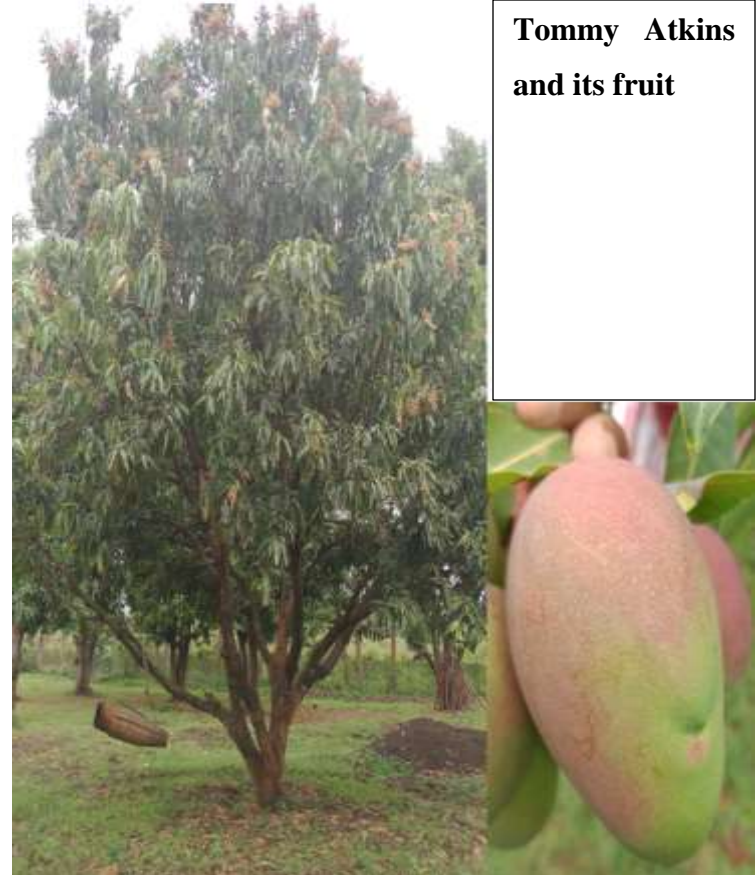


Figure in appendix 2: Fruit collection, washing, packaging, and categorizing infested to an uninfested class of mango collected from farmers

**Keitt Mango Tree and its Fruit**



**Tommy Atkins  
and its fruit**



**Hybrid apple**



**Kent mango fruit**



Figure in appendix 3: Hybrid apple and Kent mango fruit (picture was taken at Arbaminch, Ethiopia. February, 2022)

**Alphonso mango**



**Halava mango**



Figure in appendix 4: Alphonso and Halava mango variety ((picture was taken at Arbaminch, Ethiopia. January, 2022)

**Local mango variety**  
addressed all location

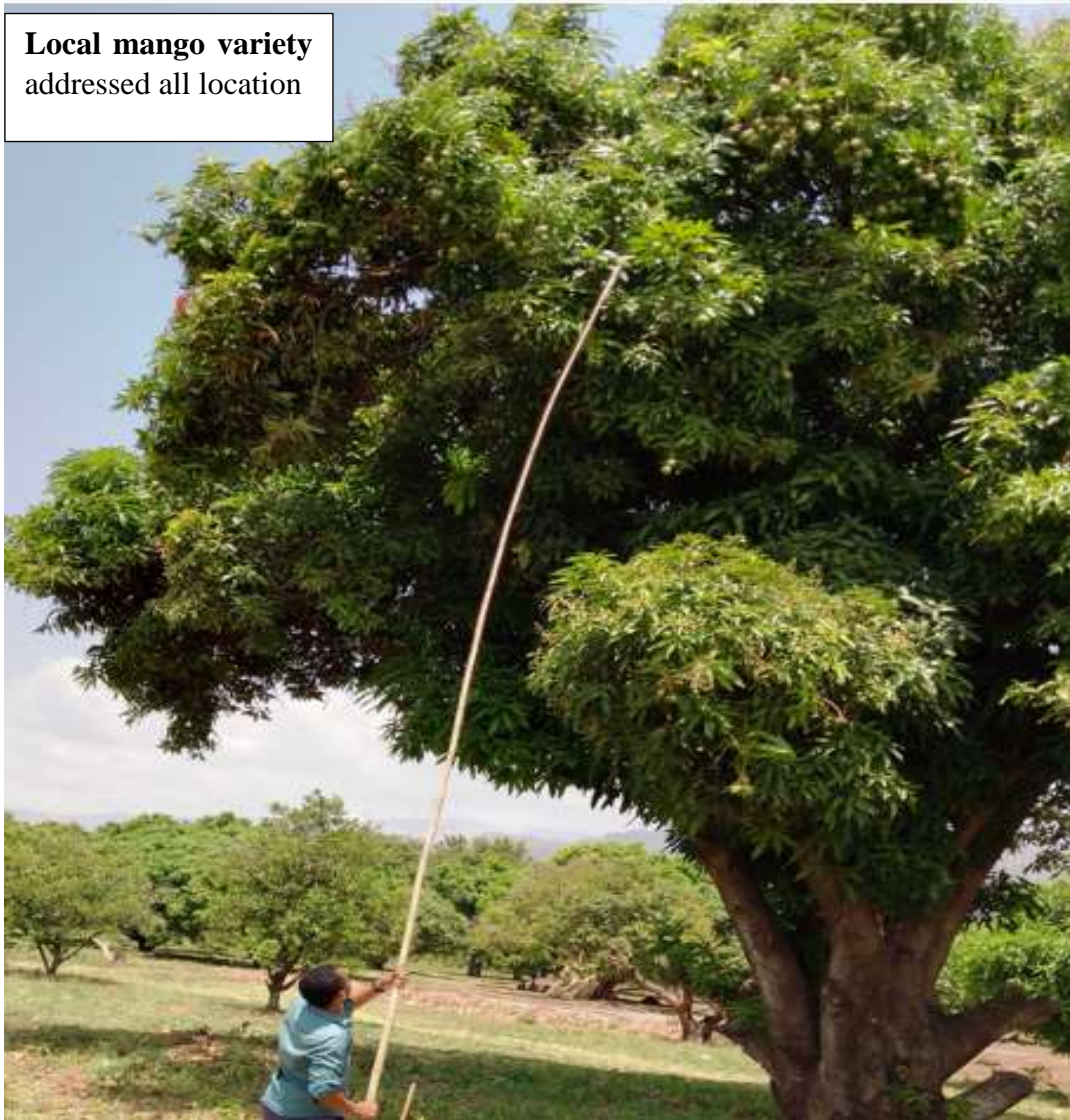


Figure in appendix 5: Local mango variety ((picture was taken at Arbaminch, Ethiopia. February, 2022)