OPTIMIZATION OF AN INTEGRATED PEST MANAGEMENT PROGRAM FOR FRUIT FLIES (DIPTERA: TEPHRITIDAE) CONTROL IN MANGO: A CASE OF MANICA PROVINCE, MOZAMBIQUE

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EXTENDED ABSTRACT

This study was undertaken to reduce the losses caused by *Bactrocera dorsalis* (Hendel) in Manica province, Mozambique, through an optimized integrated pest management (IPM) package. It involved interviews with farmers to collect baseline information on awareness of fruit producers regarding fruit fly pests and their management so that an IPM package can be developed based on the farmers' needs. Additionally, systematic trapping data of *B. dorsalis* seasonality and damage were collected and economic injury level (EIL) for *B. dorsalis* was estimated. Based on EIL, the IPM for *B. dorsalis* control developed in Tanzania by the Sokoine University of Agriculture (SUA IPM) was optimized. The SUA IPM included calendar GF 120 NF bait sprays and orchard sanitation while for the optimized IPM the GF 120 NF was only sprayed in the subplots inside the orchard when the threshold of 30 flies/trap/week was reached. The effectiveness of SUA IPM and its optimized version were also tested. Results showed that fruit flies were the main pest problem in mango and citrus orchards. More than 70% the respondents indicated low fruit quality and increasing volumes of uncommercial zed fruits as consequences of fruit flies infestation. The monetary value of losses reached a value of USD 135,784.8 during 2014/15 mango season. Results on seasonality revealed that population of *B. dorsalis* started to build up in November and reaching its peak in January. It was significantly affected by temperature, month and host availability, being observed that *B. dorsalis* were most abundant during hot season and at mango maturation stage. EIL varied among orchards and was estimated an average of 33.14 *B. dorsalis*/trap/week. The SUA IPM and optimized IPM had significantly less number of damaged fruits, pupae and *B. dorsalis*

infestation rate when compared to untreated orchard. However, the SUA IPM and the optimized IPM were not significantly different although in the optimized IPM significantly less volume of the bait was used. It can be concluded that spot application of GF 120 can provide the equivalent level of the pest control when compared to calendar spraying and should, therefore, be used to reduce the fruit losses caused by fruit flies.

DECLARATION

I, LAURA DA GRAÇA JOSÉ CANHANGA, do hereby declare to the Senate of Sokoine University of Agriculture that, this thesis is my own original work and that it has neither been submitted nor concurrently submitted for a degree award in any other institution.

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The above declaration is confirmed

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DEDICATION

This work is dedicated to my family who was always with me since the beginning of this journey. To my father José Cunaca and my mother Helena Correia (in memoria), who laid the foundation of my career and personality.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

A.s.l	Above sea level
AFFP	African fruit fly program
EIL	Economic Injury Level
ET	Economic Threshold
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
Icipe	International Centre of Insect Physiology and Ecology
IPM	Integrated Pest Management
KPP	Knowledge, Perceptions and Practices
M	Meters
NGOs	Non-Governmental Organizations
SE	Standard error
SUA	Sokoine University of Agriculture
T	Ton (s)
USD	United States Dollar

CHAPTER ONE

1.0 General introduction and literature review

1.1 General description of the Mozambican fruit sector

Mozambique is located in the South Eastern part of Africa, covering 799 382 square kilometers, with a population of about 27 million (INE, 2017). The country has more than 36 million ha of arable land, of which only 10% is used (Cunguara *et al*., 2013). Agriculture is a key sector of the economy, a source of food and livelihood majority of the population (Cunguara *et al*., 2013). It employs more than 80% of the total population and 95% of those involved, live in rural areas (Advameg, 2007). In 2002, it was estimated that 73% of the rural families' income came from agricultural products selling in formal and informal markets (Mather *et al*. 2009). Agriculture accounts for 25% of Gross Domestic Product (GDP) and grows at a rate of 8.4% annually due to an expansion of farming areas and crop diversification (Cunguara *et al*., 2013). The diversification strategy pursued by both government and private sector is leading to the growth of sectors like fresh vegetables and fruits, in which Mozambique has an enormous potential.

The country has a favorable climate, good production resources, and has an advantage of seasonal differences with major fruit producers, which reduces potential competition in the market (Weeks and Bruns, 2016). Government, Non-Governmental Organizations (NGOs) and private sector are investing in fruit sector and the average size of the commercial farms is between 10 to 200 Ha (Weeks and Bruns, 2016). The biggest farms are located in Nampula, Manica, Inhambane and Maputo provinces. Among the fresh tropical fruits, cashew, banana, citrus and mango are the most produced followed by papaya, pineapple and avocado (INE, 2017).

In recent years, tropical fruits exports increased and it reached a value of USD 169.68 million in 2011 (INE, 2017). The main fresh fruit exports from Mozambique are bananas, oranges, grapefruit, avocado and mango (INE, 2017). These fruits are exported mainly to the Middle East, United Kingdom, European Union (Netherlands, Spain and Norway), China and some SADC countries (mainly South Africa, Zambia and Swaziland) (INE, 2017).

Currently, the average national mango crop production is 30 000 t per year (Weeks and Bruns, 2016; FAO, 2017). Of the 30 000 t of mangoes produced in Mozambique each year, only a small fraction (200-300 t) are exported, mostly to South Africa (Weeks and Bruns, 2016). Overall, domestic production of mangoes and its cultivated land increased very marginally over the past decade, with a slight decrease in 2013 and 2014 (FAO, 2017). This decrease was mainly due to stalled investments caused by the detection the oriental fruit fly, *Bactrocera dorsalis* in the country.

1.2 The threat of the oriental fruit fly to the Mozambican fruit sector

Fruit flies belong to order Diptera, family Tephritidae and Subfamily Dacinae. Tephritid fruit flies are morphologically picture-winged flies of variable size (small to medium), with wings normally between 4mm and 7mm long and females have a long ovipositor (De Meyer *et al*., 2014) (Figure 1.1).

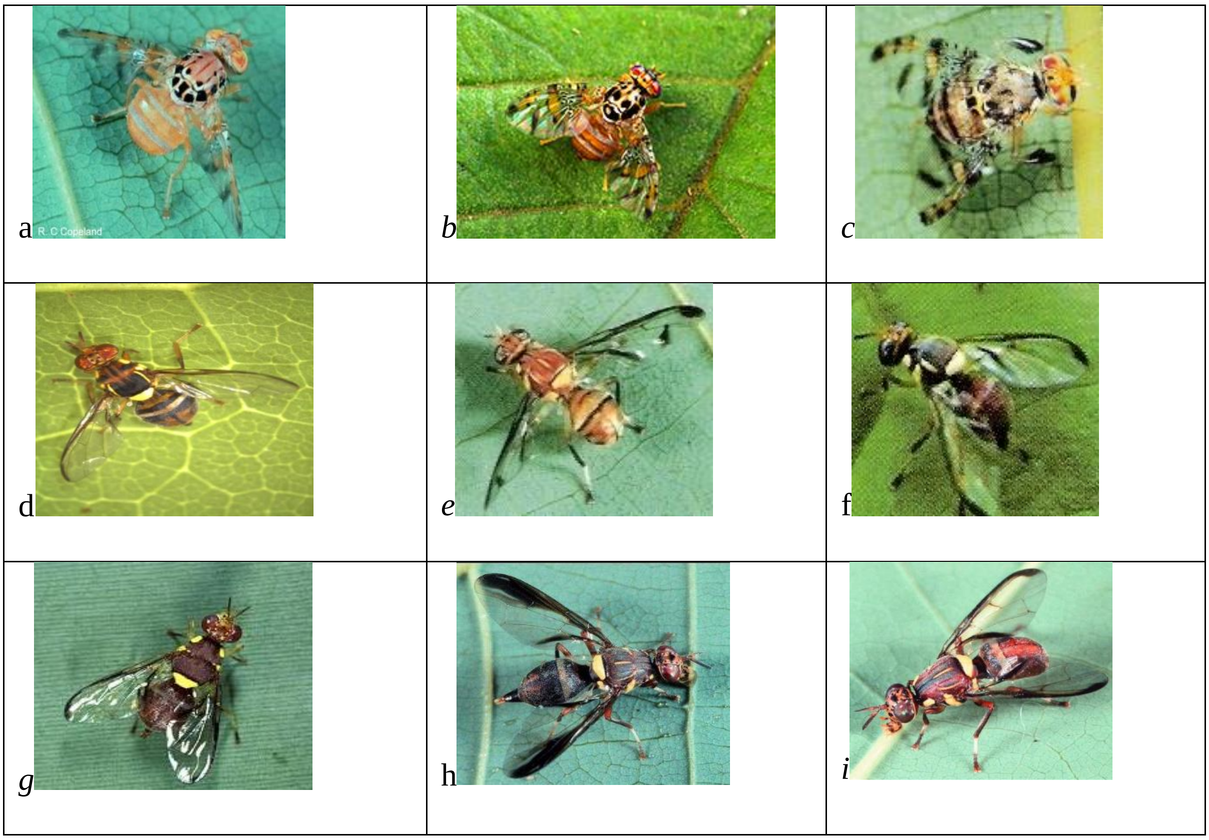

Figure 1.1: Habitus images of some African fruit flies: **(a)** ***Ceratitis cosyra*****, (b)** ***Ceratitis capitata*****, (c)** ***Ceratitis rosa*****, (d)** ***Bactrocera dorsalis*****, (e)** ***Zeugodacus cucurbitae*****, (f)** ***Bactrocera latifrons*****, (g)** ***Dacus ciliatus*****, (h)** ***Dacus bivittatus*** **and (i)** ***Dacus puntactifrons*****. Photo credits R. Copeland (a, c, e, f, h, i), S. Bauer (b), D. Cugala (d) and A. Frank (g).**

Dacinae fruit flies are economically important group of Diptera (Fletcher 1987; De Meyer *et al.*, 2013) which include the following genera: *Bactrocera* Macquart, *Dacus* Fabricius (Dacina), *Ceratitis* McLeay, *Capparimyia* Bezzi, *Carpophthoromyia* Austen, *Neoceratitis* Hendel, *Perilampsis* Bezzi and *Trirhithrum* Bezzi (Ceratitidina) (De Meyer *et al.*, 2014). Many species from these genera are known to its agricultural importance as pests of commercial fruits and vegetables (De Meyer *et al.*, 2014).

The distribution of *Dacus* and *Bactrocera* overlap in or around the Indian subcontinent, but the greatest diversity of *Dacus* is in Africa and the greatest diversity of *Bactrocera* is in south-east Asia and the Pacific (Karen *et al.,* 2012), while *Ceratitis* has predominantly Afro-tropical distribution (De Meyer, 2000; Vaníčková *et al.,* 2014). Other African and closely related genera are *Capparimyia* Bezzi, *Carpophthoromyia* Austen, *Neoceratitis* Hendel, *Perilampsis* Bezzi and *Trirhithrum* Bezzi (De Meyer *et al.,* 2013). The genus *Bactrocera* forms a very large group in Asia, Australia and the Pacific (De Meyer *et al.*, 2014).

Recently, three species from the genus *Bactrocera* namely *Bactrocera dorsalis* (=*invadens),* *Bactrocera* (*Bactrocera*) *latifrons* (Hendel) and *Bactrocera* (*Bactrocera*) *zonata* (Saunders) have found their way to Africa (De Meyer *et al.,* 2014; Vargas *et al.*, 2015). The oriental fruit fly, *Bactrocera dorsalis* initially known as *Bactrocera invadens* was first detected in Africa in 2003 in Kenya (Lux *et al.,* 2003; Drew *et al.*, 2005). The species spread rapidly and within two years it was reported in at least twenty seven countries attacking a wide variety of crops and continues to spread over the African continent (Lux *et al.,* 2003; Drew *et al.*, 2005; Rwomushana and Tanga, 2016; CABI, 2017) (Appendix 1).

Until 2005, the fruit fly fauna in Mozambique was represented by species from the genus *Dacus, Ceratitis, Trirhithrum, Perilampsis, and Carpophthoromyia* among others. *Dacus* was the most abundant, followed by *Ceratitis* (Roberto *et al*., 2005). After the first detection of *B. dorsalis* in Mozambique in Niassa province in 2007 (Correia *et al.*, 2008), in Vanduzi-Manica (central region) in August 2008, in 2012 the invasion of *B. dorsalis* in Mozambique continued and finally invaded Maputo province (Cugala *et al.*, 2016). Nowadays *B. dorsalis* is the most abundant fruit fly species in Mozambique (Cugala *et al.*, 2016) (Table 1.1).

Table 1.1: Economically important fruit flies in Mozambique

Genera	**Number of species reported in Africa**	**Number of species reported in Mozambique**
Ceratitis	95	12 (*C. anonae*, *C. bremii, C. capitata, C. cosyra, C. discussa, C. ditissima, C. edwardsi, C. fasciventris, C. millicentae, C. pedestris, C. quinaria, C. rosa)*
Trirhitrum	40	2 (*T. albomaculatum, T. nitidum)*
Dacus	191	30 (*D. africanus, D. amphoratus, D. binotatus, D. bivittatus, D. brevis, D. chiwira, D. ciliatus, D. durbanensis, D. eclipsis, D. eminus, D. famona, D. ficicola, D. flavicrus, D. frontalis, D. fuscatus, D. fuscinervis, D. fuscovittatus, D. hamatus, D. Kariba, D. longistylus, D. lounsburyii, D. opacatus, D. pallidilatus, D. pamelae, D. plagiatus, D. pullescens, D. punctatifrons, D. purpurifrons, D. umbeluzinus, D. vertebratus*)
Bactrocera	14	2 (*B. biguttula, B. dorsalis*)
Zeugodacus	1	1 (*Z. cucurbitae*)
Capparimyia	8	0
Neoceratitis	5	0
Perilampsis	17	2 (*P. curta, P. miratrix*)

Sources: Roberto *et al*. (2005); Virgilio *et al.* (2014) and Cugala *et al*. (2016).

Although each genus has distinctive morphological characteristics, its ecology and the direct damage caused to the fruits and vegetables are similar (Ekesi and Billah, 2007). The female fruit fly lays eggs inside the fruit and the larvae develop inside the fruit, as a result the fruit falls to the ground just before the larvae pupate. The adult stage of fruit flies can be found in the environment, eggs and larvae inside the fruit and pupae in the soil. The entire life cycle takes about 17 days from the egg to the adult fly emergence at 25°C and 80% RH (Ekesi *et al.*, 2006; CABI, 2017).

Bactrocera dorsalis is associated with over 40 host plants with mango being one of the most preferred host plant (De Meyer and Ekesi, 2016; Rwomushana and Tanga, 2016) (Appendix 2). In mango, *B. dorsalis* infestation can cause more than 80% of damage and complete crop loss may happen in the absence of pest control measures (Ekesi, 2010; Nankinga *et al.*, 2014; De Meyer and Ekesi, 2016). Damage assessment studies conducted in Cabo Delgado (northern part of Mozambique), showed infestation rates varying between 36.7% and 92.5% in different hosts including mango and guava (Jose *et al.*, 2013).

In addition to direct losses, indirect losses due to quarantine restrictions imposed by importing countries have been enormous (Ekesi, 2010). *Bactrocera dorsalis* is a well-documented invader and ranks high on quarantine lists worldwide (Khamis *et al*., 2009). Therefore, countries that confirmed occurrence of the pest their exports are affected by the quarantine restrictions imposed by importing countries. The export of *B. dorsalis* host fruit species such as mangoes from Uganda, Tanzania and Kenya were banned by the Seychelles, Mauritius, South Africa and United States of America (Kibira *et al.*, 2010). Although the losses across the entire African continent have not been quantified, sections of the industry believe that bans on exported goods result in losses of approximately 2 billion USD annually (De Meyer and Ekesi, 2016). Mozambique also experienced revenue losses of 2.5 million USD at Vanduzi Company, in the Central province of Manica, when South Africa imposed a three-week ban of fruits and vegetables produced in the country in 2008 (Cugala, 2011).

The occurrence of *B. dorsalis* also affects the potential income of fruit and vegetable farmers. As a result farmers fears to invest or they even consider pulling out from the sector and this jeopardizes employment opportunities that would be derived through locally produced fruits and vegetables (Cugala *et al*., 2011; Canhanga, 2012; Nankinga *et al*., 2014). On the other hand, efforts to control fruit flies by using broad-spectrum synthetic insecticides can negatively affect natural enemies, honey bees, or other non-target organisms and even the human health (CABI, 2017). Insecticide pest resistance problems and pesticide residues on fruits (minimum residue levels) are part of possible impacts to consider when management strategies are being developed and implemented.

Moreover, invasive fruit flies such as *B. dorsalis* are a serious threat to biodiversity in the regions they invade (Ekesi *et al*., 2016) because of their negative effects on the ecology of native species by competing with indigenous tephritids (Ekesi *et al*., 2009). The outcome of such competition resulted in displacement of native species. Competitive displacement between invasive species and native species was observed in several countries in Africa, for example Kenya (Ekesi *et al.,* 2009), Tanzania (Mwatawala *et al.,* 2009) and Mozambique (Jose *et al.,* 2013) where *Bactrocera* species is gradually replacing *Ceratitis* in cultivated and native hosts.

Such losses reduce the profits of the fruit growers and traders, and contribute to high cost of fruits on the local urban markets. Because of the potential direct damage it can cause and their economic, social and ecological impact, it has become a pest species of major concern to fruit growers in the continent affecting not only the mango sector but also the sources of livelihood, income and food security of horticultural farmers and families that produce and sale fresh fruit and vegetables across Africa (Ekesi *et al.,* 2009; Canhanga, 2012; De Meyer *et al.,* 2014; Nankinga *et al*., 2014; Ekesi *et al.,* 2016).

1.3 *Bactrocera dorsalis* co-existence with other fruit flies species in mango

Most of the fruit fly species in Africa are highly polyphagous with their host ranges overlapping to a varying extent (Rwomushana and Tanga, 2016). When rearing fruits, it is common to identify more than one emerged fruit fly species, particularly for cultivated hosts. Mango is one of the most commonly infested fruits that are attacked by a complex of fruit fly species (Rwomushana and Tanga, 2016).

Both invasive and indigenous tephritid fruit flies attacks mango in Africa, being the most economically important: *B. dorsalis*, *Z. cucurbitae*, *B. zonata* in the invasive group and indigenous species such as *C. anonae*, *C. capitata*, *C. catoirii*, *C. cosyra*, *C. ditissima*, *C. fasciventris*, *C. rosa*; *C. silvestrii*, *C. quinaria*, *C. punctata*, *C. flexuosa*, *D. bivittatus* and *D. ciliatus* (Vayssières *et al*. 2008; Ekesi *et al*., 2009; Mwatawala *et al*., 2009c; Rwomushana and Tanga, 2016). Of these, *B. dorsalis*, wherever it occurs on the continent is ranked as the most important pest of mango followed by *C. cosyra* (Rwomushana and Tanga, 2016). In most sampling records in Tanzania by Mwatawala *et al*. (2004), in Kenya (Ekesi *et al.*, 2006), Benin (Vayssières *et al.*, 2008) and Mozambique (Jose *et al.*, 2013), *B. dorsalis* frequently shared the same mango with *C. cosyra*.

However, prior to the invasion of *B. dorsalis*, *C. cosyra* was the primary pest of mango whose average damage was estimated at about 20-30% (Lux *et al*., 2003; Badii *et al*., 2015). In Kenya, a shift in dominance between *C. cosyra* and *B. dorsalis* was observed in mango orchards just a year after its detection in the country (Ekesi *et al*., 2009). At the same locality, over 80% of mango fruits were infested with both fly species, with *B. dorsalis* accounting for 91% of puparia collected from the fruits. Same phenomenon was reported in Tanzania (Mwatawala *et al*., 2009a) and Mozambique (Jose *et al*., 2013). It became clear that this *Bactrocera* species was competing strongly with the marula fruit fly, *C. cosyra*, being equally or even more abundant.

1.4 Management of fruit flies, with emphasis on *B. dorsalis*

Fruit fly control requires a combination of management strategies, commonly known as Integrated Pest Management (IPM). According to the Food and Agriculture Organization (FAO) and the International Organisation of Biological Control (IOBC), IPM is defined as an "approach to crop protection using methods that comply with ecological, economic and toxicological norms, giving preference to the choice of natural limitation agents, and remaining within tolerance thresholds".

A fundamental aspect of this method is that it is based on biological and economic indicators affecting pests and, therefore, their management (Vayssières *et al.,* 2009). Management components such as the use of biological control, cultural control, baiting techniques and male annihilation technique (MAT) have been recommended for fruit fly control within an IPM context (Ekesi and Billah, 2007; Badii *et al.,* 2015; Mwatawala *et al.*, 2015).

Monitoring is an important component of any pest management strategy and is used to determine the presence of a pest, to describe seasonal abundance and spatial distribution in a particular area. This information about the timing and extent of pest outbreak can improve efficiency of control measures by timely application of control measures in accordance with the economic injury levels (Ekesi and Billah, 2007; Vayssières *et al.*, 2014).

1.4.1 Monitoring of fruit flies

Tephritid fruit flies are trapped for a variety of reasons: surveillance, suppression, and ecological study among others (Tan *et al*., 2014). Tools used in monitoring fruit flies consist of attractants, traps and insecticides (used in traps as killing agents) (Manrakhan, 2016). The two main types of attractants used in fruit fly monitoring include parapheromones (male lures) and food attractants. Male lures are species-specific, attract only male fruit flies and are usually preferred in detection programmes due to their specificity while food attractants are based on host odours, not specific and generally female biased (Manrakhan, 2016) although it can capture both females and males (FAO/IAEA, 2013).

The parapheromone terpinyl acetate, capilure, β-caryophyllene-based lure commercially sold as 'Ceratitis lure', ginger root oil or egolure (EGO) and trimedlure (TML) captures species of the genus *Ceratitis* (including *C. capitata*, *C. cosyra* and *C. rosa*), methyl eugenol (ME) captures a large number of species of the genus *Bactrocera* (including *B. dorsalis*, *B. zonata*, *B. carambolae*, *B. philippinensis* and *B. musae*), spiroketal captures *B. oleae* and cuelure (CUE) captures other *Bactrocera* species (*B. tryoni*) and Z. *cucurbitae* (FAO/IAEA, 2013; Manrakhan, 2016), while for *D. vertebratus* is used vertlure (Tan *et al*., 2014). Among the food-odour attractants, is being used liquid protein hydrolysates and synthetic lures that contain synthetic versions of the main volatile components found in protein hydrolysate lures (Manrakhan, 2016).

Regarding the trapping devices, FAO/IAEA (2013) classifies it in dry traps (the fly is caught on a sticky material board or killed by a chemical agent) and wet traps (the fly is captured and drowns in the attractant solution or in water), having traps that can be used dry or wet. Some of the most widely used are easy trap, multilure trap, tephri or chempac trap and lynfield trap (Figure 1.2). In some dry traps, killing agents are a sticky material or a toxicant such as dichlorvos, malathion, fipronil and pyrethroids (such as deltamethrin).

Figure 1.2: Different trapping devices : a) Tephri, b) Multilure, c) Mcphail , d) Lynfield, e) Jackson e f) Sensus. Source: Manrakhan (2010).

Monitoring of *B. dorsalis* in Africa is done using the male attractant methyl eugenol placed in different types of bucked traps (mcPhail, multilure tephri or locally designed traps) and an insecticide strip (DDVP: 2,2 Dichlorovinyl dimethyl phosphate) (Ekesi and Billah, 2007; Vayssieres *et al*., 2009c; Cugala, 2011; Manrakhan *et al*., 2011). Protein baits as biolure 3C, torula yeast and nuLure (2% a.i.) are also used to attract flies from nearby orchards (Manrakhan *et al*. n.d.; Ekesi *et al*. 2011; Nankinga *et al*., 2014; Mwatawala *et al*., 2015). Detailed description of *B. dorsalis* detection and monitoring is harmonised in published guidelines (FAO/IAEA, 2013).

1.4.2 Control strategies

Fruit flies control strategies are intended to control one or more of the fruit flies development stages, which is achieved through preventive and curative control methods.

1.4.2.1 Preventive strategies or cultural control

Within the preventive approaches it is included the use of fruit fly resistant varieties, to early harvesting of fruit, bagging of fruit and field sanitation. Commonly used cultural practices that have been evaluated/implemented, either alone or in combination with other IPM tools, to suppress populations of *Bactrocera* species include field sanitation, fruit bagging, augmentorium and soil disturbance (Vargas *et al*., 2015).

a) Field or orchard sanitation is the main component of fruit flies IPM (Vargas *et al*. 2015) and consists in collection of infested fruits that are either buried, burned or fed to animals etc. This prevents larvae from pupating and hence breaks life cycle of the flies. Orchard sanitation was successful used against *B. dorsalis* in South Africa (Manrakhan *et al*., 2011), Tanzania (Mwatawala *et al*., 2015), Kenya (Ekesi, 2010; Muriithi *et al*., 2016) and Hawaiii (Piñero *et al.*, 2009).

b) Fruit bagging protects the fruits from oviposition by females' fruit flies. Fruit bagging has been used against fruit flies in Uganda resulting in fewer (more than 50% less) pupae recovery in fruit that have been bagged compared with unbagged fruit (Nankinga *et al*., 2014; Isabirye *et al*., 2016).

c) Augmentorium is used for disposal of fruits where parasitoids were released. The augmentorium traps the emerging large sized adult flies and but allows small sized parasitoids to escape and return to the field. Augmentorium was used against *B. cucurbitae* in Hawaii and the same sanitation technique was applicable to the other tephritids *(*Klungness *et al*., 2005).

d) Soil disturbance exposes by plowing or ground flooding, the fruit fly pupae to environmental conditions leading to increase of its mortality, but few reports exist in the literature on the effects of soil disturbance on suppression of *Bactrocera* species (Vargas *et al.*, 2015).

e) Harvesting of fruits when they are mature but not ripe reduces infestation by fruit flies. Early harvesting was used to prevent *B. dorsalis* infestation in banana in Mozambique (Cugala *et al.,* 2014) and mango in Uganda (Nankinga *et al*., 2014; Isabirye *et al*., 2016).

f) Removal of unmanaged host plants or alternative hosts is recommended as these fruits could provide ideal breeding grounds for fruit flies particularly after regular baiting had ceased at the end of the commercial harvest period (Lloyd, 2007).

1.4.2.2 Curative control strategies

a) Insecticide cover sprays

The history of fruit fly control with full cover sprays started with inorganic insecticides (e.g., lead arsenate) in the early 1900s (Vargas *et al*., 2015). it spanned the century with a transition to synthetic insecticides, such as chlorinated hydrocarbons, organophosphates (malathion, chlorpyrifos, phoxim, and triazophos), pyrethroids (alphamethrin and deltamethrin), carbamates, bioinsecticide (abamectin), neonicotinoid insecticide (imidacloprid), and phenyl pyrazole insecticide (fipronil) (Wang *et al*., 2013; Vargas *et al*., 2015).

There are also experiences with delta-methrin combined with azadirachtin, trichlorfon, cypermethrin, and avermectin with *B. dorsalis* showing pesticide resistance to a many of these insecticides (Wang *et al*., 2013). In Tanzania, for example, although there is no insecticide products registered specifically for fruit fly control, farmers use a wide range of active ingredients including dimethoate, lambdacyhalothrin, deltamethrin and dichlorovos (Mwatawala, 2016).

Among the advantages of insecticide cover sprays it is included the fact that they are affordable, convenient and provide a high level of protection against fruit fly infestation with consistent results (Vargas *et al.,* 2015). However, conventional insecticide sprays have been associated with fly resistance, environmental pollution and health problems.

Farmers targeting local, non-organic markets can use synthetic insecticides to control fruit flies (Mwatawala *et al*., 2015).

b) Protein or food baits

Food baits are hydrolysed proteins or their ammonium-based mimics combined with a killing agent and applied in localized spots by ultra-low volume in a section ($1m^2$) of the tree canopy, to the ground or aerial application (Ekesi, 2016). They are available both in liquid and dry synthetic formulations (Ekesi and Billah, 2007). A number of liquid protein baits are available commercially in Africa including GF-120, nuLure, mazoferm E802, hymLure, buminal, solbait, prolure, questlure and fruit fly mania (Ekesi, 2016; Ekesi *et al.*, 2016). A dry synthetic attractant based on ammonium acetate, trimethylamine, and putrescine was recently developed and marketed as biolure for the suppression of mainly *C. capitata* (Ekesi *et al*., 2016).

The baits tested in Africa against *B. dorsalis* included GF 120 (Vayssieres *et al*., 2009c; Mwatawala *et al*. 2015) and mazoferm E802 (Ekesi *et al*., 2014). Spray of these food baits commonly reduce fruit fly populations by 80–90 % and based on bait spray costs, yield data and monetary gains, a cost-benefit ratio of 1:9.1 has been reported in Kenya, which is generally acceptable for smallholder and large-scale fruit producers as well (Ekesi, 2016).

c) Soil drenches

Consists of the application of insecticides under host trees where fruit fly larvae, pupae or gravid adult females have been detected. Diazinon was one of the insecticides used in California and Florida, but due to its negative effects on aquatic organisms in freshwater ecosystems, diazinon was replaced by other insecticides such as 0.1% chorpyriphos, lambda-cyhalothrin, biopesticides like spinosad and soil fungal pathogen *Metarhizium anisopliae* (Vargas *et al.*, 2015).

Soil inoculation or soil treatment with fungal pathogens can also be done with *Beauveria bassiana*, *Isaria fumosorosea*, and *Lecanicillium lecanii* (Ekesi *et al.*, 2016). Exposure to *B. bassiana* and *M. anisopliae* lead to highest mortality rates of between 87 to 100% in *C. capitata* and *C. fasciventris* and between 72 and 79% in *C. cosyra* after 4 days in laboratory trials in Kenya (Ekesi *et al.,* 2016). The soil can also be inoculated with neem cake and other botanical formulations (Ekesi and Billah, 2007). In recent studies, several potential isolates were identified against *B. dorsalis* both for soil inoculation targeting pupariating larvae and adult using auto dissemination devices (Badii *et al.,* 2015).

d) Male annihilation technique (MAT)

In this technique is used a device (such as fibreboard or coconut husk blocks, cotton string or wick, or molded paper pulp) impregnated with male lures mixed with a toxicant (naled, malathion or fipronil) (SPC Land Resources Division, 2010; Vargas *et al.*, 2015; Ekesi, 2016). The aim is to reduce male fruit fly populations such that mating does not occur (in the case of eradication) or is reduced to low levels (in the case of suppression) (Ekesi, 2016). A variety of male lures are available for use in MAT but the three predominant are methyl eugenol, cuelure and trimedlure (Ekesi, 2016). For *B. dorsalis*, methyl eugenol is used as lure since the males' shows high response to this compound.

The oriental fruit fly was eradicated from Rota Island (1963), Mariana Islands (1962–1965) and Guam (Steiner *et al*. 1965 cited by Vargas *et al.*, 2014). Outstanding successes using this method have been reported for eradicating oriental fruit fly in California and the Amami Islands of Japan (SPC Land Resources Division, 2010). Combination of protein baits and MAT is gaining importance in Africa as one of the major components of fruit fly suppression strategies (Ekesi and Billah, 2007; Manrakhan *et al*., 2011; Mwatawala *et al*., 2015; Ekesi, 2016; Cugala *et al*., 2016, Ndlela *et al*., 2016). The first attempt to eradicate *B. dorsalis* was done in 2010 in South Africa, and was achieved successfully through of combination MAT with GF-120 bait sprays and orchard sanitation within a period of twelve weeks (Manrakhan *et al*., 2011).

e) Sterile insect technique (SIT) or sterile insect releases

The SIT is a form of birth control imposed on an insect pest population to reduce its numbers, which involves rearing large numbers of the target pest species, exposing them to gamma rays to induce sexual sterility, and releasing them into the target population of the pest on an area-wide basis (Klassen, 2005). It is species-specific and does not release toxic agents into the environment (Badii *et al.*, 2015) and works well in the islands (Ekesi *et al.*, 2016).

By using SIT *B. dorsalis* was successfully eradicated from Okinawa and neighbouring islands in the Ryukyu Archipelago, Japan (Enkerlin, 2005; CABI, 2017) and in Mauritius SIT has targeted *B. zonata* with significant success. SIT was successfully applied against the mediteranean fruit fly, *C. capitata* from areas it had already infested in Southern Mexico (Enkerlin, 2005). However, no SIT program specifically for *B. dorsalis* has been developed in mainland Africa (Badii *et al.*, 2015).

f) Releases of natural enemies or biological control

Biological control is the use of parasitoids, predators or pathogens to control pest populations by introduction, augmentation and/or conservation of these natural enemies. In the case of fruit fly pests, the main biological control agents are parasitoid wasps

(Hymenoptera: Braconidae, Eulophidae, Pteromalidae), ant predators (Hymenoptera: Formicidae) and a fungus *Metarhizium anisopliae* sensu lato (Metschn.) (Vayssières *et al.*, 2016). Biological control practices are advantageous in that the natural enemies can be specialized in searching for the target pests' species particularly when parasitoids are used, is also relatively safe, permanent and economical (Ekesi and Billah, 2007).

Extensive work has been conducted since 2006 through mass rearing of parasitoids for introductions and augmentative releases. For example, *Fopius arisanus* was released in Kenya in 2008, Tanzania in 2010 and Mozambique in 2012. It was also released in the Comoros Islands, Cameroon, Benin, Togo, and Senegal, and parasitism of *B. dorsalis* reached up to 40% depending on the fruit species (Ekesi *et al.,* 2016; Mohamed *et al*., 2016).

The predator weaver ant, *Oecophylla longinoda* (Hymenoptera: Formicidae) protects the fruit tree against fruit flies. Although predation on adult fruit flies took place, deterrence effects of ant cues that are left on fruits and trees as well as disturbance by ants during fruit fly oviposition seemed to be the most important causes of reducing fruit fly damage (Vargas *et al.,* 2015; Ekesi *et al.,* 2016). This weaver ant is endemic to Sub-Saharan Africa and frequently found in forested wild vegetation and unsprayed orchards of mango, *Mangifera indica* L.; citrus species (*Citrus spp*.); cashew, *Anacardium occidentale* L.; guava, *Psidium guajava* L.; custard apple, *Annona muricata* L.; cocoa, *Theobroma cacao* L.; coconut, *Cocos nucifera* L.; coffee, Coffea x arabusta Capot and Aké Assi; and oil palm, *Elaeis guineensis* Jacq. Amongst others (Vayssières *et al.,* 2016).

1.5 Fruit flies integrated management across African continent

Examples of IPM programs targeting *Bactrocera* species include the Regional Fruit Fly Project in the Pacific Island Countries and Territories and the Hawaii Area-Wide IPM program (HAWPM), implemented over a 10-year period in Hawaii (Vargas *et al.*, 2015). In Africa, the International Centre of Insect Physiology and Ecology (*icipe*) has spearheaded development and implementation of IPM strategy for managing fruit flies on mango, under the African fruit fly program (AFFP) (Muriithi *et al.*, 2016). A book by Ekesi *et al*. (2016) present case studies of fruit flies IPM from African countries including Tanzania, Benin, Nigeria and Uganda.

An IPM program against *B. dorsalis* was developed in Tanzania, by the Sokoine University of Agriculture (SUA), hereafter designated as SUA IPM , was based on calendar application of baits which were applied throughout the orchards (Mwatawala *et al*., 2015). The lowest incidence of *B. dorsalis* was recorded in fruits harvested from orchards under bait treatment when comparing to other treatments (botanical and synthetic pesticide) (Mwatawala *et al*., 2015). Therefore the program was recommended for the commercial mango farmers (Mwatawala *et al*., 2015).

The mango farmers from Mozambique and Tanzania have similar characteristics and the same IPM approach could be implemented in Mozambique. However, there was a need to optimize the SUA IPM program by introducing decision-making criteria like Economic Injury Level (EIL) and a focused control program on pest hot spots. Such program should be based on farmers' knowledge and perception on fruit flies, which is a basic information to assess the impact of the pest that will, thereafter, define the level of concern they have in relation to the pest and the efforts they would do to control the pest.

Information on the mango farmer's perception of pest infestation does not exist for Mozambique. However, in Ghana it was studied and concluded that the mango farmers were aware that tephritid fruit flies cause serious damage to their crops with detrimental consequences on their earnings (Badii *et al*., 2012).

Additionally, the formulated IPM program does not consider spatio-temporal distribution of *B. dorsalis* in Mozambique. The local population dynamic of tephritids are influenced by moisture, temperature, light, topography, host plant availability and phenology, the presence or not of bio control agents (Castrignan *et al*., 2012; Weldon *et al.*, 2014). Spatio-temporal studies are pre-requisite to optimize control strategies because of the following reasons (Vargas *et al*. 1990; Castrignanó *et al*. 2012; Aidlin-Harari *et al*., 2016):

a) Density of flies obtained from a trapping, will help to locate the origin of single infestations, to identify hot-spots/patches and cold-spots/gaps in the orchard and start control measures from hot spots rather than implementing it in the whole orchard.
b) Fruit infestation data obtained from fruit rearing provide necessary information to identify major breeding sites for implementation of field sanitation and planting of trap crops for bait sprays.
c) Area wide population dynamics data provide baseline population estimative to judge the effectiveness of IPM procedures.
d) Population dynamics data by habitat pinpoint times of the year when populations of fruit flies are lowest and mass trapping will be most effective.
e) Spatial distribution data delineate areas to be targeted for male annihilation treatments.

Currently, data on spatial and temporal abundance of *B. dorsalis* do not exist in Mozambique. Such data, however, were reported in African countries namely Kenya, Tanzania and Benin (Ekesi *et al*., 2006; Mwatawala *et al.,* 2006; Vayssières *et al*., 2009b). Hence there was no solid basis for the establishment of an IPM program in Mozambique based on data from other countries.

Finally, the existing IPM programs do not have a component of economic injury level (EIL), which are, together with the economic threshold (ET) considered the economic indicators for making decision in pest management. The ElL is defined as "the lowest population density that will cause economic damage", while the ET is “the density at which control measures should be determined (initiated) to prevent an increasing pest population from reaching the EIL” and is usually a percentage of the EIL (Pedigo *et al.*, 1986; Pedigo and Rice, 2006). EILs for *B. dorsalis* does not exist in Mozambique although it have been calculated in Benin (Vayssières *et al.*, 2009a).

EIL is a mathematical framework (model or equation) to address economic aspects of decision making on pest management. This model was proposed by Pedigo *et al.* (1986), and have four primary components affecting the ElL: (a) market value, (b) management cost, (c) injury per insect density, and (d) host damage per unit of injury. All these should be considered in defining an EIL for a specific pest species, in a specific agro-ecological area, and for a specific socio-economic system. Thus, the EIL from Benin cannot be applied in a Mozambican context.

Therefore, this study was proposed to reduce the losses caused by *B. dorsalis* in Manica province, Mozambique, through an optimized IPM package. Application of optimized IPM based on EIL will improve the efficiency of the SUA IPM program through spot and timely application thus reducing costs. Adherence to threshold levels in fruit fly management in South Africa helped fruit producers to achieve fruit fly free consignments and has led to very low export market interceptions of fruit flies in fresh fruit consignments from South Africa (Manrakhan, 2016). Besides this, Vayssières *et al*. (2009a) testing the method of EIL decision making has revealed how useful and feasible it is for mango production in the context of the small farms in Benin. The authors concluded that the EIL approach is appropriate when treatment based on GF-120 NF is used in Africa for integrated pest control of fruit flies, although it has to be adjusted for each context.

1.6 Objectives

1.6.1 Overall objective

The overall objective of this study was to reduce losses due to fruit flies in mango through an optimized IPM package against *Bactrocera dorsalis* in Manica province, Mozambique.

1.6.2 Specific objectives

Specifically, the study sought to:

a) Describe the perceptions of fruit producers on fruit flies pest status and their management practices in Manica province.
b) Establish spatial and temporal distribution of *B. dorsalis* in selected mango orchards.
c) Determine the Economic Injury Level (EIL) of *B. dorsalis* in mango.
d) Determine the effectiveness of an optimized version of the SUA IPM program for *B. dorsalis* control in Mozambique.

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CHAPTER TWO

2.0 Perception of fruit farmers on the occurrence of the oriental fruit fly *Bactrocera dorsalis* (Diptera: Tephritidae) and its associated economic impact in Manica province, Mozambique

2.1 Abstract

Fruit flies (Dipera: Tephritidae) are among the most important pests of fruits and vegetables in the world. The family comprises invasive and quarantine species that cause direct damage on fruits and vegetables and also cause economic, social and ecological impacts. The oriental fruit fly, *Bactrocera dorsalis* was detected in Mozambique in 2007, and in 2008 it was already present in Manica province, causing damage on fruits and commercial restrictions. Therefore, there was a need to implement a program for *B. dorsalis* management in Manica province. However, there was no baseline information regarding key features associated with the knowledge, perceptions, impact and practices of fruit producers regarding fruit fly pests and their management. In February 2015, fruit farmers from different districts of Manica province were interviewed. Frequencies and analysis of variance were performed through SPSS 16.0 and STATA 12.0. We interviewed 36 fruit farmers from six districts and where mango was the most produced fruit crop, alone or in combination with banana and citrus. Fruit flies were the main pest problem in more than 80% of mango and citrus orchards while only 19.0% of the banana plantations reported phytosanitary problems with fruit flies. The majority of the farmers (58.33%) could not identify fruit flies species although they could describe symptoms of damage (91.66%). More than 70% the respondents indicated that fruits damaged by fruit flies had reduced quality and could not be sold, which resulted in increasing volumes of uncommercialized fruits, since the detection of the pest. The monetary value of this loss

was more severe among the mango producers, reaching a value of USD 135,784.8 in 2014/15 crop season. Large scale mango farmers control the pest while small scale mango farmers do not mainly because they are not aware of the fruit flies management strategies. Training on pest identification and management strategies should be conducted among small scale farmers in Manica province to reduce the economic loss caused by fruit flies.

2.2 Introduction

Production of vegetables and fruits is one of the sources of income for many households in Mozambique (Mather *et al.*, 2009; Cepagri, 2017). Commercial fruits such as banana (*Musa* sp.), citrus (*Citrus* spp.), mangoes (*Mangifera indica* L.), litchi and (*Litchi chinensis* L.) and pineapple (*Ananas comosus* L.) are produced in the provinces of Maputo, Gaza, Inhambane, Manica, Sofala, Nampula and Cabo Delgado. In 2014, the estimated production of citrus, banana and mango) was about 55 000 t, 670 000 t and 27 887 t, respectively (FAO, 2017; INE, 2017). In 2014, the value of exported bananas, citrus and mango reached of USD 42 million, although the peak in exports of fresh fruits were reported in 2011 (USD 169.68 million) (INE, 2017; FAO, 2017).

Horticultural sector in the Maputo and Manica provinces could generate estimated revenues of more than USD 20.75 million per year from both commercial and smallholder (family) production (Cugala *et al*., 2016). Mozambique exports banana to South Africa, Middle East and Europe, while citrus (orange and grape fruit) are exported to Europe (Cepagri, 2017). Mango is mainly exported to South (Weeks and Bruns, 2016) Africa. Only mangoes from Manica province are being exported with quantities less than 500 t/year (CFAM, 2012; Weeks and Bruns, 2016).

However, the fruit and vegetable sector is severely threated by both biotic and abiotic constraints. Among the biotic factors, fruit flies are the most important pest causing enormous economic damage (Ekesi *et al*., 2009, Cugala, 2011). It was considered as the most destructive insect pests of fruit and vegetables in the world (Ekesi *et al*., 2009 and Vayssiéres *et al*., 2008).

The oriental fruit fly, *Bactrocera dorsalis* (Hendel) is a quarantine pest species, which was introduced in Africa from Asia, and affects both quality and yield of fruits and vegetables (Ekesi *et al*., 2009). This species was reported to reduce access to international markets due to rigorous restrictions measures imposed by the importing countries. Since its detection in Manica province in 2008 (Cugala, 2011), both national and international quarantine measures were instituted. In September 2008, South Africa banned temporarily the importation of fresh fruits from Mozambique and in February 2010, Zimbabwe did the same (Tostão *et al*., 2012). At the same time, emerging mango growers in the province wanted to give up the fruit production.

Fruit fly management became one of the national agricultural authority priorities and there was a need to test and implement different control strategies to further develop a program for *B. dorsalis* management in Manica province. However, there was no baseline information available on knowledge, perceptions and practices of fruit producers on fruit fly pests, economic impact and their management. Determination of these important pre-requisites was the major focus of this study.

This information is important in decision making, so as to help the Government or agricultural authorities to decide on the magnitude of management strategies that should be implemented to control the pest. IPM requires extensive collaboration among scientists and socio-economists because it is more easily adopted if tailored to the needs of farmers (Morse and Buhler, 2015). Reliable information of fruit producers' practices would help to assess opportunities and constraints for decision making at the farm level so that appropriate fruit fly control decision tools and control strategies can be designed to meet the needs of fruit producers (Badii *et al*., 2012).

2.3 Material and methods

2.3.1 Study area

The study was conducted in Manica province, which is located in the central part of the country. It has an area of 62,272 km² and is surrounded by Zimbabwe in the west, Tete province in the northwest, Sofala province in the east, Save river in the south, and Zambezi river in the northeast.

2.3.2 Survey methods

A semi-structured questionnaire was used to interview fruit growers that were selected through the assistance of the Provincial Directorate of Agriculture (PDA), which provided a list of officially registered fruits farmers in the province (Appendix 4). A snow ball sampling method, where the interviewed farmer indicated other/s with same characteristics were also used (Bellon, 2001).

Target farmers were purposively selected based on the criteria that the farmer had at least five consecutive harvests from his/her farm, the fruits produced were the preferred host of the fruit fly pests, like mango and guava and that a farmer owned a minimum area of 1 ha or at least 30 trees of commercial mango trees.

Methods and tools for data collection were based on procedures for analyzing agricultural problems and assessing farmers' knowledge, perceptions and practices (KPP) as documented by Bellon (2001) and Mutsaers *et al*. (1997). Semi-structured questionnaire (Appendix 5) had both closed- and open-ended questions to assess the KPP of fruit producers on fruit fly pests and their management.

Data were collected from 9th to 13th February 2015. Interviews were carried out in the farmer's field by members of the research team composed of technicians from PDA. The original questionnaire was in Portuguese but questions were translated into English and local languages when necessary.

The questionnaire recorded plantation information, knowledge of fruit fly pests, fruit fly damage and economic impact on production and commercialization as well as fruit fly management strategies used by the farmers (Badii *et al*., 2012). Colour photographs of the fruit flies were used to verify farmers' responses. Data on fruit production volumes, quantities of fruits sold in local markets and exported volumes were also collected.

2.3.3 Data analysis

All data generated from the field survey (questionnaire) were introduced into an excel spreadsheet and analyzed using appropriate statistical procedures for description (frequencies and percentages). Statistical analysis was performed using the Statistical Package for Social Sciences (SPSS for Windows version 16.0).

Analysis of variance (ANOVA) was performed using Stata 12.0, to assess the effect of the season on fruit production volumes, quantities of fruits sold in local markets, exported and in not commercialized volumes due to fruit flies infestation in mango, banana and citrus.

2.4 Results

The survey comprised a total of 36 farmers from six of the twelve districts of Manica province, namely Manica, Gondola, Barue, Vanduzi, Macate and Sussundenga districts. From the total number of the respondents, 47.2% were from Macate district followed by Bárue, Sussundenga, Manica, Vanduzi and Gondola districts with 19.4%, 11.1%, 8.3%, 8.3% and 5.6% of the total interviewed fruit farmers, respectively (Figure 2.1). Majority of the respondents from Macate district were members of an association of small scale fruit producers cultivating an area of 320 ha. In general, half of the interviewed farmers (50%) were large scale farmers with production areas of more than 5 ha and other 50% were small scale farmers.

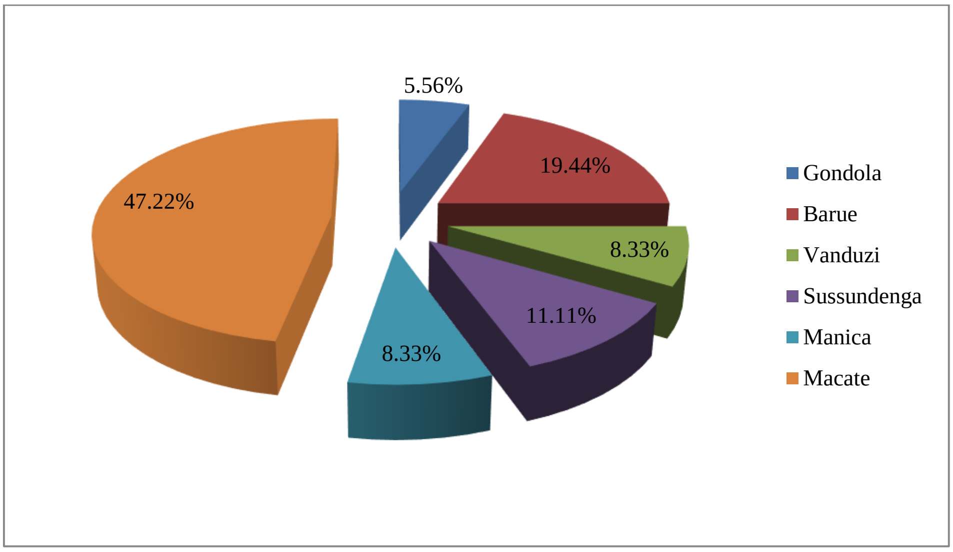

Figure 2.1: Districts covered by the questionnaire and the proportion of respondents by district.

The PDA provided a list with 13 fruit farmers and eight (8) of them, corresponding to 61.54% were interviewed. The additional 28 fruit producers were obtained using the snowball method. Most of the respondents were males (97.22%) and engaged in fruit production for about 8 years on average.

2.4.1 Fruits produced and production purposes

Figure 2.2 presents fruit production profile of the respondents. The results revealed that farmers cultivated various types of fruits but mango was the fruit crop cultivated by the majority. Results showed that 30.56% of the farmers produced only mango and other 22.22% produced mango mixed with other fruits. Cultivation of mango and banana was the most frequent combination. This makes banana to be the second most important fruit crop after mango, produced by 16.67% of the farmers. A combination of three crops (mango, banana and citrus) was recorded in 8.33% of the interviewed farmers.

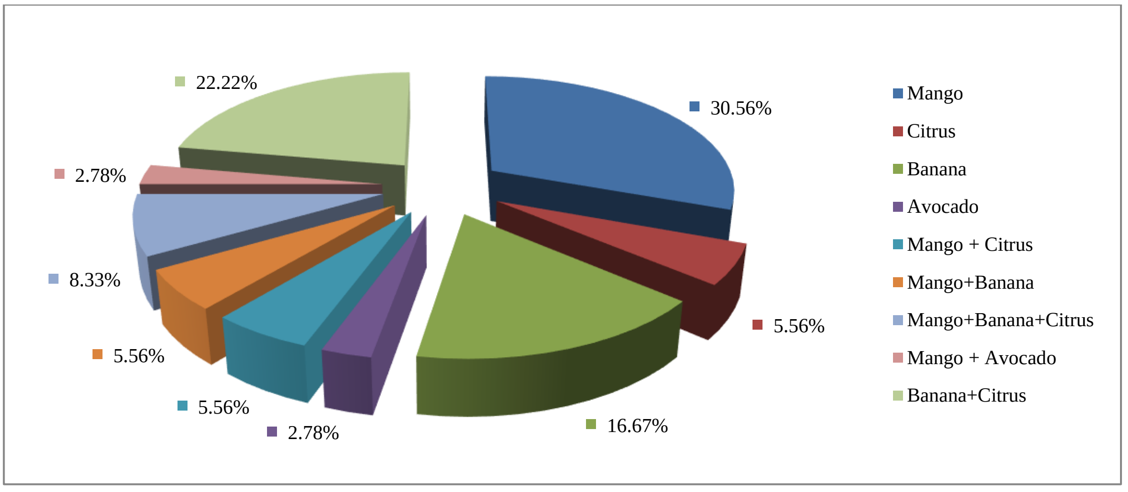

Figure 2.2: Fruit crops grown by the interviewed farmers.

The same pattern was observed in the area under production of each fruit. Mango was cultivated in 46.72% of the 352 ha surveyed, followed by banana (34.02%) and citrus (10.32%). Other hosts of *B. dorsalis* that were reported by farmers included *Psidium guajava* L. (guava), *Annona squamosa* L. (sugar apple), *Carica papaya* L. (papaya) and *Vitis vinifera* L. (grapevine).

Only three (3) of the 36 interviewed farmers produced fruits for exports purposes: two mango producers and one farmer producing bananas. The main mango varieties were exotic grafted varieties: Tommy Atkins (68.75ha), Kent (60.16ha), Keitt (23.69ha); and local varieties (11.67ha) (maberadona, palmer, seba amongst others). It also revealed that 63.15% of mango farmers selected Tommy Atkins as the main mango variety (having Kent and Keitt as well), 21.05% planted Kent and Keitt and 15.79% preferred only local varieties. The age of the plantations orchards varied between 2 and 18 years. The introduced varieties plantations of Tommy and Kent were 8 years old, Keitt was 6 years while local varieties were more than 10 years old.

2.4.2 Pests and diseases in fruit production

Farmers were asked about the main pest problems on mango, banana and citrus at each stage of the crop development. Among the mango pests, caterpillars and termites were the major insect pest problems at the seedling stage; termites were mentioned as main insects that infest vegetative stage; fruit flies, seed weevil (*Sternochetus mangiferae*), bugs (Hemiptera: Coreidae) and scale insects infested the fruits. Of these, only fruit flies were known to attack fruits particularly at the maturation stage (Table 2.1). Farmers also mentioned several diseases that include sigatoka, powdery mildew, anthracnosis, and oidium, amongst others.

Table 2.1: Pests and diseases mentioned by interviewed farmers

Crop development stages	Pests			Diseases		
	Mango	Banana	Citrus	Mango	Banana	Citrus
Seedlings	Caterpillars, termites	-	Caterpillars, termites and scale insects	Black spots	-	-
Vegetative stage	Termites	Caterpillars, termites	Termites, scale insects, aphids	Powdery mildew, rust and oidium	Sigato-ka	-
Fruitification	Fruit flies, seed weevil, bugs and scale insects	-	Termites, scale insects	-	-	-
Maturation stage	Fruit flies	Fruit flies	Fruit flies	Anthracnose	-	-

Fruit flies were the main pest problem in 17 (89.0%) of the mango orchards, in 13 (87.0%) of citrus orchards and only 3 (19.0%) of the banana plantations (Figure 2.3).

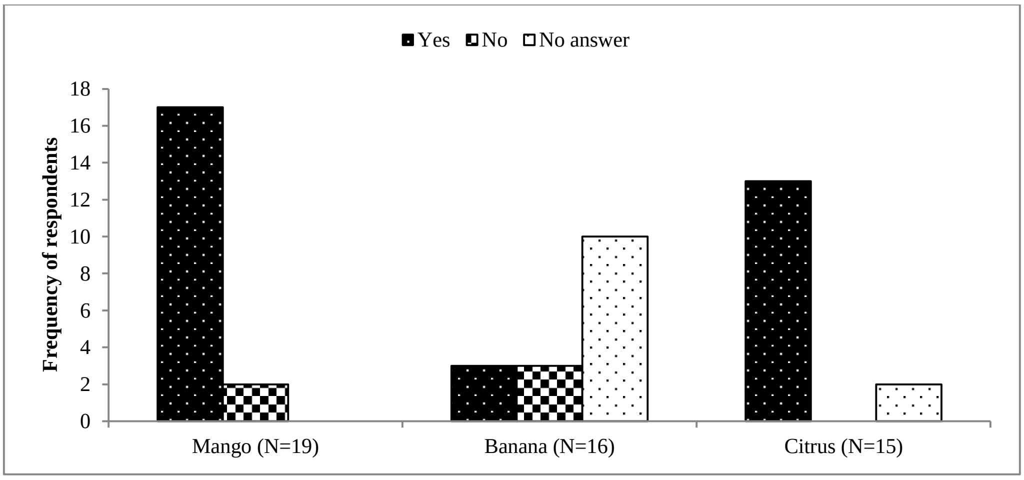

Figure 2.3: Number of respondents who reported fruit flies among the pests' problems in mango, banana and citrus.

2.4.3 Awareness on the fruit flies identification

From the 36 interviewed farmers, a total of 24 (66.67%) respondents mentioned fruit flies among their pests problems, while 4 (11.1%) didn't mention fruit flies as pests and 8 (22.22%) were not sure. The majority (58.33%) of the farmers were not able to identify the fruit fly species although they mentioned fruit flies as problems. Furthermore, 41.67% of respondents managed to identify one or more fruit fly species and *Bactrocera dorsalis* was the most known species among the interviewed farmers (Table 2.2). Other fruit fly species were *Ceratitis capitata*, *Ceratitis cosyra* and *Dacus* spp.

Table 2.2: Fruit fly species known by the farmers.

Factor	**Responses**	**Frequency**	**Percent (%)**
Known Fruit fly species (N=24)	Don't know	14	58.33
	Bactrocera dorsalis	5	20.83
	Bactrocera dorsalis, Ceratitis capitata	1	4.17
	Bactrocera dorsalis, Ceratitis cosyra	1	4.17
	Ceratitis rosa	0	0.00
	Bactrocera dorsalis, Dacus spp.	1	4.17
	Bactrocera dorsalis, Ceratitis capitata, Ceratitis cosyra, Dacus spp.	2	8.33

Out of 24 farmers who mentioned problems with fruit flies, 17 (70.83%) confirmed the presence of *B. dorsalis* in their farms while 7 (29.17%) did not confirm the pest occurrence. Farmers who confirmed presence of *B. dorsalis* got such information from various sources, mostly from Provincial Directorate of Agriculture (PDA) (58.82%). Some got the information from fellow farmers and broadcasting signals as radio, which accounted for 29.41% and 11.77%, respectively.

Among the farmers who observed fruit flies damage or reported fruit flies as one of their pests in fruit production, 12 (50.0%) out of 24 observed fruit flies damage in the farm during the 2011/12 crop season, 8 (33.33%) in the following year (2012/13) and 2 (8.33%) during the 2013/14 crop season. Two of the respondents (8.33%) didn't remember when the problem started.

2.4.4 Fruit flies damage awareness and economic impact

The majority of the respondents that mentioned fruit flies as a problem were able to describe two or three symptoms of damage correctly (91.66%) based on hands-on field experience (Table 2.3).

Table 2.3: Damage symptoms described and its frequency among the respondents.

Damage description	Yes (N=24)	No (N=4)	Not sure (N=8)
Punctures on fruits, maggots inside the fruit, fruit dropping, rotting	22(91.66%)	0	2
Punctures on fruits	1 (4.17%)	0	0
Fruit rotting	1 (4.17)	0	0
Flying around orchard	0	1(75.0%)	1
No damage	0	3(75.0%)	0
Don't know/No answer	0	0	5 (66.66%)

Some respondents were not sure about the pest problem caused by fruit flies but had managed to identify and describe symptoms and damage inflicted by fruit flies. For example, 2 (22.2%) out of 8 (that were not sure) described all symptoms related to fruit flies correctly. It was further noted that farmers received information on fruit flies symptoms and damage from the PDA.

Results showed that 45% of the farmers indicated impacts both on the fruit quality and trade. Farmers, who didn´t report problems with fruit flies were nevertheless aware of the fruit fly possible impact. Farmers knew that fruit fly infestation reduced the fruit quality and trade, which constituted their major concern. More than 70% of the respondents indicated that fruits damaged by fruit flies could not be sold (72.2%) and that fruit fly damage reduced the fruit quality (75.0%). Furthermore 23 (63.9%) of the respondents mentioned restrictions to access the national markets and 12 (33.3%) mentioned both restrictions to national and international markets as major concerns (Figure 2.4).

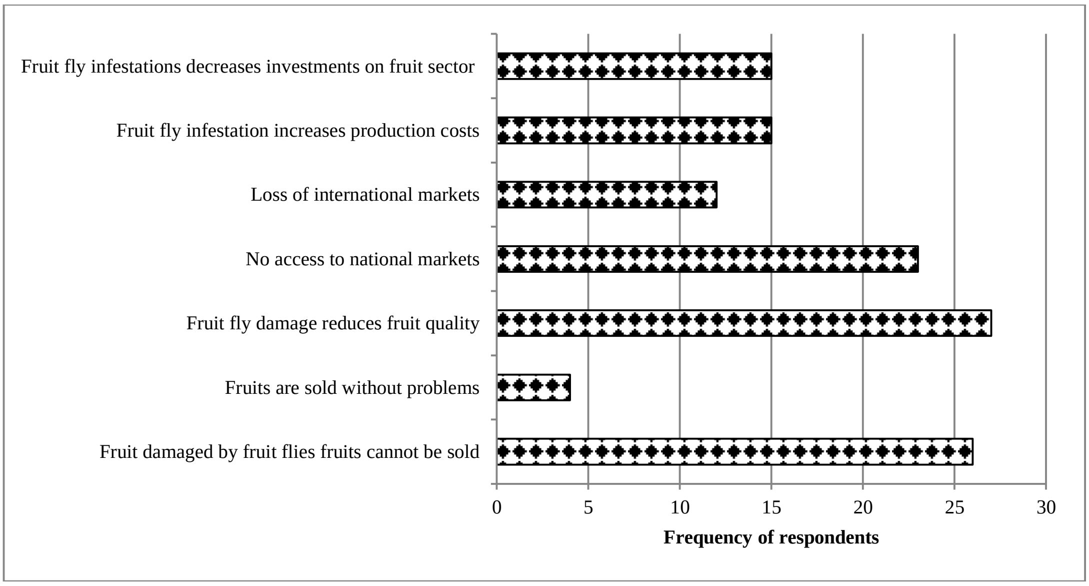

Figure 2.4: Impacts of the fly infestation described by the farmers and frequency of respondents.

Production and commercialization data provided by the farmers showed successive increasing in production, local commercialization and exports of different fruits. However, those increases were not statistically significant over the years (Table 2.4). Increasing on the area under production was also recorded over the years, except for citrus. However, such increases were not statistically significant for mango ($p = 0.99$) or banana ($p = 0.99$).

Table 2.4: Total volumes of production, local commercialization and exports of mango, banana and citrus between 2011 and 2015, in Manica province.

Season	Production (t)			Local commercialization (t)			Exports (t)		
	Mango	**Banana**	**Citrus**	**Mango**	**Banana**	**Citrus**	**Mango**	**Banana**	**Citrus**
2011/12	305.7	746.3	90.9	162.0	636.3	79.1	140.0	0.0	0.0
2012/13	441.0	945.7	85.6	249.0	697.7	74.7	180.0	239.0	0.0
2013/14	861.6	2020.7	96.4	473.3	1493.7	73.6	362.0	459.0	0.0
2014/15	916.1	3144.5	80.7	434.5	2077.5	51.5	267.0	1017.0	0.0
F value	0.01	0.37	0.16	0.04	0.38	0.44	0.12	0.54	-
p value	0.99	0.78	0.92	0.99	0.77	0.72	0.94	0.65	-

The survey data recorded increased quantities of lost or uncommercialized production over the seasons. For mango, highest quantities of uncommercialized production were recorded in 2014/15 season (214.54 t). For bananas, these volumes reached 110 t during 2011/12 season. However, such increases were not significant over the years for mango (F (3, 76) = 0.23, p = 0.33), banana (F (3, 68) = 0.42, p = 0.74) and citrus (F (3, 44) = 0.24, p = 0.54) (Table 2.5).

Table 2.5: Total volumes of uncommercialized (t) mango, banana and citrus between 2011 and 2015, in Manica province.

Season	Mango	Banana	Citrus
2011/12	3.68	110.00	11.88
2012/13	12	9.00	10.9
2013/14	26.35	67.99	22.83
2014/15	214.54	50.01	29.24
F value	0.23	0.42	0.24
p value	0.33	0.74	0.54

The monetary value associated to uncommercialized mango production showed a increasing trend over the seasons and it was more severe for this crop compared to banana and citrus (Figure 2.5).

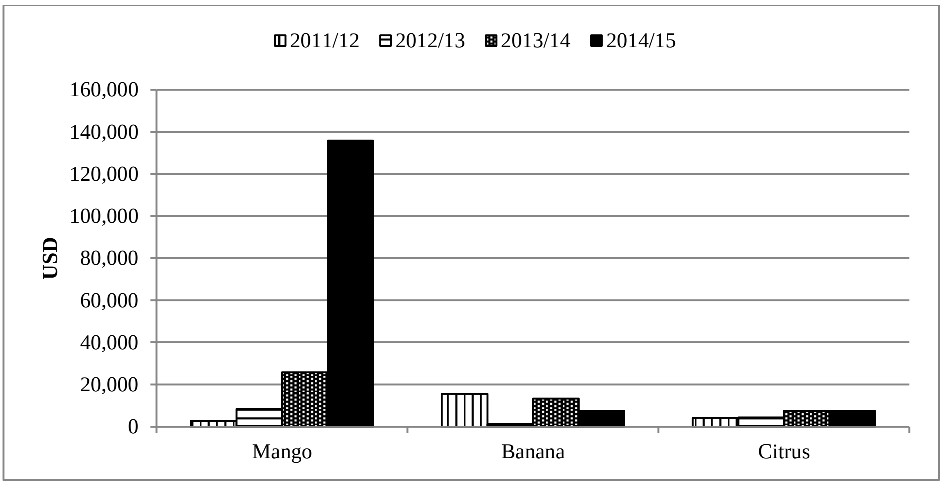

Figure 2.5: Monetary value associated with uncommercialized production, for each crop, between 2011 and 2015 in Manica province.

Highest market value per kilogram of fruit was recorded for mango. It was 4 times more than a kg of bananas and 2 times more than a kg of oranges, at the producer's gate, during the surveyed seasons. The value associated with the volumes of uncommercialized mango production corresponded to approximately USD 135,784.8, during 2014/15 season. The maximum selling prices per kilogram were 0.63, 0.15 and 0.25 USD for mango, banana and citrus, respectively, during 2014/15 season.

2.4.5 Fruit fly pest management practices

There was a follow up question to farmers who had problem with fruit flies (24) on their adopted management strategies. Survey data showed that 50% of farmers controlled the flies. The various efforts made by fruit growers to control of the fruit fly pests encountered is presented in figure 2.6. The most common fruit fly control practices used by farmers included: early harvesting, collect and disposal of infested fruits, while bait sprayings and parasitoid releases (biological control) were the least common strategies. All farmers implementing control strategies planted mainly mango crop.

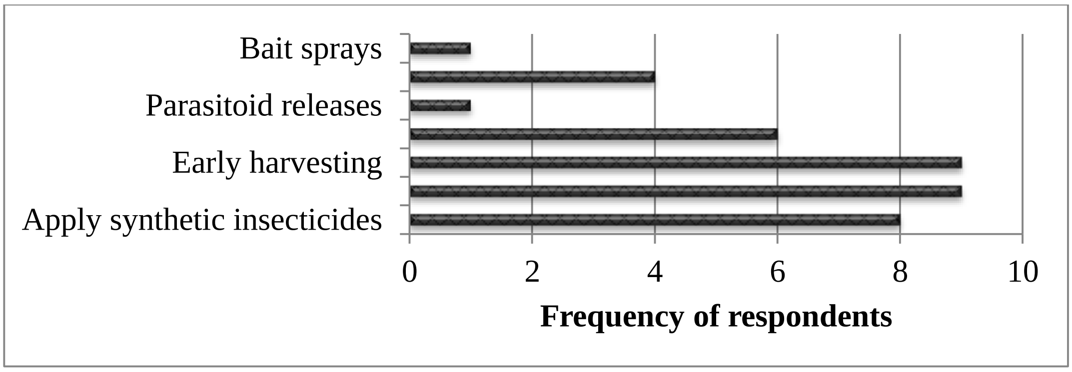

Figure 2.6: Management strategies mentioned by the farmers and frequency of respondents.

All farmers (100%) who used MAT blocks as one of the management strategies had blocks without pheromone and insecticide. Those blocks were not renewed once it was issued a year before during demonstrations organised by the National phytosanitary authorities. Additionally, biological control (*Fopius arisanus* were released in Macate district in 2014), traps and methyl eugenol for monitoring the pest were implemented by the PDA.

Therefore, the mentioned strategies for fruit fly control were not implemented by the farmers own initiative, except orchard sanitation, early harvesting and insecticide spraying. However, farmers mentioned various management strategies and this revealed that they had the knowledge on management strategies.

There was a farmer who applied bait sprays popularly known as GF 120 NF and all recommended strategies to control the fruit flies, including post-harvest treatment with hot water to comply with recommendations to export mangoes to South Africa.

More than 50% of the farmers were reported to depend on synthetic insecticides to control fruit flies. The active ingredients of the mentioned synthetic insecticides belonged to the pyrethroid chemical class of pesticides, namely lambdacyalothrin, cypermethrin and permethrin. Application of synthetic insecticides was employed in mango orchards. Farmers were not able to itemise the costs with insecticides, but was estimated to vary between USD 169.8 and 821.5 during 2010/11 and 2014/15 seasons, respectively (Figure 2.7).

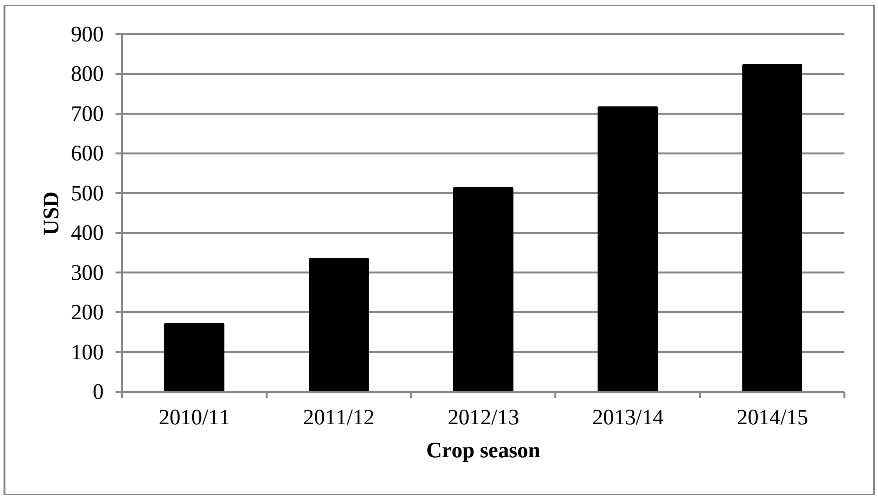

Figure 2.7: Trend in expenses on insecticides to control fruit flies between 2011 and 2015 in Manica province.

Some farmers did not implement control strategies (50% of the 24 farmers) due to various reasons. About 8.33% considered fruit flies as unimportant pest, another's were financially constrained (8.33%), while 58.33% lacked knowledge and 25.0% were both financially constrained and lacked the knowledge. The majority of the farmers who did not implement control strategies were mainly small scale farmers (75.0%). They were reported to cultivate mainly mango (88.9%) and citrus (11.1%). The other 25.0% were farmers with more than 5 ha of citrus orchards, and even though were not controlling the flies.

2.5 Discussion

The survey results suggested that the awareness of the farmers on fruit flies identification, damage description and impacts depends on the type of fruits grown by the farmers. For example, banana farmers were not reported to have problem with fruit flies due to identification difficulties. Mango and citrus producers were able to identify the fruit species easily, describe the symptoms and its associated damage.

Although mango, banana and citrus fruits are the major cultivated hosts of *B. dorsalis* in Africa (Vayssières *et al.,* 2014; Mwatawala *et al.,* 2009; Ekesi *et al.,* 2006), bananas are harvested at green stage and at this stage it is not infested by the oriental fruit fly (Cugala *et al*., 2014). Cugala *et al*. (2014), suggested that one of the reasons for less infestations in green banana could be the sticky fluid or latex exuded through the banana peel in response to oviposition puncture by the flies. These exude gets hard sealing off any egg that may have been deposited and possibly killing it by asphyxiation (Cugala *et al*., 2014).

Therefore, banana producers do not observe the direct damage caused by the oriental fruit fly in the fruit. Consequently they could not identify the flies. However, during the ripening stage, banana is also considered as a good host for *B. dorsalis* (Cugala *et al*., 2014), Rwomushana and Tanga, 2016; CABI, 2017). The green bananas with cracks and splits, ant burns, abrasions, point bruise that are mechanically damaged with tip rot or had general decay can also be infested by *B. dorsalis* (Cugala *et al*., 2014).

Farmers were aware of the fruit flies damage and described symptoms and damage correctly. Nevertheless, they could describe the symptoms, the linkage between the damage and fruit fly species or an adult fly was not clear for the farmers since they were not able to identify the fruit fly species. More than 50% of the farmers were able to have information on *B dorsalis* pest status in their farms, due to *B. dorsalis* official monitoring program conducted by PDA.

Awareness on fruit fly damage and control strategies was highly developed among farmers intending to export their crops, especially bananas due to the imposed importing restrictions. This was an expected attitude, since the farmer registration or affiliation to a commercial/production association increases the level of awareness of members of the group due to their export disposition, which ensures adoption of reasonably fair technologies that will guarantee the production of safe and high quality fruits (Abdullahi *et al*., 2011).

More efforts to control the pest were observed among the mango farmers due to direct impact of fruit fly infestations and in order to improve quality and access to international markets. In Kenya, some of the major factors positively correlated with a farmer's willingness to pay for integrated fruit fly control methods were income, the percentage fruit fly related losses and farmers' rating of fruit fly damage (Mugure, 2012).

The larger the area put under mango cultivation, the higher the percentage losses reported (Mugure, 2012). It was estimated that an increase in the size of land under mango by an acre was associated with a 2.2% increase in the magnitude of economic loss due to fruit fly damage (Mugure, 2012). In the present study, the large scale farmers were more aware of possible management strategies used for fruit flies control. This group of farmers increased their investments to by unregistered insecticides to control fruit flies and only 1 farmer was applying bait sprays, which is one of the recommended strategies to control fruit flies.

On the other hand, small scale farmers didn't have the knowledge on management strategies and, therefore, they did not control the pest. This highlights the need of farmer extension and training to be provided before the introduction of any fruit fly control package. This may help the farmers to understand the technical handling of the package components and how their current pest control practices could be counterproductive and incompatible with integrated pest management principles (Mugure, 2012).

In Kenya, respondents who had attended a farmer field day(s), training seminar, workshop, had listened to a program on radio or had contacted an extension officer in the last twelve months before the interview seemed to be aware of how the integrated pest management package works (Mugure, 2012). This reveals that training farmers to raise awareness on the potential performance of the new technology as well as its management is a key component to consider if the adoption process is to be successfully. Frequent refreshments on these issues on the first years of the awareness campaigns may also increase the levels of adoption among the farmers.

2.6 Conclusion

Mango was the dominant fruit crop cultivated by majority of the farmers, as monoculture or mixed with banana and citrus. Fruit flies was the main pest problem at the maturation stage in mango and citrus orchards. *Bactrocera dorsalis* was the most known species among the interviewed farmers and it was present 86.9% of the farms. Severe impacts of fruit flies were reported to affect fruit quality as to maggots live inside the fruit and hence reduce fruit commercialization. Awareness on fruit flies damage and implementation of control strategies were linked to the fruit produced and the size of cultivated area. Although the mango farmers were able to describe symptoms of damage correctly, only large scale mango farmers were implementing control measures. Due to fruit flies infestation, the volume of uncommercialized mango increased over the years, and the associated monetary value was more severe for mango producers, as a consequence of the highest market value of mango comparing to citrus and banana. Small scale farmers did not implement control strategies due to the lack of knowledge on fruit flies control strategies. It is therefore recommended to introduce awareness campaigns to sensitize and build capacity to the small scale farmers.

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CHAPTER THREE

3.0 Population dynamics of the oriental fruit fly *Bactrocera dorsalis* (Diptera: Tephritidae) and its economic injury level in Manica province, Mozambique

3.1 Abstract

Fruit flies (Diptera: Tephritidae) are considered as the most destructive insect pests of fruits and vegetables in the world. The oriental fruit fly, *Bactrocera dorsalis* was first detected in Manica province, in 2008 causing huge economic losses. However, there were no systematic trapping data of *B. dorsalis* seasonality, damage assessments and factors determining the changes in the pest population. Additionally, there was no information on economic injury levels (EIL) for *B. dorsalis* in Mozambique. Therefore, the present study was conducted to describe *B. dorsalis* dynamics, assess the associated damage and yield losses on mango and to determine the EIL for *B. dorsalis* in Manica province. From September 2014 to August 2015, methyl eugenol baited traps were placed in three selected orchards (Trangapasso, Produssola and Pandafarm) and mango fruits were collected and reared. Data on potential yield was estimated in each of the orchards and the owners were interviewed to collect information regarding mango selling prices. *Bactrocera dorsalis* catches per trap per day (FTD), percentage of damaged fruits and infestation rates were determined and submitted to ANOVA, Chi-square and Pearson's correlation analysis in R. The EIL was determined for each orchard. The population started to build up in November 2014 reaching its peak in January 2015 (40.26 FTD) and the population pattern was determined by temperature, month and host availability. The highest percentage of damaged fruits (77.16%) and the highest rates of infestation (68.57 flies/kg and 41.27 *B.*

dorsalis/kg) was also recorded in January. The FTD and infestation parameters were significantly affected by the time (months) with the highest levels recorded at the peak of mango ripening stage. *Bactrocera dorsalis* was the most abundant fruit fly species (70.66%) and co-occurred with *Ceratitis cosyra* and *Ceratitis rosa* in sampled mango fruits. Yield losses associated with fruit flies were estimated at 28.27 t/ha with the total financial loss of USD 17,144.84 per ha. EIL varied among orchards and was estimated at 33.14 *B. dorsalis*/trap/week in average.

3.2 Introduction

Mozambique climate, soil and topology allow the production of tropical fruits for local consumption and for export. Most of the fruits are produced by large scale and small scale farmers. Fruits provide important vitamins to human diets (FAO, 2015). Fruits trade contributes to the national economy and generates income to producers and pickers particularly during the harvesting time. In 2002, it was estimated that 73% of the rural family's income came from fruits trade both in the formal and informal markets (Mather *et al.*, 2009). Previous data showed that by 2010, the top tree fruit crops in terms of number of farms were mango (*Mangifera indica* L.) (2 284 421 farms), papaya (*Carica papaya*) (1 299 916 farms) and banana (*Musa* sp.) (1 109 051 farms), and almost 99% of them were small scale farms (Censo agropecuario, 2010).

Manica province which lies in the west of the country is characterized by rainfall of more than 1000 mm per year, low temperatures (15 to 20 ºC in the coolest months), high altitude (400 m to more than 2000 m), steep slopes, good soils and a consistent water supply. These conditions are ideal for production of fruits such as bananas (*Musa* sp.), peaches (*Prunus persica* L.), grapefruits (*Citrus* x *paradisi*), lemons (*Citrus limon* (L.) Osbeck), oranges

(*Citrus* spp.), mangoes (*Mangifera indica* L.), avocado (*Persea americana* L.), pears (*Pyrus* spp.), litchis (*Litchi chinensis* L.) and apples (*Malus pumila*) (Cepagri, 2017). The country has four main fruit provinces namely, Nampula, Manica, Inhambane and Maputo.

Most of the fruits exported to South Africa are produced in Manica province, which include mango, litchi and avocado (CFAM, 2013; INE, 2017). This province has the potential to improve mango quality in order to increase the export volumes to lucrative markets, particularly Europe. However the economic benefits of the mango value chain are greatly hampered by pests and diseases. In Africa, the major pest threats to mango include termites (Isoptera: Termitidae), mealybugs (Homoptera: Pseudococcidae) and fruit flies (Diptera: Tephritidae) (Vayssières *et al.*, 2009c). The latter was reported to cause wide-scale economic damage to the mango tree (Vayssières *et al.,* 2009c; Ekesi *et al.*, 2016).

The oriental fruit fly, *Bactrocera dorsalis* (Hendel) can cause 100 % of direct losses if control measures are not implemented (Ekesi, 2010). It is also a quarantine pest, and has, therefore, an impact on international commercialization of fruits and vegetables. In Mozambique, the pest was detected in 2007, and damage caused to the different fruit hosts have been estimated to reach 92.5% with negative impact on fruit and vegetables exports as well (Jose *et al*., 2013; Cugala *et al*., 2016).

Given the economic importance of *B. dorsalis*, many pest management programs have been developed to control the fly (Vayssières *et al*., 2009a, Ekesi and Billah, 2007). There are various IPM programs against fruit flies (Mwatawala *et al*., 2006; Vargas *et al*., 2015; Murithi *et al*., 2016). However, in practice, implementation of IPM programs targeting fruit flies should be optimized for a particular crop/pest/environment scenario based on knowledge of pest ecology and natural enemies, as well as knowledge of socio-economic factors (Vargas *et al*., 2015).

Spatio-temporal studies are pre-requisite to optimize control strategies (Vargas *et al*. 1990; Castrignanó *et al*. 2012; Aidlin-Harari *et al*., 2016) and among the socio-economic factors two key concepts are introduced: economic injury level (EIL) and economic threshold (ET) (Liang *et al*., 2012; Pedigo *et al.*, 1986). Most of the existing IPM programs do not have a component of EIL even though authors (Verghese *et al*., 2004) recognized that there is scope for the application of controls according to a threshold rule since below a certain level control may not show a net return.

Currently, data on spatial and temporal abundance of *B. dorsalis* in Manica province and the EIL do not exist. Data on *B. dorsalis* population dynamics although is available in countries like Kenya, Tanzania and Benin (Ekesi *et al*., 2006; Mwatawala *et al.*, 2006; Vayssières *et al*. 2009b). The EIL for fruit flies have only been calculated in Benin (Vayssières *et al*. 2009b). Therefore, this study sought to (i) monitor *B. dorsalis* population dynamics all year round in relation to the fruit season and temperature, (ii) assess the damage and losses caused by fruit flies in different varieties and sampling periods in Manica province and (iii) estimate the EIL for *B. dorsalis* in Manica province. This information can be used to optimize fruit fly programs adopted from other regions and thereafter present it to the farmers.

3.3 Material and methods

3.3.1 Study area

Data were collected in three selected orchards, namely Trangapasso, Produssola and Pandafarm at Manica province, Mozambique (Table 3.1). Manica province is characterized by a tropical climate modified by altitude, with two distinct seasons: a hot and rainy season (September to March) and a dry season (April to August). The mean temperature during the hot season ranges between 20 ºC and 25 °C and between 15 and 20 ºC in the coolest months.

Table 3.1: Location of the study sites and cultivated fruits.

Location/orchard	District	Fruits cultivated
Trangapasso (19º07'22.3" S; 33º25'37.1"E; 577 m.a.s.l)	Manica	Mango (*Mangifera indica* L.) varieties Tommy Atkins, Kent and local varieties; *Citrus sinensis* (L.) Osbeck. (oranges), *Citrus reticulata* Blanco (tangerines), *Persea americana* Miller (avocado), *Eriobotrya japonica* (Thunb.) (loquat), *Annona muricata* L (soursop), *Prunus persica* L. (peach), *Anacardium occidentale* (cashew), *Carica papaia* (papaya); litchi (*Litchi chinensis*).
Produssola (19º01'44.6"S; 033º03'02.2"E, 631 m.a.s.l)	Manica	Mango (*Mangifera indica* L.) varieties Tommy Atkins and Kent; *Citrus sinensis* (L.) Osbeck (orange); *Carica papaia* (papaya); *Persea americana* Miller (avocado) and *Ficus carica* (fig).
Pandafarm (18º06'52.2"S; 33º18'16.6"E; 522 m.a.s.l)	Bárue	Mango (*Mangifera indica* L.) variety Tommy Atkins; litchi (*Litchi chinensis*)

The selection of the orchards was based on the following criteria: (i) orchard size of at least one ha of grafted mango trees under production (ii) orchards with market preferred varieties/ cultivars (iii) orchards with regular spacing between mango trees, (iv) guarantee of no use of chemical pesticides in the orchards, and (v) absence of other crops requiring insecticide treatment (e.g., cotton) in the vicinity of the orchards studied (Vayssières *et al*., 2009a).

3.3.2 Data collection methods

3.3.2.1 Trapping data/ fruit fly population density

Five tephri traps baited with methyl eugenol were placed in each of the selected orchards: four in the corners and one in the middle of the orchard. An insecticide strip of dimethyl-dichloro-vinylphosphate (DDVP) was placed at the bottom of the trap to kill the attracted flies. Traps were serviced monthly when the trapped flies were removed and the lure plug was changed. Data was collected for one full year from September 2014 to August 2015. Collected flies were preserved in 70% alcohol for counting and identification. Fruit flies identification was done using standard identification keys (Ekesi and Billah, 2007; Virgilio *et al.*, 2014).

3.3.2.2 Damage assessment

Mango fruits were collected from November 2014 to January 2015. Five sampling points were marked within the orchard (four in the corners and one in the middle). About ten mango fruits were collected from each sampled point and a total of fifty fruits were collected per orchard/ month. The fruits were placed in plastic bags, labeled and sent to the Chimoio fruit fly lab (Laboratório da Mosca da Fruta de Chimoio) for rearing as per the procedures described by Ekesi and Billah (2007). The sampled fuits were weighed, counted and then checked for infestation symptoms. A fruit was considered damaged when a fly ovipuncture was visible (Vayssières *et al*., 2009a). Thereafter, the fruit was placed in plastic containers with a net lid and sterilized sand at the bottom and incubated for about six weeks.

After a week of fruit rearing, fruits were opened slightly to check the presence of larvae. A fruit was also considered infested when at least one fruit fly larvae was observed inside the fruit (Vayssières *et al*., 2009a). The containers were further checked once a week for puparia. The puparia were sieved from the sand, counted, weighed, placed in petri dishes with moisturized filter paper and transferred to a cage for adult emergence. Emerged adults were counted, sexed and preserved in 70% alcohol for later identification using standard identification keys (Ekesi and Billah, 2007; Virgilio *et al.*, 2014; De Meyer *et al.*, 2014).

3.3.2.3 Estimation of yield losses

Potential yield and yield losses were estimated by sampling fruits from commercial varieties in each of the selected orchards. It was done in late December 2014 at mango maturation stage and before harvesting. In each orchard and for each cultivar, trees were counted and ten trees were randomly selected and marked. Also the total number of fruits in each tree was counted, from which five mangoes were collected and individually weighed. The average number of fruits per tree and average fruit weight were determined as suggested by Vayssieres *et al*. (2008).

Data collected

Bactrocera dorsalis density was expressed as number of flies per trap per day (FTD) (Ekesi and Billah, 2007). Temperature sensors iButton or 1-Wire™ were placed in each orchard to record local temperatures.

Percentage of damage caused by tephritids was estimated for different mango cultivars and orchards, as a ratio of number of infested fruits per total of collected fruits. The infestation rate was determined as the number of pupae, number of emerged adult flies and *B. dorsalis* per unit weight of fruits (Mwatawala *et al*., 2015). Incidence of fruit flies was determined per variety, as the ratio of positive damaged fruits to the total number of sampled fruits (Mwatawala *et al*., 2009). The abundance of each fruit fly species was estimated as the proportion of the total number of adults of each fruit fly species to the total number of adults emerged from the fruits.

The potential yield (t) per cultivar was estimated by multiplying the number of trees in the orchard, average number of fruits per tree and average weight of each fruits. Yield losses (t) were estimated as a percentage damage*potential yield.

3.3.3 Computation of the economic injury level (EIL) and economic threshold (ET)

The EIL was determined according to the equation proposed by Pedigo and Rice (2006): $EIL = [C / (V \times I \times D \times K)]$, where C is the cost of pest control and related activities per production unit (USD/ha); V is the market value per production unit (USD/kg); I is the injury unit per insect per production unit; D is the damage per injury unit and K is the effectiveness of the control measure. The EIL was expressed as the number of *B. dorsalis* per trap and per week (Pedigo and Rice, 2006; Vayssières *et al.*, 2009a).

However, since for fruit flies it would be a problem to separate between variable I (fruit pulp consumed by the maggots) and D (yield loss per unit of pulp removed), Pedigo and Rice (2006) recommended to replace the variables I and D by a variable B representing loss per insect per area ($B=I*D$). Variable B was determined from linear regression equation between flies density and percentage of damaged fruits. Therefore, EIL were estimated as $EIL=C/(V*B*K)$.

Moreover, based on the EIL, an ET was determined. Pedigo and Rice (2006) defined the ET as "the population density at which control action should be determined (initiated) to prevent an increasing pest population (injury) from reaching the economic injury level." The fixed ET is the most common type of objective ET, and is set at a fixed percentage of the EIL e.g., 50% or 75%. In the present study ET was set at 75% of the EIL.

a) Variable C

The C variable represents the cost of the pest control treatment required to significantly lower the population level of these tephritid species. Specifically the following costs were determined; costs related to the baits sprayings, costs of deployment of male annihilation blocks, costs of field sanitation and costs for monitoring of the fruit fly populations. The bait GF 120 was recommended to be applied on weekly basis for duration of 12 weeks starting from the fruit setting to harvesting. Recommended dilution was 1:7.5 or 1:6.5 depending on the fabricant label. All the trees should be treated with a limited quantity of 0.07 to 0.09 litre/tree applied on $1m^2$ of the tree (Ekesi, 2016). The cost of the GF-120 NF available locally was about USD 237.97 for 20 litres (i.e. USD 11.89 per litre), in 2014/15 season. MAT blocks deployment followed the recommendation of the manufacturer which was 16 blocks/ha for *B. dorsalis* control. It was sold in packages of 12 blocks, at a cost of USD 45.17 each. MAT blocks should be renewed every 6–8 weeks (i.e. three times during the mango season) (Ekesi, 2016).

For better pest monitoring the recommended trapping density with methyl eugenol was 0.25-1 trap/km^2 (FAO/IAEA, 2013), which meant the minimum of 2 traps/ha. Each trap was sold at USD 16.78 while the cost of one methyl eugenol pherolure was at USD 5.15 and USD 1 for 1 DDVP. The traps should be serviced monthly. The salary of permanent worker in a farm was USD 72.5 per month and to deal with pest management issues, one person can work in 1 ha mostly during the crop season (3 months). This means, the rest of the year the owner can monitor the traps with no labor costs. The total management costs (C) were the addition of the partial costs for each of the control strategies.

b) Variable V

An estimate of V was based on current selling prices per kg of mangoes at the farmer gate which were obtained through farmers interviews. It was determined per orchard by adding the market values of each variety in the orchard.

c) Variable B

For the purpose of calculation, the injury per insect usually was assumed to have a linear relationship with insect density (Pedigo *et al.*, 1986). Thus, a linear equation ($Y = a + bx$)

were plotted in excel, between the percentage of damage (dependent variable) and number of *B. dorsalis* per trap per day (independent variable). The coefficient *b* (yield loss/insect) was used to estimate the variable **B** as follows: B = Potential yield (t/ha) * b/100 [t/*B. dorsalis*/ha].

Since both varieties in the orchard were exposed to the same *B. dorsalis* population, the calculation of the loss per insect per ha (B) were determined by adding the potential yield of the all commercial orchard varieties and then multiplied by the slope coefficient (b) of the linear regression equation.

d) Variable K

This is a proportionate reduction in potential injury or damage (for example 0.8 for 80%) (Pedigo and Rice, 2006). The combination of bait sprays and deployment of male annihilation blocks and orchard were tested in Manica province from September 2013 to February 2014, and resulted in a population reduction of 89.4% while the damage was reduced to 42% (Kazuro, 2014). Based on this study, the K value was estimated in 0.42.

3.2.4 Data Analysis

Analysis of variance (ANOVA) was performed to analyse the effect of the location, month and its interaction on FTD, percentage of damaged fruits and infestation rates, followed by post-hoc Tukey honest significant reference test. A Chi-square test was performed for the incidence of fruit flies on the main mango varieties for the sampling months. Number of *B. dorsalis* captured per trap per day was correlated with temperature (minimum, maximum and average) and with the percentages of damaged fruits using Pearson correlation test. Yield losses (per variety and per orchard) and all the variables for the EIL estimation were determined in MS Excel (Microsoft Windows 2010). T-test was performed to compare the means between the actual and potential yield. All statistical analysis was performed in R version 3.2.3 with a significance level of 5%.

3.4 Results

3.4.1 Seasonality *B. dorsalis*

The pest was present all over the year in studied orchards, with the maximum FTD recorded in Trangapasso (44.38 *B. dorsalis*/trap/day) in January 2015 and the minimum FTD (0.006) recorded in Panda farm in June 2015 (Figure 3.1).

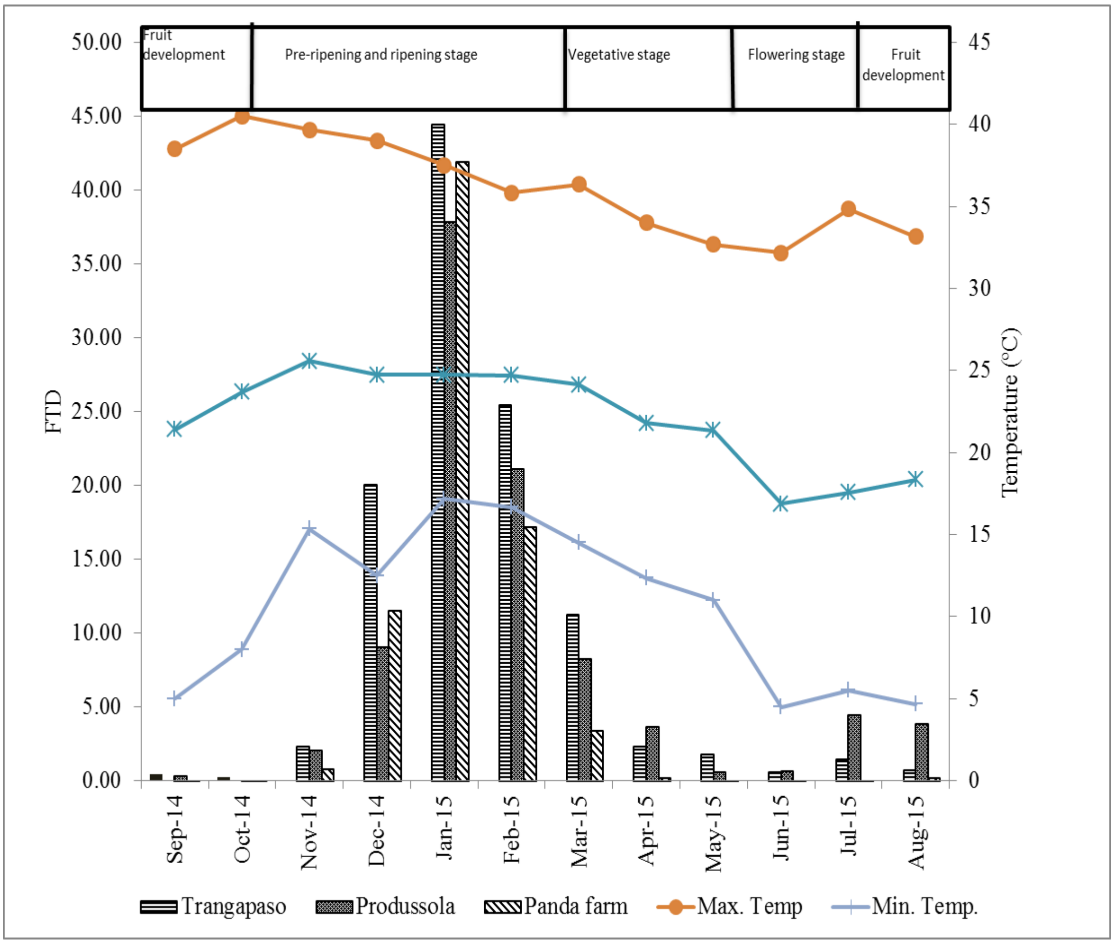

Figure 3.1: Monthly population fluctuations of males' *B. dorsalis* between September 2014 and August 2015, in three orchards, in Manica province.

The population started to build up in November 2014 peaked in January 2015. After January the population of *B. dorsalis* started to decrease and reached the lowest density in June 2015. Highest numbers of flies were trapped in January during the mango ripening stage in all orchards. Less number of flies was caught during the flowering and fruit development stage.

The results showed that number of caught *B. dorsalis* per trap per day varied significantly among the months (F (11, 136) = 231.41, $p < 0.01$), orchards (F (2, 136) = 10.79, $p < 0.01$) and the interaction were also significant (F (20, 136) = 231.41, $p < 0.01$). Mean number of *B. dorsalis*/trap/day were significantly high in December, January, February and March compared to other months (Figure 3.2).

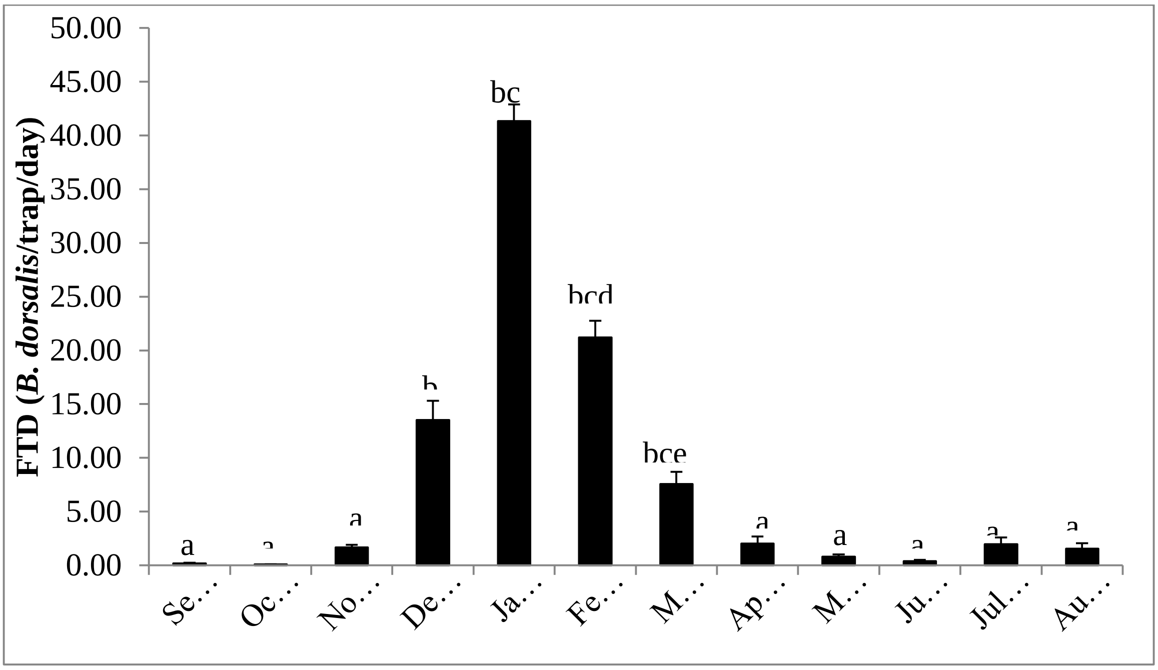

Figure 3.2: Average number of *B. dorsalis* per trap per day in each month, between September 2014 and August 2015, in Manica province. Columns bearing the same letter do not differ significantly from each other using Tukey's (HSD). Error Bars denote SE.

Trangapasso had the highest average FTD (11±4.65) followed by Produssola with 7.63 ±3.23 FTD and Pandafarm (6.26 ±3.62 FTD). However, the means from Produssola and Pandafarm was not significantly different (p = 0.48) (Figure 3.3).

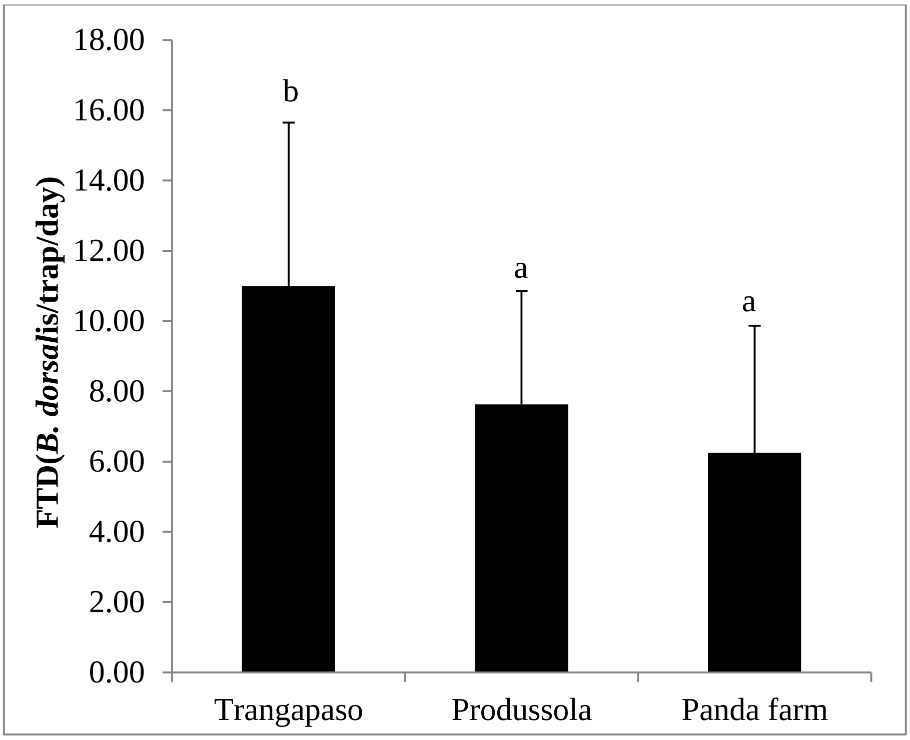

Figure 3.3: Average number of *B. dorsalis* per trap per day in each orchard, in Manica province. Columns bearing the same letter do not differ significantly from each other using Tukey's (HSD). Error Bars denote SE.

Captures increased when the average temperature increased and lowest captures were recorded in the month of June, September and October. June was the coolest month of the year recording the minimum temperatures (4.5ºC) and average temperature of 16.9ºC. Pearson correlation analysis showed significant correlation between FTD and average temperature (r (31) = 0.5, $p < 0.01$), minimum temperature (r (31) = 0.42, $p < 0.05$) and maximum temperature (r (31) = 0.41, $p < 0.05$).

3.4.2 Damage assessment, rate of adult fruit flies infestation and yield losses

A total of 3 600 pupae were collected from the reared fruits, from which emerged 2986 adult flies of the following species: *Bactrocera dorsalis* (2 110), *Ceratitis cosyra* (863) and *Ceratitis rosa* (13). *Bactrocera dorsalis* was the most abundant species that accounted for 70.66% of the total emerged flies, followed by *C. cosyra* (28.9%) and *C. rosa* (0.44%).

3.4.2.1 Percentage of damage

A total of 118.14 kg, which is equivalent to 592 mango fruits (592) were collected from the three tested orchards. The fruits belonged to different cultivars/ varieties, with Tommy Atkins being the most abundant. Percentage of damaged fruits ranged between zero (0) and 100%. Less percentage of damaged fruits was recorded in local varieties (27.5%) and higher damage in introduced improved varieties namely, Tommy Atkins (41.92%) and Kent (56.61%).

Trangapasso had the highest percentage of damaged fruits with an average 38.15%, followed by Pandafarm (37.75%) and Produssola (30%). The results showed that the effect of location on the percentage of damaged fruits was not significant (F (2, 36) = 2.00, p = 0.15). Results further showed that time of collection (month) significantly affected number of damaged fruits (F (2, 36) = 129.17, $p < 0.01$). December (21.1%±5.63) and November (24.07%±13.03) were the least infested months. January was the highly infested month (77.93%±3.57) it doubled the average number of damaged fruits compared to other months (Figure 3.4). The interaction was also not significant (F (4, 36) = 1.13, p = 0.36).

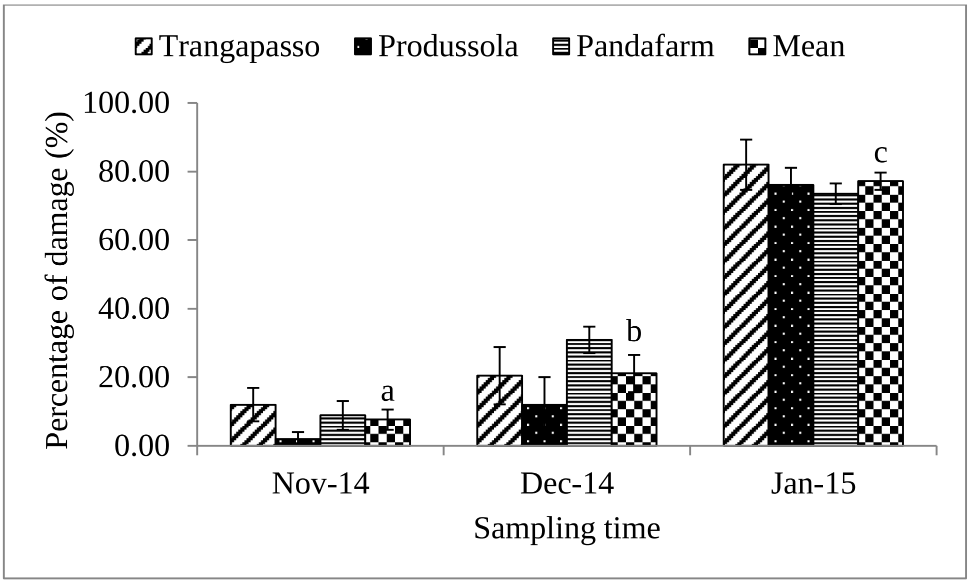

Figure 3.4: Percentage of damaged fruits at different sampling months. Means presented in the mean column bearing the same letter do not differ significantly from each other using Tukey's (HSD). Error *Bars* denote SE.

Results showed that introduced or exotic mango varieties had more positive samples for fruit flies infestation. Results showed that the number of positive samples were related with the variety for the fruits sampled in December ($\chi2$ (2, N = 148) = 20.97, $p < 0.001$) and January (χ^2 (2, N = 149) = 47.08, $p < 0.001$) but the same was not observed in November (χ^2 (1, N = 145) = 0.82, p = 0.37).

3.4.2.2 Infestation rates

The average number of pupae/kg, adult Tephritidae/kg and *B. dorsalis*/kg are presented in tables 3.2, 3.3 and 3.4. The infestation rates varied between orchards and time, with an increasing tendency with time. In January, Produssola recorded the highest infestation rates (115.1pupae/kg, 99.9 Tephritidae/kg and 73.0 *B. dorsalis*/kg) while in November and December the highest infestation rates were recorded in Trangapasso.

Results showed that month of sampling (*F* (2, 36) = 18.83, $p < 0.001$) as well as the interaction month*location (*F* (4, 36) = 3.83, $p = 0.01$) had a significant effect on the pupae infestation rate (Table 3.2). The effect of location (orchards) was not significant on pupae infestation rate (*F* (2, 36) = 1.98, $p = 0.15$).

Table 3.2: Analysis of variance for the effect of time on pupae infestation rate during the sampling months in 2014/15 mango season in Manica province.

Location		Nov2014	Dec 2014	Jan 2015
Trangapasso		13.47±5.49a	18.64±6.69a	43.42±4.6a
Produssola		3.71±3.71a	10.0±6.09a	115.1±36.66b
Pandafarm		9.42±4.62a	14.59±3.03a	47.21±6.22b
	F		18.83	
Factor time	df		2, 36	
	p value		0.0001	

Means with the same letter (s) in a row do not differ significantly by Tukey (HSD) test (P=0.05).

Furthermore, month of sampling had a significant effect on Tephritidae/kg (*F* (2, 36) = 18, $p < 0.001$) (Table 3.3) and *B. dorsalis*/kg (*F* (2, 36) = 15.19, $p < 0.001$) (Table 3.4) as well as the interaction for both Tephritidae/kg (*F* (4, 36) = 3.77, $p = 0.01$) and *B. dorsalis*/kg (*F* (4,36) = 3.95, $p = 0.009$) were also significant. The effects of location was not significant on Tephritidae/kg (*F* (2, 36) = 2.13, $p = 0.13$) and on *B. dorsalis*/kg (*F* (2, 36) = 2.46, $p = 0.09$).

Table 3.3: Analysis of variance for the effect of time on Tephritidae infestation rate during the sampling months in 2014/15 mango season in Manica province.

Location		Nov 2014	Dec 2014	Jan 2015
Trangapasso		11.27±4.41a	16.15±6.05a	40.11±3.76a
Produssola		3.39±3.39a	7.8±4.85a	99.9±32.28b
Pandafarm		7.89±4.08a	10.91±2.89a	39.28±6.62b
Factor time	F		18.00	
	df		2, 36	
	P value		0.0001	

Means with the same letter (s) in a row do not differ significantly by Tukey (HSD) test (P=0.05).

Table 3.4: Analysis of variance for the effect of time on *B. dorsalis* infestation rate during the sampling months in 2014/15 mango season in Manica province.

Location		Nov 2014	Dec 2014	Jan 2015
Trangapasso		8.96±3.24a	14.72±5.52a	25.84±4.37a
Produssola		3.09±3.09a	6.2±3.81a	73.0±23.66b
Pandafarm		5.69±3.11a	5.48±1.6a	25.04±5.34b
Factor time	F		15.19	
	df		2, 36	
	P value		0.0001	

Means with the same letter (s) in a row do not differ significantly by Tukey (HSD) test (P=0.05).

The peak of infestation occurred at the peak of mango ripening stage (January) and when the number of flies per trap per day were also high (Figure 3.1). Pearson correlation tests was consistent with the hypothesis that there was a strong positive and significant correlation between the number of *B. dorsalis* per day and percentage of damaged fruits (*r*

(43) = 0.87, p < 0.01) as well as between the number of *B. dorsalis* per day and infestation rates (r_{pupae} (43) = 0.61, $p < 0.01$; r_{flies} (43) = 0.59, $p < 0.01$; $r_{dorsalis}$ (43) = 0.56, $p<0.01$).

3.4.2.3 Yield and yield losses

Trangapasso had highest potential yield (15.93 t/ha for Tommy and 14.09 t/ha for Kent variety), followed by Produssola (with 9.97 t/ha for Tommy Atkins and 9.92 t/ha for Kent variety) and Pandafarm (8.35 t/ha) during the 2014/15 crop season (Table 3.5). The potential yield from the three tested orchards for the Tommy Atkins variety were estimated at 46.93 t/ha, which was associated with a total yield losses of 14.51 t/ha as a consequence of fruit flies damage. In Trangapasso, yield losses was estimated at 6.9 t/ha for Tommy Atkins variety, while for Panda farm and Produssola it was less than 4.5 t/ha. Results showed that the actual yields (29.99 t/ha) were significantly lower comparing to potential yields (58.26 t/ha) (t (5) = 3.97, p = 0.01). The total financial losses for the three orchards was estimated in USD 17144.84 per ha, with higher financial loss of yield for Tommy Atkins variety which is sold at higher prices at the farmer gate (USD 0.759 per kg) comparing to Kent variety (0.51 to USD 0.63 per kg).

Table 3.5: Yield losses and financial loss of yield of the commercial varieties in the three study areas for crop season 2014/15.

Location	Variety	Nr of trees	Average nr of fruits/tree	Average weight of fruit (g)	Average Yield (t/ha)	Average damage (%)	Yield losses (t/ha)	Price (USD/t)	Financial loss (USD/t)	Financial loss of yield (USD/ha)
Trangapasso	Tommy atkins	617	68	379.73	15.93	43.33	6.90	759.49	329.09	5243.00
	Kent	478	81.2	362.95	14.09	60.71	8.55	632.91	384.24	5412.92
Produssola	Tommy atkins	510	51.2	419.91	9.97	44.77	4.46	506.33	226.68	2259.54
	Kent	392	65	428.37	9.92	52.50	5.21	506.33	265.82	2637.66
Pandafarm	Tommy atkins	600	60	556.50	8.35	37.66	3.14	506.33	190.68	1591.73
Total		2597	325.4	2147.45	58.26	238.97	28.27	2911.39	1396.52	17144.84

3.4.3 Economic injury level

The total and partial costs for *B. dorsalis* management are presented in Table 3.6. Pandafarm had the highest cost of *B. dorsalis* control as a consequence of the highest area under mango cultivation (2.4 ha) comparing to Trangapasso (1ha) and Produssola (1.1 ha).

Table 3.6: Costs for *B. dorsalis* control in USD in each of the sampling orchards

Location	**Partial costs (USD)**					**Total (C) (USD)**
	GF spraying	MAT	Monitoring	Orchard cleaning material	Labour	
Trangapasso	1298.99	135.51	181.16	18.23	216.46	1850.34
Produssola	1078.69	152.45	181.16	18.23	216.46	1646.99
Pandafarm	733.98	330.31	452.90	18.23	432.91	1968.32

The regression of percentage of damage against *B. dorsalis* density was carried out using *B. dorsalis* counts alone since 79.67% of the damage that was shown here could be attributed to *B. dorsalis*. Thus, for Trangapasso the b value were estimated at 1.60, 1.99 for Produssola and 1.43 for Pandafarm (Table 3.7). The loss per *B. dorsalis* per ha is presented in table 3.8.

Table 3.7: Regression analysis of percentage of damage and *B. dorsalis* density, for each of the sampled orchards at P=5%.

Location	**b**	**SE**	***t* value**	***p* value**	**R2**	**F**
Trangapasso	1.60	0.31	5.25	0.00	0.68	27.61
Produssola	1.99	0.23	0.87	0.00	0.86	78.1
Pandafarm	1.43	0.17	8.43	0.00	0.85	71.13

Table 3.8: Estimated loss caused by a unit of *B. dorsalis* per ha (t/insect/ha) in each of the sampling orchards.

Location	Potential yield(Ton/ha)	b value	B (t/insect/ha)
Trangapasso	30.02	1.60	0.48
Produssola	19.89	1.99	0.40
Pandafarm	8.35	1.43	0.12

The average EIL was estimated in 15.93 *B. dorsalis* /ha/day, with least flies/ha/day (6.59) in Trangapasso, where the crop had the highest commercial value (USD 1392.41 per tonne) (Table 3.9). Pandafarm had the highest EIL (32.31 *B. dorsalis*/ha/day) and lowest commercial value of the mangoes (USD 506.33 per ton).

Table 3.9: Estimation of the Economic injury level (EIL) and ET (75% of EIL) for each of the orchards, 2014/15 mango season.

Location	V (USD/t)	B (t/ *B. dorsalis* /ha)	K	EIL (*B. dorsalis* /ha/day)	EIL (*B. dorsalis* /trap/week)*	ET (*B. dorsalis* /trap/week)*
Trangapasso	1392.41	0.48	0.42	6.59	23.05615	17.29211
Produssola	1012.66	0.40	0.42	8.89	31.12834	23.34626
Pandafarm	506.33	0.12	0.42	32.31	45.23124	33.92343
Average	970.46	0.33	-	15.93	33.14	24.85

*trap density were estimated in 2 traps/ha according to FAO/IAEA (2013).

Results showed an economic threshold between 17.29 and 33.92 *B. dorsalis* per trap per week, which results in an average of 24.85 *B. dorsalis* per trap per week that can be used as threshold to start *B. dorsalis* control measures.

3.5 Discussion

Highest captures of *B. dorsalis* males was recorded in January which coincided with the peak of the mango ripening stage. Mango harvesting season in Manica province started at the end of November to February, depending on the variety. Local varieties were the first ones to be harvested (end of November), followed by Tommy Atkins (end of November to end of December), Kent (end of December to end of January) and Keitt in February (CFAM, 2013). Vayssières *et al.* (2005), Mwatawala *et al*. (2006), Vayssières *et al*. (2009b), Materu *et al*. (2014) and Rwomushana and Tanga (2016) also linked the ripening of different mango cultivars to the increasing populations of *B. dorsalis* in Benin and Tanzania and Kenya.

Bactrocera dorsalis showed a clear discrimination between different ripening stages of mango fruit. It was found that one of the reasons for that is the decreasing of pericarp toughness and simultaneous increasing of total soluble solids that characterized the mango ripening process (Vayssières *et al.*, 2008; Rattanapun *et al*., 2009). The oviposition was therefore much easier when the fruit was ripe and the soluble solids were a guarantee of good nourishment for the larvae.

A strong correlation between the availability of fruiting host plants and fruit fly populations was previously reported in Benin and Kenya (Vayssières *et al*, 2009b; Rwomushana and Tanga, 2016). Previous records associated *B. dorsalis* with over 300 species of commercial/edible and wild hosts (CABI, 2017). In Pandafarm, where mango was the only fruit fly host, captures were only recorded when mango fruits were available with captures of more than 1 FTD in December, January and February and less than 1 FTD from April to November. Orchards with other fruit fly hosts e.g. citrus (*Citrus* spp.) and avocados (*Persea americana*), recorded fewer numbers of *B. dorsalis* male population even after the end of the mango season (July and August). Vayssières *et al*. (2009b) reported higher *B. dorsalis* populations in the mixed orchard than in the homogeneous, and attributed that to availability of alternative hosts throughout the year.

Temperature was considered as one of the most important factors determining the developmental rate of tephritid fruit flies (Weldon *et al*., 2014; Ekesi *et al.*, 2016, Rwomushana and Tanga, 2016). In Manica province a positive correlation between male *B. dorsalis* catches with average temperature, maximum and minimum temperatures were observed. Population increased from the beginning of the hot and rainy season (September to March) and decreased during the cold and dry season (April to August). Similar trends were also reported in Benin (Vayssières *et al*., 2005) and Tanzania (Mwatawala *et al*., 2006). The optimal temperature for *B. dorsalis* survival was found to be 25°C while 35°C was the most lethal temperature (Ekesi *et al*., 2006; Gordon, 2008). The orchards average minimum and average maximum temperatures were within the survival range for *B. dorsalis*, with the minimum average temperature recorded in June (16.87 ºC) while the maximum average temperature was recorded in November (25.59 ºC).

The reported percentages of damaged fruits agree with other authors studies (Mwatawala *et al*., 2006; Vayssières *et al*., 2009b and Nankinga *et al*., 2014). In Tanzania, 34.81% of the 385 fruit samples collected from April and mid-December 2005, were infested by fruit flies (Mwatawala *et al*., 2006). In Uganda, fruits samples collected from March to August 2010, were infested in a range between 33 and 83% (Nankinga *et al*., 2014). In this study the late variety Kent had the highest percentage of damaged fruits. The higher fruit fly damage in mid and late varieties was also reported in previous studies (Vayssières *et al*., 2009b). Studies in Benin revealed that losses varied from 17% in early season for early varieties and exceeded 70% at the end of the season (Vayssières *et al*., 2008). In Kenya, mango fruits were also previously reported to be more susceptible and attractive to fruit flies when fruits are at the ripening stage (Materu *et al.*, 2014). Additionally, the correlation between percentage of damaged fruits and *B. dorsalis*, as reported in the present study, was similar to that reported in Benin, which was very high, positive and highly significant for all varieties tested (Vayssières *et al*., 2009b).

Mango infestation rates vary among seasons, countries, regions, agro-ecological areas and varieties (Vayssières *et al*., 2009b). This study recovered an average of 176.3 flies/kg of mangoes at the peak of mango ripening stage. Similar results were reported in Tanzania, where an average of 149.8 flies/kg emerged from mangoes sampled in 2005 at the mango season (Mwatawala *et al*., 2006). In Kenya an infestation rate of 130.3 flies per kg of mangoes was reported (Rwomushana *et al*., 2009). Nankinga *et al*. (2014) also reported in Uganda higher fruit fly infestation indexes in the exotic mango varieties.

Trangapasso and Produssola had more diverse composition of host fruits which was a condition to maintain fruit fly population high and consequently highly infestation rates. However, in January the infestation rates in Trangapasso were less compared to other farms. It was a result of proper management practices that included orchard sanitation, correct irrigation and fertilization. These findings are supported by Piñero *et al*. (2009) studies in which they found significantly more female *B. dorsalis* in plots that were categorized as having bad sanitation than either in good sanitation plots. Good irrigation and fertilization was the reason for highest potential mango production in Trangapasso (15.93 t/ha), while for Pandafarm, the low potential yield can be attributed to poor management of the orchard.

Differences in yield loss have been observed for each variety and they might be due to several intrinsic and extrinsic factors. Specific intrinsic factors for each variety are: (i) the kairomonal complex (very attractive smells), (ii) fruit color, which depends on ripening stage, and (iii) ripening date (Vayssières *et al.*, 2008). Thus, late, yellow varieties with thin skins (such as Tommy and Kent) are more attractive than early, green cultivars with thicker skins (such as local varieties with fiber) (Vayssières *et al.*, 2008). Losses attributed to tephritidae ranged from 3.14 to 8.55 t/ha depending on the variety. Similar range was reported by Materu *et al.* (2014) in Kenya, with losses caused by fruit flies between 0.34 t/ha and 6.5 t/ha.

The EIL were low in the orchards where the crop value was high, meaning that for highly valuable crop the pest tolerance level is very low to prevent economic losses. Vayssières *et al.* (2009a) estimated for Benin an EIL ranging from 20 to 269 Tephritidae/ha/week when considering the minimum prices of the varieties, an EIL between 9 and 107 Tephritidae/ha/week with maximum prices of the varieties and an average EIL of 12-153 Tephritidae/ha/week when considering the average selling prices of the varieties. The EIL presented in this study is within the range reported by Vayssières *et al.* (2009a). However, Vayssières *et al.* (2009a) used a K value of 80% (0.8), which was determined based on the efficay tests of Success Appat (GF-120) in Benin (Vayssières *et al*. 2009b), while in the present study was used 0.42.

3.6 Conclusion

It can be concluded that the population of fruit flies was determined by temperature, availability of hosts and hosts ripening stage. Highest *B. dorsalis* population levels were recorded in January during the hot season and peak of maturation stage of mango. Fruits collected in January were also highly infested. The time of fruit collection (month) significantly affected number of damaged fruits, pupae, number of Tephritidae/kg and *B. dorsalis*/kg while the farms (location) did not show significant effect in any of the estimated infestation parameters. In December and January the variety were related with the number of positive samples, in which the exotic varieties Tommy Atkins and Kent were most infested when comparing to the local varieties.

Yield losses varied among farms and the financial loss were higher in the farms cultivating high commercial valuable varieties such as Tommy Atkins and investing on crop management to have high potential yields. EIL was low for the farms in which the potential financial loss was high. The EIL was estimated in 23.06 *B. dorsalis*/trap/week for Trangapasso, 31.12 *B. dorsalis*/ trap/week for Produssola and 45.23 *B. dorsalis*/trap/week for Pandafarm.

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CHAPTER FOUR

4.0 Optimization of an integrated pest management against the oriental fruit fly *Bactrocera dorsalis* (Diptera: Tephritidae) and its effectiveness in Manica province, Mozambique

4.1 Abstract

The fruit and vegetable sector in the world is severely hampered by fruit flies (Diptera: Tephritidae). Since the detection of the oriental fruit fly, *Bactrocera dorsalis* in Manica province, in 2008, huge economic losses have been reported. An IPM for *B. dorsalis* control was developed in Tanzania by the Sokoine University of Agriculture (SUA IPM) based on sanitation and calendar application of bait sprays. However, there was a need to optimize this package by introducing decision-making criteria to focus the control on pest hot spots. Trials were conducted in four selected orchards at Manica province, for 2 seasons. Each orchard received one treatment (SUA IPM, optimized IPM, sanitation, untreated). The SUA IPM was evaluated during the 2015/16 mango season in Produssola, having Trangapasso under standard sanitation while the optimized IPM was tested in Chandroca during the 2016/17 mango season having a fourth orchard (Frutis) as untreated. The SUA IPM included calendar GF 120 NF bait sprays and orchard sanitation while for the optimized IPM the GF 120 NF was only sprayed in the subplots inside the orchard when the threshold of 30 flies/trap/week was reached. *Bactrocera dorsalis* density as well as percentages of damaged fruits and infestation rates were calculated and ANOVA and t-test was performed in R. SUA IPM reduced the *B. dorsalis* density in 62.61% during 2015/16 season and had 75.77% less flies comparing to the untreated orchard, during 2016/17 season. In general, the effect of the treatment was significant on the estimated variables. The SUA IPM recorded the lowest number of damaged fruits and infestation

rates followed by the optimized IPM, sanitation and untreated orchard. However, the SUA IPM and optimized IPM did not differ significantly, although significantly less bait were used in optimized IPM. Both treatments differed significantly from the untreated orchard. Results showed that spot application of GF 120 NF by using action thresholds can provide the equivalent level of the pest control comparing to calendar spraying, and should therefore be used by the farmers to prevent the fruit losses caused by fruit flies as well as reduce the costs on pest control.

4.2 Introduction

Agriculture is a key sector of the Mozambique's economy. The sector grows at a rate of 8.4% annually due to an expansion of farming areas and crop diversification and contribute for 25% of GDP (Cunguara *et al.,* 2013). The country as favorable climate, good production resources, and advantage of seasonal differences with major fruit producers favor the increase investment in fruit sector. The average size of commercial farms is between 10 and 200 ha (Weeks and Bruns, 2016).

Manica province is among the major fruit producers, as well as Nampula, Inhambane and Maputo provinces (INE, 2017). Of the 30 000 t of mangoes *Mangifera indica* L., produced in Mozambique each year, 200 to 300 t are exported, mostly to South Africa mostly from Manica province (Weeks and Bruns, 2016). The domestic production of mango as well as the land under mango cultivation, increased very marginally over the past decade, with a slight decrease in 2013 and 2014 (FAO, 2017). The decrease in production was mainly due to stalled investments, occurrence and economic impact of the oriental fruit fly, *Bactrocera dorsalis* in the country (Weeks and Bruns, 2016).

Fruit flies (Diptera: Tephritidae) are considered the most destructive insect pests of fruit and vegetables in the world (Vayssières *et al.,* 2008; Ekesi, 2010). They are associated with over 300 species of commercial/edible and wild hosts. Mango, is one of the major cultivated hosts in Africa amongst others (Mwatawala *et al.,* 2009; Ekesi *et al.,* 2006; Vayssières *et al.,* 2014; CABI, 2017). Both invasive and indigenous tephritid fruit flies attack mango in Africa. The economically important species include exotic species such as *Bactrocera dorsalis* (Hendel), *Zeugodacus cucurbitae* (Coquillett), *Bactrocera zonata* (Saunders) in the invasive group and indigenous species such as *Ceratitis anonae* (Graham), *Ceratitis capitata* (Wiedemann), *Ceratitis cosyra* (Walker), *Ceratitis ditissima* (Munro), *Ceratitis fasciventris* (Bezzi), *Ceratitis rosa* Karsch, *Ceratitis punctata* (Wiedemann), *Dacus bivittatus* (Bigot) and *Dacus ciliatus* Loew (Vayssières *et al.* 2008; Ekesi *et al.*, 2009; Mwatawala *et al.*, 2009; Rwomushana and Tanga, 2016). Of these, *B. dorsalis,* is ranked as the most important frugivorous pest of mango wherever it occurs in many parts of the continent followed by *C. cosyra* (Rwomushana and Tanga, 2016).

The oriental fruit fly affects not only the quality of the fruit but also reduces access to international markets due to rigorous restriction measures imposed by the importing countries. *Bactrocera dorsalis* was detected for the first time in Mozambique in 2007 in Niassa province (Correia *et al.*, 2008). Damage inflicted by *B. dorsalis* in Cabo Delgado province was estimated between 36.7% and 92.5% (Jose *et al.*, 2013). Additionally, the volume of sales was reduced, private investments in fruit sector were temporarily suspended, and that caused losses of about USD 23 million (Cugala *et al.*, 2011).

Many Integrated Pest Management (IPM) programs were developed against the economically important *B. dorsalis* in Africa (Ekesi and Billah, 2007; Vayssières *et al.*, 2009c). Management components such as biological control, cultural control, baiting techniques and male annihilation technique (MAT) were recommended for fruit fly control within an IPM context with different levels of success (Ekesi and Billah, 2007; Badii *et al.*, 2015; Mwatawala *et al.*, 2015). Fruit fly population suppression mainly relies on the use of food baits (Vayssieres *et al.*, 2009c; Ekesi *et al.*, 2014; Mwatawala *et al.*, 2015; Ekesi, 2016).

Recently, an IPM program against *B. dorsalis* was developed by the Sokoine University of Agriculture (SUA) in Tanzania (Mwatawala *et al.*, 2015). That program was based on calendar application of baits that were applied throughout the orchards. The program reduced fruits damage when compared other treatments. This SUA IPM could be adopted and tested in Mozambique, especially in Manica province, where a sound program did not exist. However, there was a need to test how this program could perform in the Mozambican environment. There was also a need to optimize the SUA IPM programme by introducing decision-making criteria such as economic injury level (EIL) and a focus the control program on pest hot spots.

Therefore, the present study was conducted to test the efficacy of the SUA IPM and its optimized version in Manica province. The use of EIL and targeting flies hotspots, could improve the efficacy of an IPM program through spot and timely application. Adherence to threshold levels in fruit fly management in South Africa helped fruit producers to achieve fruit fly free consignments and led to very low export market interceptions of fruit flies in fresh fruit consignments from South Africa (Manrakhan, 2016). Israel optimized its area wide IPM for medfly *C. capitata* by identifying medfly hotspots and reinforced treatments only at those points (Aidlin-Harari *et al.*, 2016).

4.3 Materials and methods

4.3.1 Description of the study sites

Studies were conducted in Manica province, Mozambique, located in Centre-Western part of the country, along the border with Zimbabwe. Manica province lies between latitudes 21º 34'07" and 16º 24' 05" South and between Longitudes 34° 01'47" and 32º 42'45" West. It is characterized by a tropical climate modified by altitude, with two distinct seasons: a hot and rainy season (September to March) and a dry season (April to August). The average temperatures range from 20 ºC to 25 °C in the hot and rainy season, and from 15 to 20 ºC in the coolest months.

Four orchards were selected during the two seasons trials (2015/16 and 2016/17). These orchards were Trangapasso, Produssola, Chandroca and Frutis (Table 4.1).

Table 4.1: Description of the study sites.

Orchard	District	Fruits cultivated
Trangapasso (1ha) (19º07'22.3" S; 33º25'37.1"E; 577 m.a.s.l)	Manica	Mango (*Mangifera indica* L.) varieties Tommy Atkins, Kent and local varieties; *Citrus sinensis* (L.) Osbeck. (Oranges), *C. reticulata* Blanco (tangerines); avocado *Persea americana* Miller; loquat (*Eriobotrya japonica* (Thunb.) Lindley); soursop (*Annona muricata* L.); peach (*Prunus persica* L.); cashew (*Anacardium occidentale* L.); papaya (*Carica papaya* L.); litchi (*Litchi chinensis* Sonn.).
Produssola (1.1ha) (19º01'44.6"S; 033º03'02.2"E, 631 m.a.s.l)	Manica	Mango (*M. indica*) varieties Tommy Atkins, Kent and local varieties; orange (*C. sinensis*)*;* papaya (*C. papaya*); avocado (*P. Americana*) and fig (*Ficus carica* L.).
Chandroca (10ha) (18º06'52.2"S; 33º18'16.6"E; 522 m.a.s.l)	Vanduzi	Mango (*M. indica*) varieties Tommy Atkins, Kent and local varieties; guava (*P. guajava*); litchi (*L. chinensis*).
Frutis (1ha) (19º11'15.5"S; 33º27'15.2"E; 521 m.a.s.l)	Manica	Mango (*M. indica*) varieties Tommy Atkins, Kent and local varieties; avocado (*P. Americana*)*;* papaya (*C. papaya*); litchi (*L. chinensis*); guava (*P. guajava*); banana (*Musa* sp.)

The selection of the orchards was based on the following criteria: (i) orchard size of at least 1 ha of grafted mango trees under production (ii) orchards with market preferred varieties/ cultivars (iii) orchards with regular spacing between mango trees, and (iv) availability / readiness of the owner to participate in the study. Besides this, the mango orchards were selected because of their relative isolation from unmanaged smallholder units dominated by very old mango trees of local varieties. Most of the mango orchards used in the study were also relatively far (approximately 1.5 km) from one another which was crucial to minimize movement of flies between replicates and blocks (Ekesi *et al.*, 2011).

The performance of SUA IPM was tested in the 2015/16 mango season, while the optimized version of the SUA IPM was tested in the 2016/17 mango season.

4.3.2 Treatments description / experimental setting

4.3.2.1 Evaluating the SUA IPM

Trials were conducted in the 2015/16 mango season to evaluate the IPM package developed in Tanzania by Sokoine University of Agriculture (SUA IPM). The components of the IPM program were male annihilation, bait spray, early harvesting and orchard sanitation (Mwatawala *et al.*, 2015; Mwatawala, 2016). Three treatments: SUA IPM, orchard sanitation and untreated control were tested. Each treatment was applied in a single orchard as follows: SUA IPM (Produssola), orchard sanitation (Trangapasso) and untreated control (Chandroca). The within treatment subjects were five methyl eugenol traps and five fruits sampling points. The subjects were sampled repeatedly during the season.

Orchard sanitation was carried out once per week by removing all fallen fruits and buried in pits of 90 cm deep. Sanitation was conducted from the first week of November 2015 until the end of the mango season (February 2016). It was a standard practice applied in all orchards.

The food bait solution was prepared by mixing one litre of water and 6.5 litre of GF 120 NF (active ingredient- Spinosad 0.24g/l). The mixture was sprayed at a rate of 50 ml per tree, using a shoulder-carried knapsack sprayer (of 10 or 16 liters). The toxic bait spraying started from first week of November 2015 until the end of the mango on February 2016. GF 120 NF was sprayed weekly throughout the mango season. Baits were applied weekly on $1m^2$ spots on tree canopies at a rate of 1 L/ha (Mwatawala *et al.*, 2015).

Mass trapping was not implemented to avoid interference with methyl eugenol traps for population monitoring.

4.3.2.2 Comparing effects of the optimised IPM and SUA IPM

Trials were conducted in in four orchards during 2016/17 mango season. Each treatment was applied in a single orchard as follows: Chandroca (optimized IPM), Produssola (SUA IPM), Trangapasso (orchard sanitation) and Frutis (untreated orchard). Similarly, the within treatment subjects were five methyl eugenol traps and five fruits sampling points. The subjects were sampled repeatedly during the season.

The SUA IPM was optimised by spraying GF 120 NF (i) in hot spots, that were determined in previous seasons by catches in torula traps (Bota, 2016) (ii) after a threshold 30 flies/trap/week was reached. Orchard sanitation was part of the package and started in 18/10/2016. Sanitation was done in all of the plots in the orchard using the procedures described above. In Produssola, GF 120 NF was sprayed weekly starting on the first week of November 2016 until the end of the mango season on February 2017. Additionally, the volumes of GF 120 used per week for each of the treatments were recorded.

4.3.3. Data collection

4.3.3.1 *B. dorsalis* population density

a) Methyl eugenol trapping

Five chempac traps baited with methyl eugenol were placed in each of the selected orchards (Trangapasso, Produssola and Frutis) from September 2015 to August 2017; four in the corners and one in the middle of the orchard. A strip of dimethyl-dichloro-vinylphosphate (DDVP) was placed at the bottom of the trap to kill the attracted flies. Traps were serviced monthly and trapped flies were removed and the lure was changed. Collected flies were preserved in 70% alcohol for sorting, counting and identification. Fruit flies identification was done using standard identification keys (Ekesi and Billah, 2007; Virgilio *et al.*, 2014; De Meyer *et al.*, 2014). *Bactrocera dorsalis* density was expressed as number of *B. dorsalis* flies per trap per day (FTD) (Ekesi and Billah, 2007).

b) Protein bait trapping

Chempac bucket traps baited with torula yeast (250 ml per trap), were placed in Chandroca from August 2016 to February 2017. Traps were placed in twenty six (26) sub-plots that were marked inside the orchard and each sub-plot composed of six trees. Torula was diluted in water at a proportion of three tablets in a liter of water. One torula baited trap was placed in each sub-plot. Torula solution was replaced weekly, after washing the traps. Collected flies were preserved in 70% alcohol for sorting, counting and identification. Fruit flies identification was done using standard identification keys (Ekesi and Billah, 2007; Virgilio *et al.*, 2014; De Meyer e*t al.*, 2014). Data were reported as the number of flies per trap per week (FTW) in each sub-plot.

4.3.3.2 Percentage of damage and infestation rates

Mango fruits were collected three times in each season namely November, December and January. Five sampling points were marked inside the orchard (four in the corners and one in the middle) and in each sampling point were collected at least ten mango fruits per month, making a total of fifty fruits per orchard/ month. The fruits were placed in plastic bags, labeled and sent to the Chimoio fruit fly lab (Laboratório da Mosca da Fruta de Chimoio) for rearing, following the procedures described by Ekesi and Billah (2007). Fruits were weighed, counted and then checked for infestation symptoms. A fruit was considered damaged when a fly's ovipuncture mark was visible (Vayssières *et al.*, 2009a). Thereafter, the fruit was placed in plastic containers with a net lid and sterilized sand at the bottom and incubated for about six weeks.

Fruits were opened slightly to check the presence of larvae after a week of rearing. A fruit was also considered infested when at least one fruit fly larvae was observed inside the fruit (Vayssières *et al.*, 2009a). The containers were further checked once a week for puparia. Puparia were sieved from the sand, counted, weighed, placed in petri dishes with moisturized filter paper and transferred to a cage for adult emergence. Emerged adults were counted, sexed and preserved in 70% alcohol for further identification. Fruit flies identification was done using standard identification keys (Ekesi and Billah, 2007; Virgilio *et al.*, 2014, De Meyer *et al.*, 2014). Percentage of damage caused by tephritids was estimated per month and orchard, as a ratio of number of infested fruits per total number of collected fruits. Infestation rate was determined as the number of pupae, number of emerged *B. dorsalis* per unit weight of fruits (Mwatawala *et al.*, 2015). The effect of the treatment was assessed on the percentage of damaged fruits and infestation rates (pupae/kg, *B. dorsalis*/kg) (Vayssieres *et al.*, 2009c).

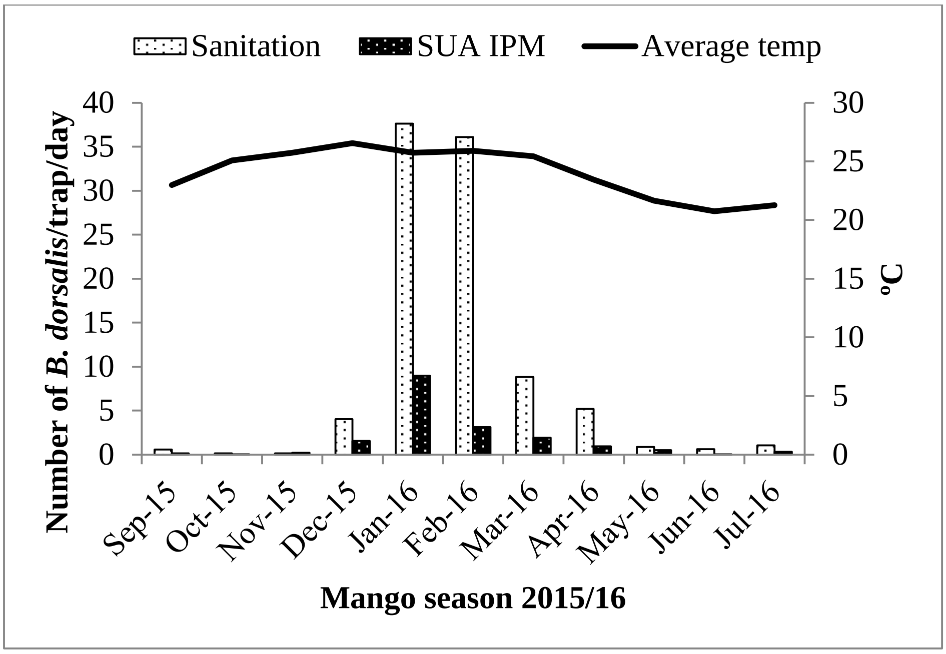
4.3.4 Data analysis

The collected data were subjected into an excel spreadsheet where *B. dorsalis* density as well as the percentages of damaged fruits and infestation rates were calculated. Repeated measures ANOVA (done independently for each season) was performed to assess the effect of the treatments and time on damage and infestation rates, followed by post-hoc Tukey honest significant reference test. Five methyl eugenol traps and five sampling points in each orchard were within treatment subjects and sampled repeatedly during respective seasons. T-test was performed to compare the used volumes of GF 120 per week in SUA IPM and optimized IPM. All statistical analysis was performed in R version 3.2.5 with a significance level of 5%.

4.4 Results

4.4.1 Effect of SUA IPM on *B. dorsalis* density

Population density of *B. dorsalis* sampled during the two seasons at orchards under different treatments is shown in figure 4.1. Similar population density trend of *B. dorsalis* was observed for both seasons with the peak in January. The average population density in January was 23.31 *B. dorsalis*/trap/day in first season and 223.42 *B. dorsalis*/trap/day during the second season. An outbreak of pest population was recorded during the 2016/17 season, with higher flies densities in all orchards compared to the previous year.

(a)


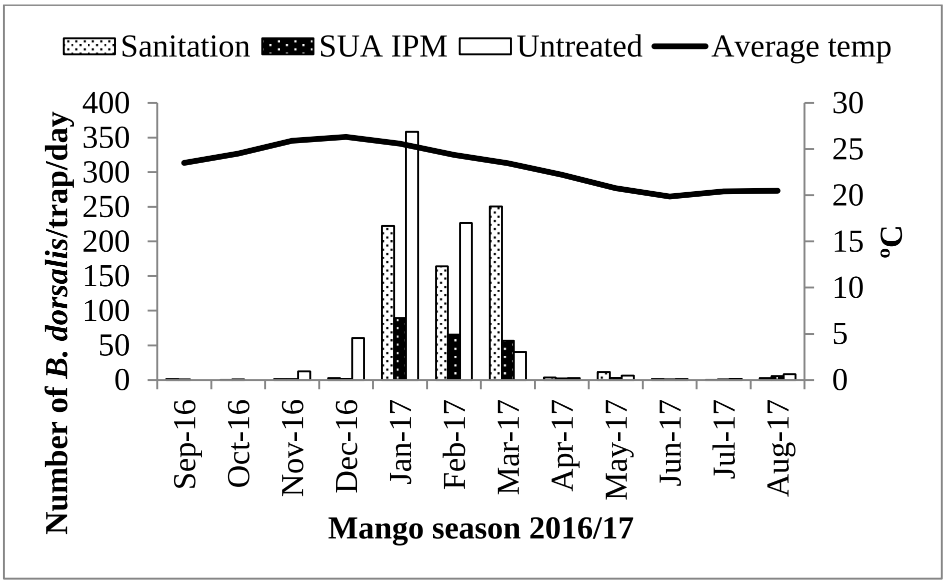
(b)


Figure 4.1: Seasonality of B. dorsalis (a) 2015/16 season, (b) 2016/17 season.

Spot application of GF 120 NF plus orchard sanitation, was recorded to reduce the *B. dorsalis* average density in 62.61% during 2015/16 mango season. During the season 2016/17, the SUA IPM orchard recorded the least *B. dorsalis* density of 39.27 *B. dorsalis*/trap/day, while the orchards under sanitation orchard and untreated had the average densities of 131.53 and 162 *B. dorsalis*/trap/day, respectively (Figure 4.2). The

SUA IPM had 70.14 % less flies than the sanitation orchard and 75.77% less flies compared to the untreated orchard.

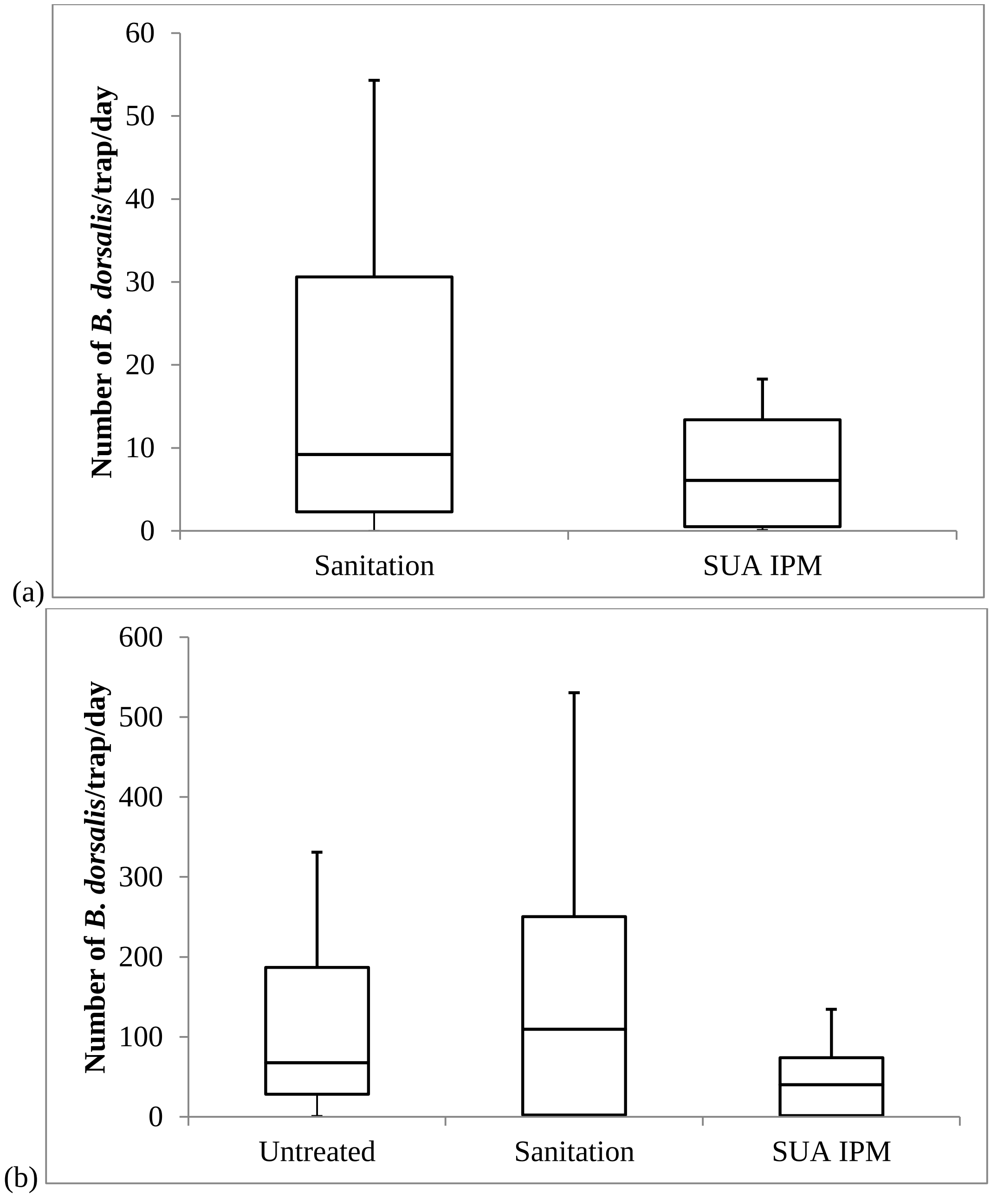


Figure 4.2. Variation among treatments on *B. dorsalis*/trap/day for the two seasons: (a) 2015/16 season and (b) 2016/17 season.

4.4.2 Effect of IPM programs on damage and infestation rates

4.4.2.1 Percentage of damage

In general, untreated orchards had the highest percentage of damaged fruits compared to other treatments. This means that orchards treated with SUA IPM and optimized IPM had the lowest number of damaged fruits.

Effect of SUA IPM on percentage damage of fruits

Results showed that the orchard treated with SUA IPM had an average of 21.99% of damaged fruits. Orchards subjected to sanitation and no treatment had 36.59% and 40.34% of damaged fruits, respectively during the 2015/16 mango season. Results showed that the effect of treatment on the percentage of damaged fruits was not significant (F (2, 28) = 2.04, p= 0.15). Results further showed that time (F (2, 28) = 7.87, p < 0.001) and interaction (F (2, 28) = 23.49, p = 0.04) significantly affected the percentage of damaged fruits, with the mean of January 2016 differing significantly from the November´s mean (p = 0.001) (Table 4.2).

Table 4.2: Percentage of damaged fruits (X±SE) during sampling months in the 2015/16 mango season, in Manica province.

Treatment		**Nov-15**	**Dec-15**	**Jan-16**
SUAIPM		16±5.09a	20.5±2.78a	29.48±7.64a
Sanitation		3.34±3.34a	35.78±14.8a	70.64±17.93ab
Untreated			40.34±9.09a	
Factor time	F		7.87	
	df		2, 28	
	p value		0.0019	

Means with the same letter(s) in a row are not significantly different at the 0.05 level of significance.

Comparison of effects of Optimized and SUA IPM on percentage damage of fruits

The SUA IPM had the lowest number of damaged fruits (23.29%) followed by the optimized IPM with 30.91%, sanitation (43.15%) and untreated orchard (57.36%) during 2016/17 season. The mean percentage of damaged fruits was significantly affected by the treatment (F (3, 48) = 8.23, p = 0.0). Also the number of damaged fruits varied significantly over time (F (2, 48) = 4.35, p = 0.02). The effect of the interaction was also significant (F (6, 48) = 3.84, p < 0.01). Orchards treated with SUA IPM had less damaged fruits than those from sanitation (p = 0.04) and untreated orchard (p < 0.001). Similarly, orchards treated with optimized IPM had less damaged fruits comparing with untreated orchard (p < 0.01). However, the mean percentage of damaged fruits in SUA IPM was not statistically different from the optimized IPM mean (p = 0.73) (Table 4.3).

Table 4.3: Percentage of damaged fruits (X±SE) during sampling months in the 2016/17 mango season, in Manica province.

Treatment		Nov-16	Dec-16	Jan-17
SUAIPM		22±15.62Aa	26±2.44Aa	21.86±5.02Aa
Optimized IPM		28.6±10.36Aa	34±9.79Aa	30.14±5.38Aa
Sanitation		5.46±5.46Aa	48±14.62Aa	76±9.79ABb
Untreated		58±3.34Ba	54±9.27Aa	60.08±5.19Aa
	F		8.23	
Factor treatment	df		3, 48	
	p value		< 0.001	
	F		4.35	
Factor time	df		2, 48	
	p value		0.02	
	F		3.84	
Interaction	df		6, 48	
	p value		0.003	

Means with the same upper case letter(s) in a column are not significantly different at the 0.05 level of significance. Means with the same lower case letter(s) in a row are not significantly different at the 0.05 level of significance.

4.4.2.2 Infestation rates

The number of pupae/kg and adult flies /kg recorded from fruits collected in orchards treated with SUA IPM and optimized IPM were below the infestation rates of the untreated orchard, in the two seasons.

Effects of SUA IPM on infestation rates of fruit flies

Fruits harvested from the orchard treated with SUA IPM had the lowest number of pupae and emerged *B. dorsalis* (13.43 pupae/kg and 7 *B. dorsalis*/kg). The orchard treated with sanitation had the highest means of infestation rates (38.43 pupae/kg and 25.1 *B. dorsalis*/kg). ANOVA results showed that treatment had a significant effect on pupae infestation rate (F (2, 28) = 3.39, p = 0.04). However neither time (F (2, 28) = 4.35, p = 0.2) nor interaction (F (2, 28) = 3.09, p = 0.06) had significant effects on number of pupae per kilogram of fruits. The mean pupae infestation rate of fruits treated with SUA IPM was significantly lower than those from the sanitation treatment (p = 0.041) (Figure 4.3).

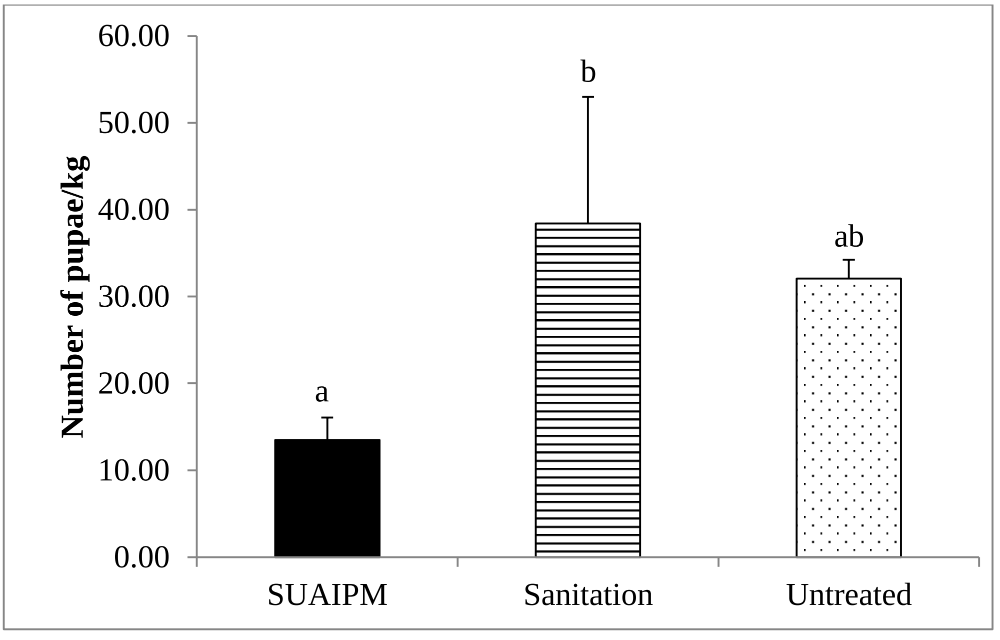


Figure 4.3: Effect of the treatment on pupae infestation rate during 2015/16 season, in Manica province. Columns bearing the same letter do not differ significantly from each other using Tukey's (HSD). Error *Bars* denote SE.

Results further showed that *B. dorsalis* infestation rate was not significantly affected by the treatment (F (2, 28) = 3.23, p = 0.054), neither the time (F (2, 28) = 1.35, p = 0.28) nor interaction (F (2, 28) = 1.91, p = 0.17).

Comparison of effects of the optimized IPM and SUA IPM on infestation rates of fruit flies

Low number of pupae/kg and *B. dorsalis* flies /kg were recovered from fruits sampled in orchard treated with SUA IPM and optimized IPM compared to the ones from untreated orchard.

Treatment had significant effect on pupae infestation rate (F (3, 48) = 15.58, p < 0.001). However neither the time (F (2, 48) = 2.28, p = 0.11) nor the interaction (F (6, 48) = 3.09, p = 0.56) significantly affected pupae infestation rate. The number of pupae per kg of fruits from orchards treated with SUA IPM and optimized IPM were not significantly different (p =0.92) but both differed significantly from the untreated orchard (Figure 4.4).

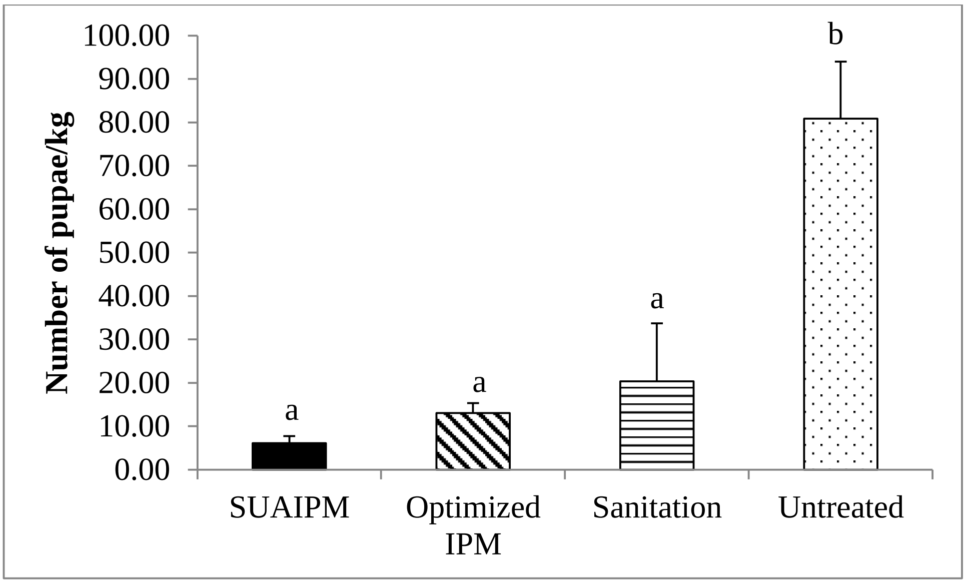


Figure 4.4: Effect of the treatment on pupae infestation rate during 2016/17 season, in Manica province. Columns bearing the same letter do not differ significantly from each other using Tukey's (HSD). Error *Bars* denote SE.

Treatment also significantly affected infestation rate of adult flies (*F* (3, 48) = 14.45, $p < 0.001$). However, the infestation rate was not significantly affected by time (*F* (2, 48) = 1.33, $p = 0.27$) or interaction (*F* (6, 48) = 0.81, $p = 0.56$). The infestation rates by *B. dorsalis* per kilogram of fruits in orchards treated with SUA IPM and optimized IPM were not significantly different ($p = 0.94$). However, SUA IPM differed significantly from the untreated orchard (p < 0.001) and similar results were reported for optimized IPM which *B. dorsalis* infestation rate differed significantly from the untreated orchard (p < 0.001) (Figure 4.5).

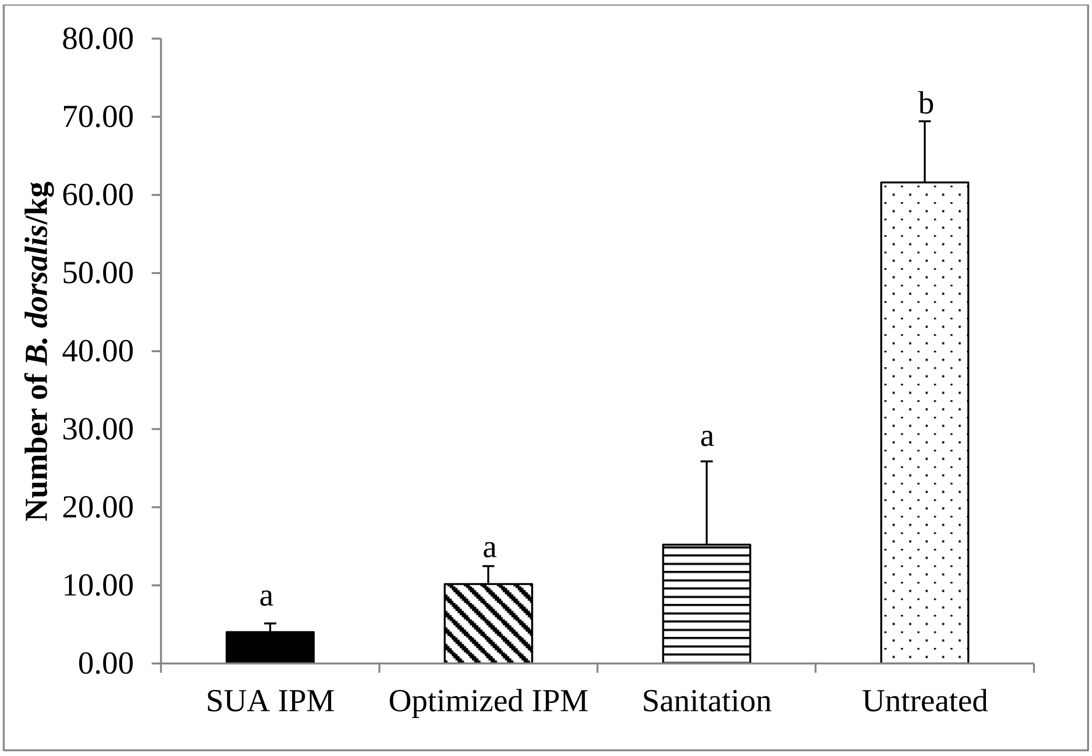


Figure 4.5: Effect of the treatment on *B. dorsalis* infestation rate during 2016/17 season, in Manica province. Columns bearing the same letter do not differ significantly from each other using Tukey's (HSD). Error *Bars* denote SE.

The GF 120 was applied at a weekly basis in SUA IPM and optimized IPM. However, the volumes of GF 120 used per week in SUA IPM (2.5 l/ week) and optimized IPM (0.7 l/ week), differed significantly from each other (t (37) = 7.48, $p<0.001$).

4.5 Discussion

Low densities of *B. dorsalis* were recorded from the orchards treated treated with GF 120 NF and orchard sanitation. This can be attributed to the efficacy of these baits in controlling *B. dorsalis*. The combination of GF 120 NF and orchard sanitation in the study, resulted in 2.5-11 times less *B. dorsalis*/trap/day in orchards treated with SUA IPM compared to sanitation alone during the first year trial (2015/16) and 2.5 times less *B. dorsalis*/trap/day during the second year trial. A similar result was also reported in Benin, where the treated orchards had in general less *B. dorsalis* density, however, there were no significant differences between treatments in the mean number of *B. dorsalis* adults captured per week and per trap throughout the trapping period (Vayssieres *et al.*, 2009c). In Kenya, the untreated orchard had 3 times more flies than those treated with GF 120 NF (Ekesi *et al.*, 2011).

High *B. dorsalis* density was recorded in second season trial (2016/17) as a consequence of the host availability. Mango fruits were harvested too late, at the end of January 2017, which was beyond the normal harvesting time (December) due to market difficulties. The late harvesting subjected the mango fruits to overripening which increased the oviposition by the female fruit flies and, therefore, the density of *B. dorsalis.* At the peak of mango season (January) the flies' density reached a maximum of 358.47 *B. dorsalis*/trap/day in untreated orchard. However, those levels were lower than those reported in Tanzania (Mwatawala *et al.* 2006) and Benin, which *B. dorsalis* population peaked during June – July period (Vayssières *et al.*, 2009b).

This study showed that percentage of damaged fruits and infestation rates was high untreated orchards comparing to orchards treated with IPM. This can be attributed to the low *B. dorsalis* density as a consequence of the effect of bait sprays in reducing the *B. dorsalis* population, especially the female flies, which is attracted by a protein source that is part of the GF 120 composition. The direct damage is caused by the female fruit fly and the reduction of female population results in less oviposition and less damage to the fruits. In fact, previous studies reported highly significant and positive correlation between percentage of damaged fruits and *B. dorsalis* density (Ekesi *et al*., 2006; Vayssières *et al*., 2009b).

The reduction in infestation rates might also be a consequence of the reduction in *B. dorsalis*. Immature stages of flies that develop inside the fruits and are protected from the direct insecticide contact and therefore, can only be controlled with systemic insecticides (Ekesi, 2016). However, the use of systemic insecticides is associated with residues and consumer sensitivity precludes their use on many fresh fruits (Ekesi, 2016).

Vayssieres *et al.* (2009c) also reported significantly lower number of pupae/kg in the orchard treated with GF 120 NF compared to untreated orchards, for both years his study was conducted. In Hawaii a significant reductions in both numbers of female *B. dorsalis* captured in monitoring traps and in level of papaya fruit infestation were achieved in plots subjected to GF 120 NF bait use compared with untreated plots, but only after sanitation practices were improved (Piñero *et al.,* 2009).

IPM treatments with protein hydrolysate (0.1%) + spinosad (0.03%), also reduced fruit fly infestation of Kinnow mandarim (a hybrid between *Citrus nobilis* and *Citrus deliciosa*), with the lowest percentage of infested fruits in IPM treatments (4.6 %) compared to untreated plot (50.5 %) (Singh and Sharma, 2016). In the same study the number of larvae per fruit was significantly lower in the IPM treated orchards (9.2/fruit) and the fruit yield was significantly higher in the IPM orchard compared to the two other orchards, and resulted in higher net income/acre in the IPM orchard.

The effectiveness of baiting techniques can be less than desirable, especially under high pest population pressure, highlighting the need to integrate these techniques with all the other management methods available (Ekesi *et al.*, 2016). In Australia, fruit flies were historically controlled with the pesticides dimethoate and fenthion, organophosphate cover sprays that kill insect pests systemically or by contact (Arevalo-Vigne *et al.*, 2016). Between 1987 and 1996, the protection inferred to be provided by the IPM package which included, together with orchard sanitation, the cover sprays of insecticide (e.g. fenthion 0.05%, deltamethrin 0.0028%, carbaryl 0.2%, deltamethrin 0.0028% and dimethoate 0.06%) for the management of *B. dorsalis* on mango in India, was as a reduction of between 76.7% and 100% of infested fruits (Verghese *et al.*, 2004).

Guedes *et al.* (2016) stated that there is window that allows the pesticide application as a way to optimize pest management efforts within an IPM approach. Therefore, the judicious use of selective pesticides, at the time when the number of *B. dorsalis* increase above the expected values, would have increased the likelihood of controlling the pest and at lower costs, during the second season trials.

Economic threshold was assessed in this study as a decision tool for determining the moment to start the bait sprayings. Through this method was possible to reduce the volume of GF 120 needed each week to control the flies, since the bait was not sprayed in all the trees. Although other authors recommended the application of control according to a threshold rule in order to guarantee a net return (Verghese *et al*., 2004; Vayssieres *et al.*, 2009a), the optimized IPM tested in the present study requires the monitoring of the pest in sub-plots and in a weekly basis. Therefore, an economic evaluation of the program is recommended before its implementation among the large scale farmers because of costs related to the proposed monitoring schedule. However, for the small scale farmers, the monitoring of the pest is much easier and thus, optimized IPM can be recommended since it guaranties the equivalent level of control comparing to calendar bait spraying and low cost (less bait is used in optimized IPM).

4.6 Conclusion

SUA IPM reduced the *B. dorsalis* density in 62.61% and 72.96% during the 2015/16 and 2016/17 mango season, respectively. The calendar application of bait sprays recommended in the SUA IPM and hotspots application of GF 120 reduced significantly the percentage of damaged fruits, the number of pupae/kg and *B. dorsalis*/kg when comparing to untreated orchard for both seasons the study was conducted. Although SUA IPM and optimized IPM treatments did not differ significantly from each other on infestation parameters, the optimized IPM spraying schedule resulted in significantly less volume of GF 120 per week. Both treatments had the potential to reduce de damage and infestation rates even at high pest population density. Thus, it is recommended to include other variables such as economic aspects in order to build a more powerful decision tool.

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CHAPTER FIVE

5.0 General conclusions and recommendations

5.1 General conclusions

This study was designed to reduce the damage caused by fruit flies, particularly *Bactrocera dorsalis*, through an optimized integrated pest management program. It can be concluded that fruit flies was the main pest affecting mango and citrus fruits at the ripening stage. Severe impacts of these flies were reported in fruit quality due to maggots. This kind of infestation resulted in reduction in fruit quality, which lowers its value of the fruits in local and international markets. The monetary value of this loss was more severe for mango farmers, as a consequence of the highest market value of mango when compared to citrus and banana. Large scale farmers were more aware of fruit flies' damage and management strategies than small scale farmers. High population density of *B. dorsalis* was recorded during the hot season and peak of maturation stage of mango which resulted in high level of infestation in the sampled fruits. Yield losses varied among location and the financial losses were higher to the farmers who cultivated high commercial valuable varieties such as Tommy Atkins and invested on crop management to get high potential yields. Economic injury level was estimated for Manica province in 33.14 *B. dorsalis*/trap/week, which corresponded to an action threshold of 24.85 *B. dorsalis*/trap/week. EIL was low to the farmer whose potential financial losses were high. The calendar application of bait sprays recommended in the SUA IPM and hotspots application of GF 120 NF reduced more than 50% the number of damaged fruits and the number of pupae/kg and *B. dorsalis*/kg when compared to untreated orchard for both seasons.

5.2 General recommendations

The following recommendations are suggested based on the key findings and major conclusions from the present study. For the farmers the following recommendations are made:

(i) The use of the economic injury level and economic threshold as a decision tool to start localized sprayings of GF 120 NF for *Bactrocera dorsalis* and other Tephritidae control. For this it is recommended to the mango fruit farmers in Manica province to divide the orchard in subplots and establish a weekly based pest monitoring schedule in each subplot.

(ii) Establishment of a weekly based pest monitoring schedule using methyl eugenol (starting from October up to March if only mangoes are cultivated), weekly removal and destruction of fallen mango fruits (during all mango season) and sprays of GF 120 NF in subplots with more than 25 *B. dorsalis*/trap/week.

For the agricultural authorities the following recommendations are made:

(i) Reinforcement of awareness campaigns about fruit flies identification and management among the small scale fruit farmers. This group of fruit farmers do not implement control strategies mainly due to lack of knowledge on the possible management strategies for fruit flies control.

For researchers the following recommendations are made:

(i) Conduct an economic evaluation the optimized IPM

(ii) Explore GIS models to see the effect of “cooling” the “hotspots” in optimized IPM.

APPENDICES

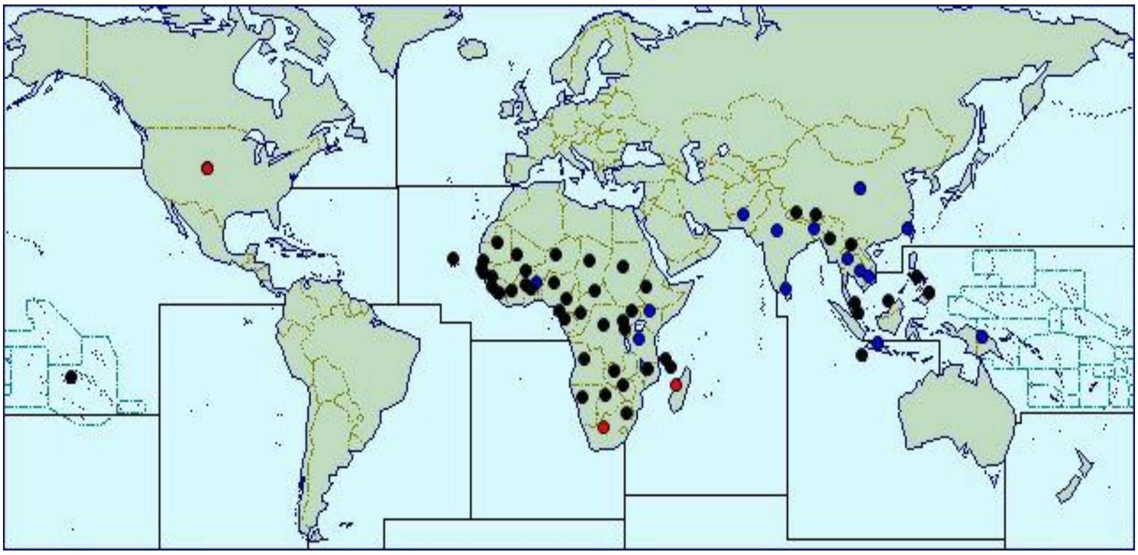
Appendix 1. Economically important fruit flies in Africa by Virgilio *et al.* (2014) and presence in Mozambique according to Roberto *et al*.(2005) and Cugala *et al*. (2016).

Genera	Species reported in Africa
Ceratitis	*C. acicularis, C. aliena, C. andranotobaka, C. anonae*[+]*, C. antistictica, C. argenteobrunnea, C. argenteostriata, C. barbata, C. bicincta, C. brachychaeta, C. bremii*[+]*, C. brucei, C. caetrata, C. capitata*[+]*, C. catoirii, C. chirinda, C. colae, C. connexa, C. contramedia, C. copelandi, C. cornuta, C. cosyra*[+]*, C. cristata, C. curvata, C. cuthbertsoni, C. discussa*[+]*, C. ditissima*[+]*, C. divaricata, C. dumeti, C. ealensis, C. edwardsi*[+]*, C. epixantha, C. faceta, C. fasciventris*[+]*, C. flava, C. flexuosa, C. fulicoides, C. graham, C. gravinotata, C. guttiformis, C. hamata, C. hancocki, C. inauratipes, C. lentigera, C. lepida, C. lineata, C. lobata, C. lunata, C. malgassa, C. manjakatompo, C. marriotti, C. melanopus, C. millicentae*[+]*, C. mlimaensis, C. morstatti, C. munroanum, C. munroi, C. nana, C. neostictica, C. nigricornis, C. obtusicuspis, C. oraria, C. ovalis, C. paracolae, C. paradumeti, C. pedestris*[+]*, C. penicillata, C. pennitibialis, C. perisae, C. perseus, C. pinax, C. pinnatifemur, C. podocarpi, C. punctata, C. querita, C. quinaria*[+]*, C. rosa*[+]*, C. roubaudi, C. rubivora, C. scaevolae, C. semipunctata, C. serrata, C. silvestrii, C. simi, C. stictica, C. stipula, C. striatella, C. sucini, C. tananarivana, C. tripteris, C. turneri, C. venusta, C. whartoni, C. whitei, C. zairensis.*
Trirhitrum	*T. albomaculatum*[+]*, T. albonigrum, T. albopleurale, T. argenteocuneatum, T. argutum , T. basale, T. brachypterum, T. coffeae, T. crescentis, T. culcasiae, T. demeyeri, T. dimorphum, T.divisum, T. fraternum, T. homogeneum, T. inscriptum, T. iridescens, T. leonense, T. manganum, T. meladiscum, T. micans, T. nigerrimum, T. nigrum, T. nitidum*[+]*, T. notandum, T. obscurum, T. occipital, T. ochriceps, T. overlaeti, T. psychotriae, T. quadrimaculatum, T. resplendens, T. scintillans, T. senex, T. stecki, T. stubbsi , T. teres, T. transiens, T. validum, T. viride.*
Dacus	*D. abbabae, D. abditus, D. abruptus, D. acutus, D. adenae, D. adenionis, D. adustus, D. africanus*[+]*, D. albiseta, D. amberiens, D. amphoratus*[+]*, D. annulatus, D. apectus, D. apiculatus, D. apostata, D. apoxanthus, D. arabicus, D. arcuatus, D. armatus, D. aspilus, D. attenuatus, D. bakingiliensis, D. basifasciatus, D. bequaerti, D. bidens, D. binotatus*[+]*, D. bistrigulatus, D. bivittatus*[+]*, D. blepharogaster, D. bombastus, D. botianus, D. brevis*[+]*, D. brevistriga, D. briani, D. brunnalis, D. carnesi, D. carvalhoi, D. ceropegiae, D. chamun, D. chapini, D. chiwira*[+]*, D. chrysomphalus, D. ciliatus*[+]*, D. clinophlebs, D. collarti, D. congoensis, D. copelandi, D. croceus, D. cyathus, D. delicatus, D. deltatus, D. demmerezi, D. diastatus, D. disjunctus, D. durbanensis*[+]*, D. eclipsis*[+]*, D. elatus, D. elegans, D. elutissimus, D. eminus*[+]*, D. erythraeus, D. etiennellus, D. externellus, D. famona*[+]*, D. fasciolatus, D. ficicola*[+]*, D. fissuratus, D. flavicrus*[+]*, D. freidbergi, D. frontalis*[+]*, D. fumosus, D. fuscatus*[+]*, D.*

	fuscinervis[+], *D. fuscovittatus*[+], *Dacus gabonensis, D. ghesquierei, D. guineensis, D. gypsoides, D. hamatus*[+], *D. hapalus, D. hargreavesi, D. herensis, D. humeralis, D. hyalobasis, D. iaspideus, D. ikelenge, D. inclytus, D. inflatus, D. inornatus, D. insolitus, D. jubatus, D. kakamega, D. kaplanae, D. Kariba*[+], *D. katonae, D. kurrensis, D. langi, D. limbipennis, D. linearis, D. longistylus*[+], *D. lotus, D. lounsburyii*[+], *D. luteovittatus, D. macer, D. madagascarensis, D. magnificus, D. marshalli, D. masaicus, D. maynei, D. mediovittatus, D. meladassus, D. melanaspis, D. merzi, D. mirificus, D. mochii, D. mulgens, D. nairobensis, D. namibiensis, D. nanus, D. nigriscutatus, D. nigrolateris, D. notalaxus, D. obesus, D. okumuae, D. opacatus*[+], *D. ostiofaciens, D. pallidilatus*[+], *D. pamelae*[+], *D. panpyrrhus, D. parvimaculatus, D. pecropsis, D. pergulariae, D. persicus, D. phantoma, D. phimis, D. phloginus, D. plagiatus*[+], *D. pleuralis, D. pseudapostata, D. pseudomirificus, D. pulchralis, D. pullescens*[+], *D. punctatifrons*[+], *D. purpurifrons*[+], *D. purus, D. pusillator, D. quilicii, D. radmirus, D. rubicundus, D. rufoscutellatus, D. rufus, D. rugatus, D. ruslan, D. rutilus, D. sakeji, D. scaber, D. schoutedeni, D. segunii, D. seguyi, D. semisphaereus, D. senegalensis, D. serratus, D. setilatens, D. siliqualactis, D. sphaeristicus, D. sphaerostigma, D. spissus, D. stentor, D. stylifer, D. telfaireae, D. temnopterus, Dacus tenebricus, D. theophrastus, D. transitorius, D. transversalis, D. triater, D. trigonus, D. umbeluzinus*[+], *D. umbrilatus, D. umehi, D. velutifrons, D. venetatus, D. vertebratus*[+], *D. vestigivittatus, D. viator, D. woodi, D. xanthaspis, D. xanthinus, D. xanthopterus, D. xanthopus, D. yangambinus, D. yaromi, D. yemenensis.*
Bactrocera	*B. amplexa, B. biguttula*[+], *B. cogani, B. dorsalis*[+], *B. latifrons, B. lucida, B. menanus, B. mesomelas, B. montyanus, B. munroi, B. nesiotes, B. nigrivenata, B. oleae, B. zonata.*
Zeugodacus	*Z. cucurbitae*[+]
Capparimyia	*C. aenigma, C. aristata, C. bipustulata, C. maeruae, C. melanaspis, C. mirabilis, C. savastani, C. spatulata.*
Neoceratitis	*N. albiseta, N. cyanescens, N. efflatouni, N. flavoscutellata, N. lycii*
Perilampsis	*P. amazuluana, P. atra, P. curta*[+], *P. decellei, P. deemingi, P. diademata, P. dryades, P. formosula, P. furcata, P. incohata, P. miratrix*[+], *P. pulchella, P. rubella, P. tetradactyla, P.umbrina, P. unita, P. woodi.*

[+] Species reported in Mozambique

Appendix 2. Distribution of *Bactrocera dorsalis* in Africa and other continents (blue spots= widespread, black spots = present, red spots = localized infestation) (source: CABI, 2017).



Appendix 3. Host plants of the oriental fruit fly, *B. dorsalis*, in Africa (Rwomushana and Tanga, 2016 and CABI, 2017)

Plant family	Host plant species
Anacardiaceae	*Anacardium occidentale* L. (cashew nut), *Mangifera indica* L. (mango), *Sclerocarya birrea* (A. Rich.) Hochst. (marula), *Sorindeia madagascariensis* Thouars ex DC., *Spondias dulcis* Parkinson (otaheite apple), *Spondias mombin* L. (tropical plum), *Spondias cytherea* Sonner. (hog plum).
Annonaceae	*Annona cherimola* Mill. (cherimoya, *Annona muricata* L. (soursop), *Annona senegalensis* Pers., *Annona squamosa* L. (sugar apple), *Cananga odorata* (Lam.) Hook.f. and Thomson (perfume tree).
Apocynaceae	*Landolphia* P. Beauv.sp, *Saba senegalensis* (A.DC.) Pichon
Asparagaceae	*Dracaena steudneri* Engl
Bromeliaceae	*Ananas comosus* (L.) Merr. (pineapple)
Caesalpinioideae	*Cordyla pinnata* (Lepr. ex A. Rich.) Milne Redhead (cayor pear tree)
Capparaceae	*Maerua duchesnei* (De Wild.) F. White
Caricaceae	*Carica papaya L.* (papaya)
Clusiaceae	*Garcinia mannii* Oliv.
Combretaceae	*Terminalia catappa L.* (tropical almond)
Cucurbitaceae	*Citrullus colocynthis* (L.) Schrad. (colocynth)*, *Citrullus lanatus* (Thunb.) Matsum. and Nakai (watermelon), *Cucumis ficifolius* A.Rich., *Cucumis melo* L. (melon), *Cucumis sativus* L. (cucumbers, gerkins), *Cucurbita pepo* L. (ornamental gourd, squash), *Lagenaria siceraria* (Molina) Standl. (calabash, water bottle), *Momordica charantia* L. (bitter gourd).
Ebenaceae	*Diospyros kaki* Thunb. (persimmon), *Diospyros montana* Roxb.
Irvingiaceae	*Irvingia gabonensis* (Aubry-Lecomte ex O'Rorke) Baill. (wild mango)
Lauraceae	*Persea americana* Mill. (avocado)
Leguminosae	*Cordyla pinnata* (A.Rich.) Milne-Redh.
Loganiaceae	*Strychnos mellodora* S. Moore
Malvaceae	*Durio zibethinus* L. (durian)
Moraceae	*Antiaris toxicaria* Lesch. (antiaris, false iroko, false mvule), *Ficus ottoniifolia* Miq., *Ficus sycomorus* L. (sycamore fig).
Musaceae	*Musa acuminata* Colla (cavendish banana), *Musa × paradisiaca* L. (plantain), *Musa* sp L. (banana)
Myrtaceae	*Acca sellowiana* (O. Berg) Burret, *Eugenia uniflora* L. (surinam cherry, pitanga cherry), *Psidium guajava* L. (guava), *Syzygium jambos* (L.) Alston (rose apple), *Syzygium malaccense* (L.) Merr.and L.M.Perry (malay-apple), *Syzygium samarangense* (Blume) Merr. and L.M. Perry (water apple)
Oxalidaceae	*Averrhoa carambola* L. (carambola, starfruit)
Rhamnaceae	*Ziziphus mauritiana* Lam. (jujube)
Rosaceae	*Cydonia oblonga* Mill., *Eriobotrya japonica* (Thunb.) Lindl. (loquat), *Malus domestica* Borkh. (apple), *Prunus persica* (peach) (L.) Stokes
Rubiaceae	*Sarcocephalus latifolius* (Sm.) E.A. Bruce (pin cushion tree, Guinea peach)
Rutaceae	*Citrus aurantium* L. (sour orange), *Citrus japonica* Thunb.(round kumquat), *Citrus limon* (L.) Burm. f. (lemon), *Citrus x paradisi*

	Macfad. (grapefruit and Orlando), *Citrus reticulata* Blanco (mandarin and Tangelo cv and Ortanique), *Citrus sinensis* (L.) Osbeck (navel orange and Tangor cv)
Salicaceae	*Flacourtia indica* (Burm. f.) Merr. (governor's plum)
Sapindaceae	*Blighia sapida* K.D. Koenig (Akee apple)
Sapotaceae	*Chrysophyllum albidum* G. Don (white star-apple), *Manilkara zapota* (L.) P. Royen (sapodilla, chicle), *Vitellaria paradoxa* C.F. Gaertn. (shea butter)
Solanaceae	*Capsicum annuum* L. cov. *longum* A. DC. (bell pepper), *Capsicum frutescens* L. (chilli), *Solanum lycopersicum* L. (tomato)
Sterculiaceae	*Theobroma cacao* L. (cocoa)
Vitaceae	*Vitis vinifera* L. (grapevine)

Appendix 4. List of commercial fruit producers in Manica Province (Source DPA Manica)

District	Name of the orchard/Owner	Main fruit crop	Area (ha)	Local comerc./export	Other fruits
Manica	Mario Menezes	Mango	3	Local/ export	Litchi
Sussundenga	Ceta	Mango, Banana	10	Export	
Vanduzi	Chandroca	Mango	10	Local	
Manica	Produsola	Mango	1.1	Local/export	
Barue	Panda Farm/ Lukman	Mango	2.4	Export	
		Litchi	2.6	Export	
Sussundenga	Pedro Langa	Mango	6.5	Local /export	
Barue	Nzara yapera/ Peter Wazuwei	Diversity of fruits	3	Local	
	Frutas de Ouro/ Dave	Banana, litchi	5	Local	
Sussundenga	RDI / Danielle Wiggins	Litchi, avocado	20	Export	
Barue	Macs in Moz/ Christopher Breytenbach	Citrus, Macadamia	10	Export	
Sussundenga	Ganel/ Jac Smith	Mango	74	Export	-
Gondola	Codfarm/Sergio Ye	Mango	8	Export	Banana, passion fruit
Sussundenga	Pinto Matavele	Mango	30	Export	-
Sussundenga	Pascoal Alves	Mango	16	Export	Banana
Manica	Agriza	Banana	37	Export	Litchi
Manica	Aus-moz	Banana	16	Export	-
Gondola	Associação de produtores de Macate	Banana	320	Local	Citrus
Gondola	Frutis Lda/Issufo Valy	Litchi	20	Export	Mango
		Banana	6	Local	
Gondola	Pedro Paulino	Mango	24	Export	Banana

Appendix 5. Questionnaire used to assess farmers' knowledge, perceptions and practices (KPP).

UNIVERSIDADE EDUARDO MONDLANE

CULDADE DE AGRONOMIA E ENGENHARIA FLORESTAL

Departamento de Protecção Vegetal

Questionaire

Project S1_TNZ_MOZ_IPM: INTEGRATED PEST MANAGEMENT (IPM) FOR FRUIT FLIES IN MANICA PROVINCE, MOZ

Date____/_____/2015

1. Farmer identification

Name ____ Year that started activities ________

Location: District:______________________Locality:________________________GPS coordinates: _______________S_____________E

2. Fruits produced (2014/15)

	Variety	Área (ha)	Nº of trees	Compass	Age	Yield (ton/ha)	Importance (1,2,3,4)*	Fruit sales	
								Local market	Export
1.Mango									
2.									
3.									
4.									

*1 is the most important fruit and 4 the least important

Other

fruits:____

____

3. Production costs (Mt/unit): quantify for the two main fruit crops . (Unit=Ha/ Kg/ bags of 25 kg/ bags of 50 kg/litre/men per hour)

Fruit: Mango

	Seedings	Water	Land preparation		Fertilizer		Herbicide	Insecticide	Personel				
			Manual	Mecanized	Organic	Inorganic			Permanent	Sazonal-planting	Sazonal-weed control	Sazonal - pruning	Sazonal-harvesting
2010/ 2011													
2011/ 2012													
2012/ 2013													
2013/ 2014													
2014/ 2015													

Other

costs:____

____

Fruit : ________________

	Seedings	Water	Land preparation		Fertilizer		Herbicide	Insecticide	Personel				
			Manual	Mecanized	Organic	Inorganic			Permanent	Sazonal-planting	Sazonal-weed control	Sazonal - prunning	Sazonal-harvesting
2010/2011													
2011/2012													
2012/2013													
2013/2014													
2014/2015													

Other

costs:____

____

4. Phytosanitary problems (pests and diseases)

List phytosanitary problems discriminating them by importance (pest / disease of greater or lesser importance) evaluated by the time and resources spent for their control. Mention the name of the pest or disease or a brief description of the symptoms.

Fruit: Mango

Stage	Pests		Diseases	
	Major importance	Minor importance	Major importance	Minor importance
Seedling	1.	1.	1.	1.
	2.	2.	2.	2.
	3.	3.	3.	3.
Tree devopment/vegetative stage	1.	1	1	1
	2.	2.	2.	2.
	3.	3.	3.	3.
Fruit development	1	1	1	1
	2.	2.	2.	2.
	3.	3.	3.	3.
Maturation/harvesting	1	1	1	1
	2	2.	2.	2.
	3.	3.	3.	3.

Fruit: _______________

Stage	Pests		Diseases	
	Major importance	Minor importance	Major importance	Minor importance
Seedling	1.	1.	1.	1.
	2.	2.	2.	2.
	3.	3.	3.	3.
Tree devopment/vegetative stage	1.	1	1	1
	2.	2.	2.	2.
	3.	3.	3.	3.
Fruit development	1	1	1	1
	2.	2.	2.	2.
	3.	3.	3.	3.
Maturation/harvesting	1	1	1	1
	2	2.	2.	2.
	3.	3.	3.	3.

5. If fruit flies have been mentioned above, do you know some of the fruit fly species and / or the type of damage they cause? (Write an X in the mentioned option)

Known fruit fly species

Bactrocera dorsalis	*Ceratitis capitata*	*Ceratitis cosyra*	*Ceratitis rosa*	*Dacus spp.*

Others:

____

____

Fruit fly damage

They fly around the fruit	Pierce the fruit	Change fruit colour	Fruits falls before ripening	Fruit rooting	Eat the skin of the fruit	Fly in the farm

Other:

____

____

6. Does *Bactrocera invadens* occurs in your farm? Yes **_______** (go to the question 6.1); No **______** (go to the question 6.2).

6.1. **If Yes, since when**? **(Write an X in the mentioned option)**

This year (2014/2015)	Last year (2013/2014)	3 years ago (2012)	More than 4 years ago	Don´t know

6.1.1. Source of information

____

6.2. If it does not occur in your farm, how did you hear about this pest? (Write an X in the mentioned option)

Mídia	Friends	Agriculture department	Other fruit producers	Other____________

7. What is the impact of this species or the impact that you think it may cause to the production and marketing of mangoes and other fruits? (Write an X in the mentioned option)

1. It is no longer possible to sell the infested fruit _______; 2. Fruit continues to be sold without problems______; 3. Loss of fruit quality ______; 4. Loss of local market _______; 5. Loss of exports markets _______; 6. Increases production costs ______; 7. Discourages investments _______

Others:

____

____

____

______

8. Fruit fly control methods

Do you use any method to control the invasive fruit fly? **(Write an X in the mentioned option)** Yes____ (go to question 9.1); No _____ (go to the question 9.3)

9.1 If Yes, which methods do you use? (Write an X in the mentioned option)

a. Spray with Insecticide_____(Which one? ____________________________________);

b. Do regular pruning____; c. Keep the field clean from weeds_____; d. Doesn´t leave falling fruits in the ground______; e. Early harvesting_____; f. *B. invadens* population monitoring through traps_____; g. Use of parasitoids /other natural enemy____; h. Has MAT blocks in the field ____; i. Has bait stations _____(Name________________________________); j. Other (specify) ______________________________

9.2. Cost for invasive fruit fly control (2014/2015)

Input	Supplier	Cost/unit	Quantity	Nr of permanent employees	Nr of sazonal personel
Insecticide 1.___________					
Insecticide 2.___________					
Sprayers					
Black plastic bags					
Traps					
Atractives					
MAT blocks					
Bait stations					
Parasitoid					
Other (___________)					
Other (____________)					
Other (_____________)					

9.3. If Not, what is the reason? (Write an X in the mentioned option)

It is not important pest	Has no financial conditions to control the pest	Doesn't know how to control the pest	It causes no damage to the fruits	Just think that the government should do something	The inputs for fruit fly control is not available in the country	Other (specify)

10. History of production and marketing

Fruit: MANGO

Crop season	Production (ton)	Area (ha)	Exported Quantity (ton)	Price of the exported fruit (MT/kg)	Name of the internationa market	Quantity sold in local market (ton)	Price in local market (MT/kg)	Name of the local markets
2011/2012								
2012/2013								
2013/2014								
2014/2015								

CULTURA: OTHER (WHICH?)____________________

Crop season	Production (ton)	Area (ha)	Exported Quantity (ton)	Price of the exported fruit (MT/kg)	Name of the internationa market	Quantity sold in local market (ton)	Price in local market (MT/kg)	Name of the local markets
2011/2012								
2012/2013								
2013/2014								
2014/2015								

CULTURA: OTHER (WHICH?)____________________

Crop season	Production (ton)	Area (ha)	Exported Quantity (ton)	Price of the exported fruit (MT/kg)	Name of the internationa market	Quantity sold in local market (ton)	Price in local market (MT/kg)	Name of the local markets
2011/2012								
2012/2013								
2013/2014								
2014/2015								

11. History of the number of the employees

	2011/2012	2012/2013	2013/2014	2014/2015
Nr. Of permanent employees				
Nr. Of Sazonal personel				

12. History of Investimentos

Do you had plans to increase the areas of fruit trees and not made it due to the occurrence of invasive the fruit fly? No _____ Yes ______ (fill the following table).

ANO	Planed AREA (ha)	Planted AREA (ha)	invested Money (milhões de MT)	Money not used (milhões de MT)
2011/2012				
2012/2013				
2013/2014				
2014/2015				