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Master in Plant Protection

EFFICACY OF LOCAL FOOD BAITS IN FRUIT FLY MANAGEMENT AND ESTIMATION OF INFESTATION INDICES OF FRUIT FLIES IN GUAVAS IN MAPUTO, MOZAMBIQUE.

BY

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A Dissertation submitted to the Department of Plant Protection as part of the requirements for obtaining a degree of Masters of Plant Protection from Eduardo Mondlane University.

Maputo, December 2025

DECLARATION

"I declare that this dissertation has never been submitted for the purpose of obtaining any degree or in any other field and that it is the result of my individual labor. This dissertation is presented in partial fulfillment of the requirements for obtaining the degree of masters of plant protection, from the University of Eduardo Mondlane."

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Date 1st -February-2026

I confirm that the work reported in this dissertation was carried out under my supervision.

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ABSTRACT

Fruit flies (Diptera:Tephritidae) are serious pests of crops, requiring effective monitoring tools to guide management. This study evaluated the attractiveness of local food baits for monitoring fruit flies in guava orchards in Maputo Province. Additionally, the study assessed guava infestation levels, examined the relationship between trap catches and adult emergence from fruits, and analyzed how climate variables and fruit availability influence fruit fly population density. A randomized block design with four treatments (palm sap, molasses, torula yeast, and water) and four replications was used. Four trees per block were randomly assigned baited Tephri traps, which were inspected weekly. Collected flies were counted, sexed, and identified. Simultaneously, guava fruits from trees and the ground were sampled weekly, incubated, and examined for pupal and adult emergence to estimate infestation indices. Three genera were trapped: *Bactrocera*, *Dacus*, and *Ceratitis*, with *Bactrocera dorsalis* dominant (90.37%). Torula was the most attractive bait (FTD = 4.15±0.804), followed by palm sap, with no statistical difference. Molasses and water were least effective. Fruit fly population fluctuations were strongly linked to fruit availability and temperature. Guava fruits exhibited high infestation, averaging 245.06±16.10 pupae/kg and 208.46±13.34 adults/kg. A significant positive correlation ($r = 0.652$, $p = 0.0297$) was found between trapped *B. dorsalis* and emerged adults, with regression analysis showing trap catches explained 42.5% of emergence variation suggesting that factors external to the orchard have a greater influence on infestation. Overall, the results showed that palm sap is a promising, low-cost alternative bait, and highlighted the importance of orchard sanitation as well as the need to consider area wide fruit fly management strategies in order to reduce infestation.

Key words: monitoring, Tephritidae, palm sap, molasses, torula.

RESUMO

As moscas-da-fruta (Diptera: Tephritidae) são pragas sérias das culturas, exigindo ferramentas de monitoria eficazes para orientar o seu maneio. Este estudo avaliou a atractividade de íscas alimentares locais para a monitoria de moscas-da-fruta em pomar de goiaba na Província de Maputo. Adicionalmente, o estudo determinou os níveis de infestação da goiaba, examinou a relação entre capturas em armadilhas e emergência de adultos a partir dos frutos, e correlacionou-as com as variáveis climáticas e a disponibilidade de frutos. Foi utilizado um delineamento em blocos casualizados com quatro tratamentos (seiva de palmeira ou sura, melaço, atractivo alimentar sintéctico torula e água) e quatro repetições. Foram selecionadas quatro árvores por bloco, nas quais foram aleatoriamente montadas armadilhas Tephri com os diferentes atractivos, que foram inspecionadas semanalmente. As moscas recolhidas foram contadas, separadas por sexo e identificadas. Simultaneamente, 1 vez por semana, frutos de goiaba foram colhidos das árvores e do solo, incubados em laboratório e examinados para registar a emergência de pupas e adultos, de modo a estimar os índices de infestação. Foram registados três géneros: *Bactrocera*, *Dacus* e *Ceratitis*, sendo a espécie *Bactrocera dorsalis* a mais dominante (90.37%). A torula foi mais atrativa (FTD = 4.15±0.804), seguida da sura, contudo, sem diferença estatística entre ambas. O melaço e a água foram os menos eficazes. As flutuações populacionais das moscas-da-fruta estiveram fortemente associadas à disponibilidade de frutos e à temperatura. Os frutos de goiaba apresentaram elevada infestação, com uma média de 245.06±16.10 pupas/kg e 208.46±13.34 adultos/kg. Foi encontrada uma correlação positiva significativa ($r = 0.616$; $p = 0.0297$) entre *B. dorsalis* capturados e adultos emergidos, com a análise de regressão a indicar que as capturas nas armadilhas explicaram 42.5% da variação na emergência, sugerindo que factores externos ao pomar tenham maior influência na infestação.. De forma geral, os resultados mostram que a sura é um atrativo alimentar alternativo promissor e de baixo custo, e destacam a importância da limpeza do pomar e da necessidade de se considerar o maneio de moscas-da-fruta em larga escala para reduzir a infestação.

Palavras-chave: monitoria, Tephritidae, sura, melaço, torula.

DEDICATION

I dedicate this dissertation to my family, whose unwavering love, encouragement, and sacrifices have been my source of strength throughout this journey. This achievement is as much yours as it is mine.

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LIST OF ABBREVIATIONS

CABI- Center for Agriculture and Bioscience International

FAEF- Facullty of Agronomy and Forestry Engineering

FAO- Food and Agriculture Organisation

FTD- Fruit fly per trap per day

GDP- Gross Domestic Product

IAEA- International Atomic Energy Agency

INE - Instituto Nacional de Estatística

IPPC- International plant convention

ITA- Internatinal Trade Organisation

MAT- Male Annihilation Technique

USDA- United States Department of Agriculture

I.0. INTRODUCTION

1.1. Background

Agriculture is a core sector of the world economy, with an estimated output worth $3 trillion per year, supporting billions of livelihoods and especially in the developing world (Fuglie *et al.*, 2024; FAO, 2024a). Sub-Saharan African agriculture accounts for 15–20% of GDP and more than 60% of employment, much through smallholder agriculture. The farmers provide approximately 35% of total food cultivated on the continent (Ormaza-Zulueta *et al.*, 2024). In Mozambique, agriculture remains a key socio-economic activity, with about 70% of the country's work force (nearly 69.5% as of 2023) and accounting for around 23–25% of national GDP (FAO, 2023). It plays an important role in the economy, both as a source of food security, employment and income for the majority of the population as well as a source of government revenue through the export of agricultural products (Carrilho *et al*., 2021). An important aspect of agriculture in Mozambique is fruit production.

Global production of fruits reached over 887 million tons during 2020 and included guava (*Psidium guajava*) (sometimes classified among mangoes and mangosteens) contributing about 59.2 million tons, mostly grown in India (about 44%), followed by Indonesia and China; (FAO, 2024b). In Africa, guava is widely cultivated across subsistence and small commercial systems, yet continent-wide production data remains fragmented (Angulo-López *et al*., 2021). In Mozambique, guava production, alongside mango (*Mangifera indica* L.) and mangosteen (*Garcinia mangostana*), reached 28.9 thousand metric tonnes in 2022 (FAOSTAT, 2024)**.**

The fruits play an important role in the human diet due to their nutritional value, contributing as an excellent source of vitamins and minerals essential in the regulation of almost all vital functions of the body (Teshome *et al.*, 2023). Guava is valued not only for fresh consumption but also for making juice, jams, and pulps, and for its health benefits because it is rich in vitamins, fiber, and antioxidants (Angulo-López *et al*., 2021). However production of these fruits is put at a threat by infestation with fruit flies.

Fruit flies in the family *Tephritidae* are among the most significant global insect pests, infesting over 200 fruit and vegetable species, including guava, mango, and citrus (Nanga Nanga *et al*., 2022). They are economically important because they have the ability to cause significant damage to fruits (De Meyer *et al*., 2007; Martins *et al*., 2024; Opoku *et al*., 2025).

They have high reproduction rate, and are strongly mobile, allowing for wide infestation on a large variety of commercial and wild host plants (Martins *et al*., 2024). There are many species of fruit flies affecting different types of crops.

In Africa, *Bactrocera dorsalis* (Diptera: Tephritidae) is presently a major invasive pest of fruits like guava, mango (*Mangifera indica* L.), bananas (*Musa* spp.), papaya (*Carica papaya*), oranges (*Citrus sinensis*), pineapples (*Ananas comosus*) and many others. Since its initial detection on the African mainland in Kenya in 2003 (Lux *et al*., 2003), *B. dorsalis* has also spread extensively throughout East, Central, and Southern Africa. In Mozambique, it was first detected in 2007 in the province of Niassa (Correia *et al*., 2008; Cugala *et al*., 2008) and is negativelly affecting the fruit production systems (Canhanga *et al*., 2021).

The ecological adaptability of *B. dorsalis*, particularly in tropical and subtropical climates, allows it to survive and form stable populations. Its life is strongly associated with fruiting cycles, and fallen and overripe fruits are perfect breeding sites (Bota *et al*., 2020). The guava and mango fruit production in Mozambique is high at some times of the year, which is a perennial source of fruit fly multiplication, leading to widespread damage and loss of crops. The economic impacts of infestation include not only reduced marketable output but also increased production costs and impediments to export by virtue of quarantine restrictions (Vayssières *et al*., 2015; Opoku *et al*., 2025).

1.2. Problem statement

Fruit flies (Diptera: Tephritidae) are recognized globally as devastating pests of horticultural crops, particularly in tropical and subtropical regions where they thrive year-round (Papadopoulos *et al*., 2024). For example, fruit flies are estimated to cause an economic loss of more than US$2 billion across Africa annually (Niassy *et al*., 2020). In Mozambique, the invasive species *B. dorsalis* has become the most dominant and economically significant. It causes infestation levels exceeding 90% in guava fruits and other preferred hosts (José *et al*., 2013; Canhanga *et al.*, 2021).

Even though chemical attractants and protein baits have been developed for monitoring and management of fruit flies, they are not affordable and therefore not within the reach of most small-scale farmers (Ekesi *et al*., 2009). Prior research has shown the efficacy of protein baits for trapping and controlling fruit flies, but not much has been examined to assess the efficacy

of baits that are locally available like palm sap and molasses, especially in Mozambique. Also fruit availability and climate variables like temperature, rainfall and humidity that affects the population of fruit flies (Vayssières *et al*., 2015; Nanga Nanga *et al.*, 2022; Chandra *et al*., 2022) needs to be studied. Understanding their influence on fruit fly population density in orchard microclimate is usually key to develop and guide effective management. In addition, predicting infestation indices based on trap catches remains a challenge.

Therefore, this research aimed to assess the efficacy of local food baits in attracting fruit flies, to determine the fruit fly population density fluctuations and its association with climate variables and fruit availability, to estimate the infestation indices and the extent to which the number of trapped flies can reliably predict the number of emerged flies and hence estimate damage. The outcome will give farmers effective and cheaper means of monitoring and suppression than the conventional chemical insecticides, which is among the principal pillars of sustainable production of fruits and improvement of lives. Determining the association of fruit fly populations with the fruit availability and climate variables would also help in explaining the population fluctuations of flies and finding out the best management strategies of fruit flies in the orchard. Also by estimating the correlation between the trapped flies and the emerged flies from the incubated fruits, more effective management strategies can be recommended since it will provide information on the main source of fruit flies, if from inside or outside the orchard and to potentially estimate the damage on fruits using data from the trap catches.

1.3. Objectives of the study

1.3.1. General objective

- To assess the efficacy of palm sap and molasses in attracting fruit flies, estimate the fruit fly population fluctuations with its association with climate variables, and estimate infestation indices in guava orchards in Maputo, Mozambique.

1.3.2 Specific objectives

1. To estimate fruit fly's species abundances as well as the proportion of male and female in each treatment;
2. To determine the population density of the most abundant fruit fly species in each treatment and how it is associated with host fruit availability and climate variables;
3. To estimate the pupae and adult infestation indices of fruits flies on guavas; and

4. To determine the correlation and regression relationship between the trapped and the emerged fruit flies.

1.4. Research questions

1. What is the estimated absolute and relative abundance of the fruit fly species in each food bait in the orchards?
2. What is the population density of the most abundant fruit fly species in each attractant and its association with fruit availability and climate variables?
3. What are the estimated pupae and adult infestation indices of fruit flies in the guavas?
4. What is the correlation and regression relationship between the trapped and the emerged fruit flies from the incubated fruits throughout the study period?

1.5. Hypotheses

1. There would be a difference in the species number, absolute and relative abundance of the fruit fly species attracted in each food bait.
2. The population density of the fruit fly species would be different in each attractant and influenced by host fruit availability and climate variables.
3. Water as a negative control would have the lowest number of fruit flies trapped while torula as a positive control would have the highest number of fruit flies trapped
4. There would be a positive correlation and regression relationship between the trapped and emerged fruit flies from guavas.

2.0. LITERATURE REVIEW

2.1. Role of fruits in food

Fruits constitute a group of foods with great nutritional value and a particular importance in the human diet, being rich sources of water, vitamins A (papaya- *Carica papaya*; mango-; *Mangifera indica*, persimmon- *Diospyros kaki*), C (orange-*Citrus sinensis*, lemon- *Citrus limon*, guava- *Psidium guajava*, strawberry- *Fragaria* × *ananassa*, acerola – *Malpighia emarginata*, tangerine- *Citrus reticulata*), potassium (banana- *Musa spp*., melon- *Cucumis melo*, nuts), fiber and bioactive compounds (Teshome *et al.*, 2023). Furthermore, they have an excellent repository of carbohydrates, which is the fundamental fuel for the brain, whose regular consumption is associated with a reduced risk of cancer, cardiovascular diseases, Alzheimer's disease and cataracts. They also promote longevity with quality and health, as well as being essential for the prevention of diseases related to nutritional deficiencies (Wallace *et al*., 2020).

2.2. Importance of fruit growing in Mozambique

According to Cugala *et al*. (2008) and International Trade Administration (2024), in Mozambique fruit production is the responsibility of the family sector as well as the business sector. The family sector's production is fundamentally intended to satisfy the needs of the local market while the business sector directs its production mainly to the foreign market, especially to the countries of SADC, European Union, Switzerland and Japan, and only in cases where export requirements are not met do they direct their production to the local market. Based on 2022–2024 estimates, Mozambique's good agro-ecological conditions enable private companies and recently emerging large-scale horticultural enterprises to commercially cultivate tropical fruit trees such as mango, avocado, litchi, citrus, guava, and banana (International Trade Administration, 2024).

Among fruit products, mango is produced on a commercial scale, particularly in the provinces of Manica (Sussundenga district) and Maputo. In Manica, mango is produced for export to South Africa, Zimbabwe and European Union countries (Tostão *et al*., 2012). In Mozambique, guava production is classified with mango and mangosteen as a FAO commodity group 0571, within which the three fruits are aggregated in world production statistics. In 2022, Mozambique produced about 28.9 thousand metric tons in the overall

category, with a small yearly increase of 0.24%, (FAOSTAT, 2024). This ranked Mozambique as position 48 in the world in the production of mango, mangosteen, and guava. However guava production in Mozambique is done at a subsistence level and it is not considered as a commercial crop, but it is one of the main hosts for the fruit flies, that's why it was used for the study (José *et al*., 2013).

2.3. Origin and taxonomy of fruit flies

Fruit flies belong to the kingdom *Animalia*, phylum *Arthropoda*, class *Insecta*, order *Diptera* and family *Tephritidae*. They are considered insects of great economic importance, as they attack different types of fruits, whether commercial or wild, causing considerable damage to agricultural crops (CABI, 2012).In Mozambique, the species *Bactrocera dorsalis* native to Asia was identified for the first time in 2007 in the province of Niassa (Correia *et al*., 2008). There are no reliable explanations as to how this species was introduced, and the same author emphasizes that it was probably an accidental introduction. It has now spread all over Mozambique and it has out competed the native fruit fly species leading to up to 90% infestation rates in fruits like guavas, mangoes and many other crops leading to serious losses (Canhanga *et al.*, 2021).

2.4. General life cycle of fruit flies

Insects of the order *Diptera* complete their life cycle by going through the following metamorphoses: egg, larva, pupa and adult (Figure 1). Depending on the climatic conditions of the region and availability of host fruits (Ekesi & Billah, 2006), the life cycle of fruit flies is described by the following stages:

i. Mating: the fruit fly adults are sexually mature 10 days after emergence.
ii. Oviposition: the laying of eggs in the fruit occurs shortly after mating, where the female uses her long, sharp ovipositor to lay whitish banana-shaped eggs in the fruit.
iii. Development of larvae: they develop in cylindrical and elongated shape, funneled and centrally curved anterior end, feeding on the fruit pulp, thus accelerating the maturation of the fruit, which detaches and falls to the ground. This lasts 3 to 12 days.
iv. Pupa: the larvae migrate to the soil where they pupate, after the fruit falls; Pupae can be white, brown or dark. This phase lasts 10 to 20 days.
v. Adult emergency: the adult emerges from the ground, and then rises to the surface where it searches for the food it needs to reach sexual maturity.

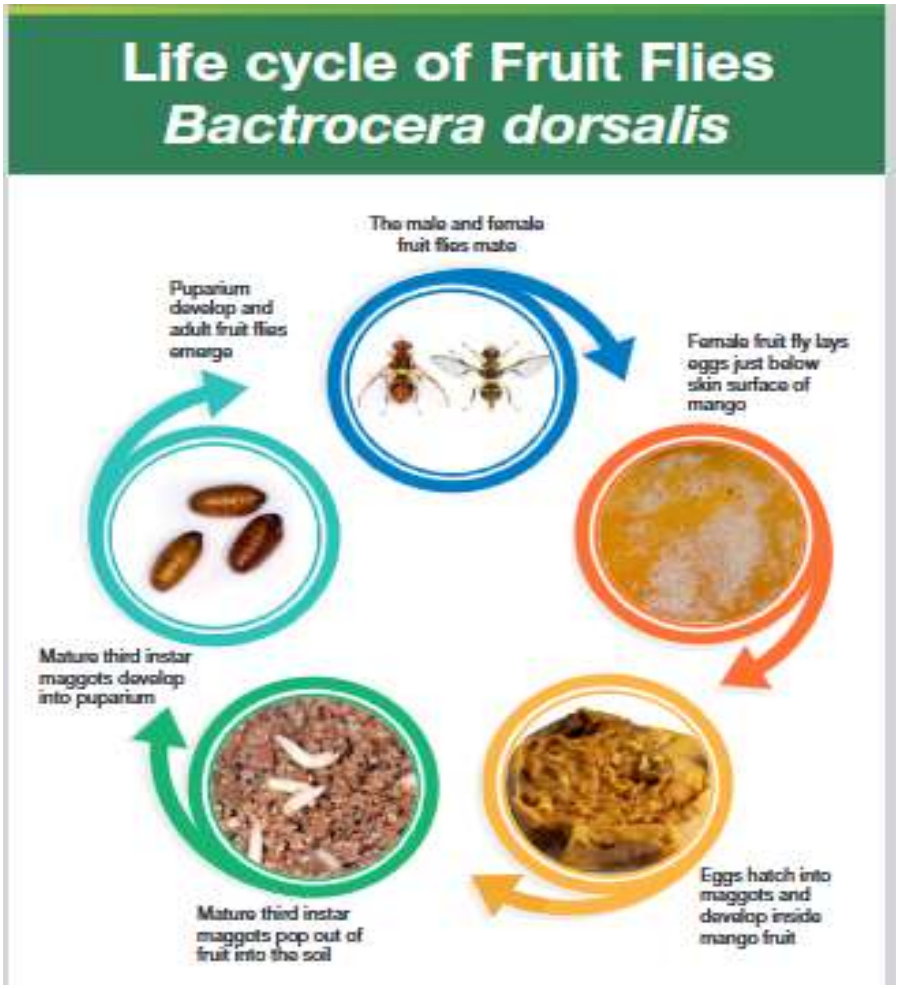


Figure 1- General life cycle of fruit flies. Source: (ICIPE, n.d.)

2.5. Damage caused by fruit flies and their respective losses

According to Ekesi *et al*. (2016) and Opoku *et al*. (2025) the classification of damage caused by fruit flies can be direct and indirect.

a) Direct damage:

Fruit fly larvae feed on fruit pulp and the damage begins when the female deposits eggs inside the fruit tissue. During egg deposition, bacteria from the fly's intestinal flora are introduced into the fruit, multiply and cause decomposition of the tissues around the eggs, which is reflected on the outside of the fruit by a purple stain around the deposition hole and favors the attack of pathogens, which accelerates fruit rot and increases its depreciation (Eddy-Doh *et al.*, 2017). As a consequence of this damage, there is a premature fall of fruits on the ground that is, before reaching the

consumption stage. The larvae inside the fruit feed on the pulp leading to degeneration and rotting of the fruits (figure 2).

Figure 2- Damage caused by fruit flies. Source:Cugala & Mangana (2010).

b) Indirect damages

These result from quarantine restrictions that are imposed by countries importing fresh fruit as a way to prevent the entry and establishment of unwanted fruit fly species and the prohibition of internal movement of host fruit from affected areas to non-affected areas (Opoku *et al*., 2025) this leads to large losses of markets in general for example *B. dorsalis* invasion into southern Africa caused Mozambique to lose export revenue worth approximately USD 20 million annually, as fresh produce export bans were enforced during peak incidence (Cugala & Mangana, 2010; Icipe, 2023). A fruit fly outbreak originating in Manica Province rapidly spread, including into the strategic port region of Maputo. This led to a provisional one-year ban on exports of several fruits including mangoes, oranges, tangerines, and bananas to neighboring countries like South Africa (Cugala *et al*., 2014) (figure 3).

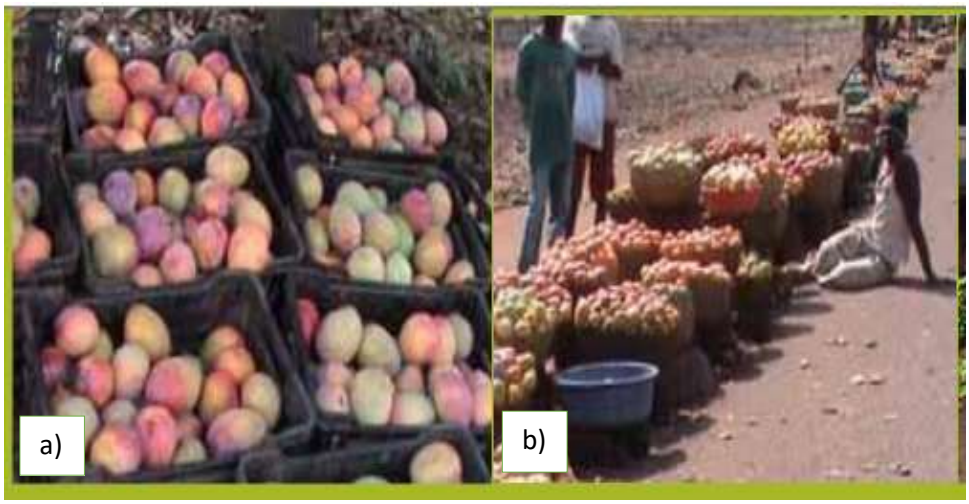


Figure 3- Excess of the product on the domestic market due to quarantine restrictions. Source: **Cugala & Mangana (2010)**.

Also, the damage caused by fruit flies can be classified into**:**

i. **Cultural:** the fruits become unsuitable for fresh consumption and industrialization; there is depreciation of infested orchards; losses can reach up to 100%; commercial depreciation of fruits (Opoku *et al*., 2025).
ii. **Economic:** orchards become uneconomical, causing loss of investment and producer insolvency; impossibility of selling the fruits on the foreign market, not generating foreign exchange for the country; when fruit from the infested area is placed on the domestic market it does not reach rewarding prices; lower tax collection (Cugala *et al*., 2020; Opoku *et al*., 2025).
iii. **Social:** Declining profitability and market access reduce labor demand in fruit production, increasing rural unemployment and driving migration to urban areas (Niassy *et al*., 2022).

2.6. Fruit flies of economic importance in fruit growing, most problematic in Africa and most damaging in Mozambique

According to Cugala & Mangana (2010), fruit flies of economic importance belong to 5 genera which include: *Anastrepha* (occurring in Central and South America); *Bactrocera* (native to Asia); *Ceratitis* and *Dacus* (native to Africa), and *Rhagoletis* (occurring in Europe and North America). The genera *Bactrocera, Ceratitis* and *Dacus* are those that cause most problems in Africa, including Mozambique with *Bactrocera* being the most predominant (Ekesi & Billah, 2006; Cugala, 2011; Canhanga *et al*., 2021). Another genus is *Zeugodacus* which was originally classified under genus *Bactrocera* with *Zeugodacus cucurbitae*, originally known as *Bactrocera zeugodacus* (Virgilio *et al*., 2014; Doorenweerd *et al*., 2018) being the most important species in Mozambique (Cugala *et al*., 2016).

2.6.1. Description of the genera *Bactrocera, Zeugodacus, Dacus* and *Ceratitis*

2.6.1.1. The Genus *Bactrocera*

Comprises over 500 species globally, the majority of which are Asian and Oceania species. Invasive pests like *Bactrocera dorsalis* (previously *B. invadens*) are now significant pests in sub-Saharan Africa, including Mozambique. Morphologically, *B. dorsalis* can be distinguished by the predominantly dark color, yellow stripes on the thorax, and a translucent compound T-shaped black mark on the abdomen (De Meyer *et al*., 2012) (figure 4). Its wide

host range comprises mango, guava, papaya, and citrus, and the species is presently the most economically important fruit fly in Mozambique (Cugala *et al*., 2016). Other important species belonging to this genus are: *B. latifrons* and *B. zonata* (Cugala & Mangana, 2010). Of these pests, the one that occurs in Mozambique is the species *B. dorsalis*.

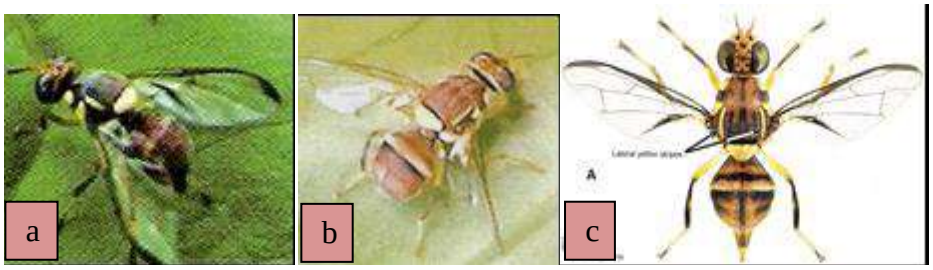


Figure 4- Fruit flies of the genus *Bactrocera:* a) *Bactrocera latifrons***; b)** *Bactrocera zonata***; c)** *Bactrocera dorsalis.* **Source: Ekesi & Billah (2006).**

2.6.1.2. The Genus *Zeugodacus*

This genus was formerly part of *Bactrocera,* which was placed under this genus after genetic and morphological research. The most important species is the melon fly (*Zeugodacus cucurbitae*) (Virgilio *et al.*, 2014; Doorenweerd *et al*., 2018). *Z. cucurbitae* has a broad distribution across tropical and subtropical areas including Mozambique, where it infests cucurbit crops like cucumber, pumpkin, and melon. *Zeugodacus* species are distinguished from *Bactrocera* by having distinctive abdominal band patterns and preferences for lures in males (figure 5). Although not as geographically extensive as *B. dorsalis*, *Z. cucurbitae* is important in vegetable production systems and has been found in a number of provinces of Mozambique (Cugala *et al*., 2016).

Figure 5-A sample specimen of *Zeugodacus cucurbitae*. **Source: Ekesi & Billah (2006).**

2. 6.1.3. The Genus *Dacus*

These originate from Africa and are similar in size to the genus *Bactrocera*, but are characterized by having tergites attached to the abdomen and generally do not have yellowish stripes on the scutellum. They largely infest cucurbits and solanaceous crops. Of this genus,

only 11 species are considered agricultural pests, notably *D. puntactifrons*, *D. bivittatus*, *D. ciliatus* (Ekesi & Billah, 2006) (figure 6).

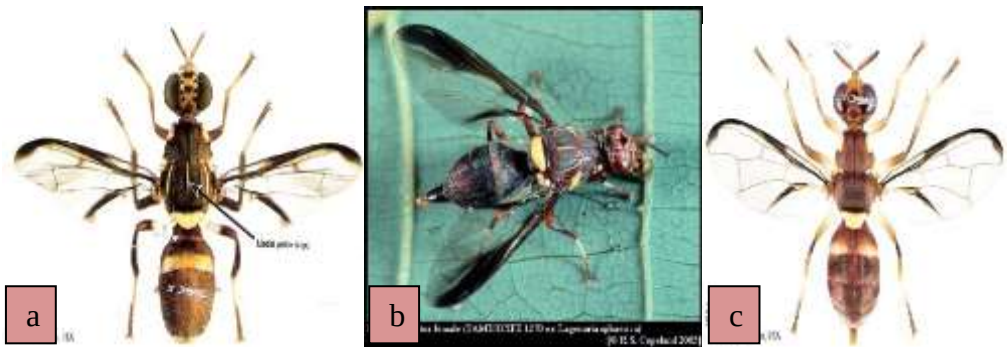


Figure 6- Species of the genus *Dacus:* a) *D. punctatifrons***; b)** *D. bivittatus***; and c) *D. ciliatus*. Source: Ekesi & Billah (2006).**

2.6.1.4. The Genus *Ceratitis*

Fruit flies in this genus are also native to Africa. They are characteristically small in size with bands on the wings, with the apex of the "M" vein and sub-apical band. This genus has around 100 species, many of which are of economic importance, notably *Ceratitis cosyra*, *Ceratitis rosa* (now within the C. FAR complex) and *Ceratitis capitata* (De Meyer, *et al*., 2012; Virgilio *et al*., 2014) (figure 7). More than 100 plants belonging to 30 families have been reported as hosts of this genus in Africa. In Mozambique, *C. rosa* and *C. cosyra* are lower in population than *B. dorsalis* but are still a threat in fruit plantations (José *et al*., 2013).

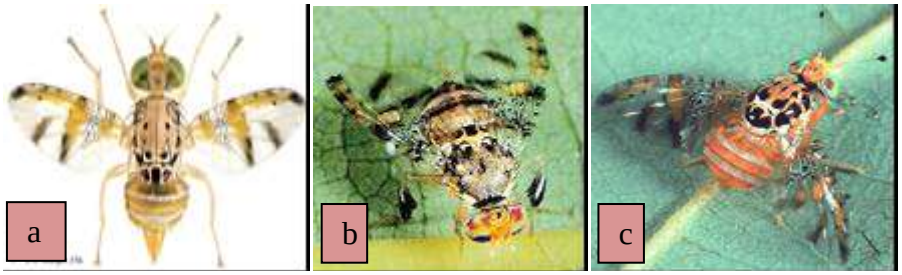


Figure 7- Fruit flies of the genus *Ceratitis:* a) *Ceratitis cosyra***; b)** *Ceratitis rosa***; and c)** *Ceratitis capitata***. Source: Ekesi & Billah (2006).**

2.7. Ecology and behavior of the oriental fly

The fruit fly population is monitored by traps to determine their density, dynamics, occurrence and fluctuation. There are certain extremely important factors that influence the development of the fruit fly population, such as: temperature, relative humidity, precipitation

and the host. *Bactrocera dorsalis* species is easily adaptable in subtropical and tropical regions, which can behave in optimal conditions with temperatures between 25ºC and 30ºC, with relative air humidity of 80% and precipitation, which proves to be a strong factor and positively related to the development of population (Cugala & Mangana, 2010). According to the same authors, *B. dorsalis* occurs all year round at low altitudes and can also occur at high altitudes. Fruit fly eggs, larvae and adults have their development influenced by air temperature, while pupae by soil temperature (Choi *et al*., 2020; Lin & Okuyama, 2024).

2.8. Fruit fly hosts

Fruit flies attack numerous cultivated fruit species (mango, grape, guava, papaya, melon, etc., including coffee) and wild (Surinam cherry, star fruit, Spanish plum, yellow mombin, jabuticaba, etc.), tending to infest orchards migrating from areas of wild vegetation or backyard fruit trees (Cugala *et al.*, 2016; Martins *et al*., 2024) .This behavior is known as incursionist infestation caused by flies originating from areas with fruit trees whose fruiting cycle has already concluded, and the adults disperse to other orchards at the beginning or completion of fruiting. *B. dorsalis* is a polyphagous species because it has been reported that attacks plants from different families and species. Ekesi & Billah (2006) report the registration of 13 plant families with 40 species from different hosts. Most of the hosts already described have been recorded in Africa, however, research is being carried out to identify other hosts of the invasive fly, although they may not be of major commercial interest internationally and the list of hosts may not be definitive. Among the most preferred hosts for *B. dorsalis* are mango (*Mangifera indica*), guava (*Psidium guajava*), citrus fruit (*Citrus spp.*), papaya (*Carica papaya*), tomato (*Lycopersicon esculentum*), banana (*Musa*), custard apple (*Annona spp*.) and other wild fruits (example in Mozambique: *Sclerocarya birrea* and *Vangueria infausta*) (Ekesi & Billah, 2006; De Meyer *et al*., 2012).

2.9. Fruit fly control methods

In order to reduce losses in fruit and vegetable yields due to fruit fly infestation, and to promote the internal and external quality of fruits, several control methods have been studied (Ekesi & Billah, 2006). For better effectiveness of control methods from an economic, environmental and social point of view, they must be applied in a combined or integrated manner (Cugala *et al.*, 2016). The same authors point out that the efficiency of the methods

will be better if they are applied on a large scale (wide coverage area) and applied for a long period of time. These methods include:

1. **Cultural Control methods**

This method is mainly based on these aspects:

- **Cleaning orchards** and destroying (burying or burning) all infested fruit on trees and fallen to the ground which can help reduce fruit fly populations in orchards. Fruits must be collected and destroyed twice a week throughout the production season and the larvae contained in fallen fruits are destroyed through solar heating (Cugala *et al.*, 2016). The collected fruits can also be fed to the animals.
- **Timely harvesting** (when physiological maturation is complete): The development of fruit flies does not occur in certain phenological states of fruits such as papaya, banana and when they are 100% green. Therefore, timely harvesting can avoid fruit fly infestation. When harvesting in a timely manner, only ripe fruits are good hosts. But attention should be paid to some species of fruit flies such as *B. dorsalis* and *C. cosyra* which have the ability to infest green as well as ripe mangoes (Vayssières *et al*., 2009).
- **Post-harvest treatment:** consists of subjecting the fruit to hydrothermal treatments (hot or cold) or radiation after harvesting to kill the eggs and fruit fly larvae found inside the fruit. The treatment serves to ensure safe export of fresh fruit and vegetables to profitable markets, which are limited due to quarantine restrictions (Ekesi & Billah, 2006).

2. **Biological control methods:** consists of the use of living and useful organisms (parasitoids, predators and pathogens biological control agents) to reduce the damage caused by a pest (Cugala & Mangana, 2010; Ratto *et al*., 2022).

- **Use of parasitoids;** this involves the use of egg parasitoids like *Fopius arisanus* against *Bactrocera dorsalis*. It attacks the eggs of the target fly and develops during the larval stage of its host and emerges as an adult in the pupa of the host fruit flies which eventually dies (Nanga Nanga *et al*., 2019).
- **Use of fungal pathogens**; the fungus *Metarhizium anisopliae*, which occurs in the soil, is being used throughout the world as a biological pesticide to control different types of pests. This fungus is effective against adults and larvae (when they fall to the ground) of fruit flies (*B. dorsalis, B. cucurbitae, C. cosyra, C. rosa, C. capitata*).

- **Use of predators:** predators such as *Oecophylla longinoda*, the African weaver ant, play a key role in managing *B. dorsalis* infestations on mango fruit plantations. The flies are intimidated by the ants through direct attacks on the flies, inhibiting them from landing and ovipositing and are aided by behavioral observations as well as chemical repellent responses (Bekelehem *et al*., 2021). The trees with established ant colonies always exhibit lower levels of fruit infestation because fruit flies tend to shy away from them and are physically ejected (Ndlela *et al*., 2022).

3. Legislative control

- Quarantine: is a control method that makes it possible to prevent the entry and/or spread of the pest in the country and thus declare the country or a certain region free of it. To this end, monitoring, particularly in possible entry areas, and taking quick action to eliminate detected outbreaks is very important (Tostão *et al*., 2012). It is also seen as a method that aims to capture males in order to detect the occurrence of the fly, followed by irradiation and dissemination.

4. Chemical control

- **Spraying with toxic baits:** use of food baits (hydrolyzed proteins) combined with an insecticide (Malathion) applied to localized points to kill the pest. This method aims to attract and kill fruit flies before they infest the fruit. The target is adult flies, mainly females (Ekesi & Billah, 2006).
- **Male Annihilation Technique (MAT):** aims to reduce the number of male fruit flies to levels that exclude crossing with females, thus eradicating the species in question (Ekesi, 2016).Traps are placed at high densities (400 units/ha), using impregnated wooden blocks containing male attractant products (such as Methyl eugenol, GF120) mixed with an insecticide (malathion). This method aims to reduce the population of male fruit flies to such a low level that it reduces the possibility of male-female encounters for mating (Ekesi, 2016; Ndlela *et al*., 2016).

2.9.1. Fruit fly monitoring

Monitoring fruit fly populations through trapping is not just about catching insects but it provides crucial ecological insights that guide management decisions. By systematically recording trap captures, researchers and practitioners can identify the specific locations where

fruit flies occur and track the periods when populations begin to rise. This information is essential for predicting outbreaks and designing timely, integrated control programs, rather than reacting after damage has already been done (FAO/IAEA, 2018; Kean *et al*., 2024). Beyond guiding pest management, surveillance plays broader roles in plant protection. Data generated from trapping networks are routinely used in scientific research, to assess the effectiveness of interventions, and in eradication campaigns where rapid detection and delimitation are critical to success. In addition, monitoring is increasingly tied to trade and market access where surveillance outcomes often provide the evidence required for quarantine certification and for demonstrating pest-free status to importing countries (IPPC, 2012; Caley *et al*., 2024; USDA-APHIS, 2024).

The prerequisite for rational and efficient control of fruit flies is knowing the appropriate time to initiate control measures through monitoring (Alves *et al*., 2019). Monitoring fruit fly populations whether in open or orchard environments is important for detecting their presence and also for quantifying population levels. It also helps to show the onset of population growth. Effective surveillance involves deploying traps baited with either food-based or sexual attractants at carefully selected sites throughout the orchard (FAO/IAEA, 2018; Kean *et al*., 2024). It is important to note that, attractants in such monitoring programs are not designed for control, as their influence is localized and insufficient for meaningful suppression of fruit fly populations (Ahmad *et al*., 2023).

Traps

The success of adult tephritid surveillance depends on multiple components which include: the quality of the attractant, the design of the trap, installation and placement of the trap, and consistent trap checking (FAO/IAEA, 2018; Kean *et al*., 2024). Trap selection must be guided by the nature of the lure whether it targets feeding behavior or mating and tailored to your target species or monitoring needs (Ahmad *et al*., 2023). For example, employing a variety of trap types, each baited with distinct attractants, enhances capture of the adult fly population by accommodating behavioral differences among species (Ahmad *et al*., 2023) (figure 8).

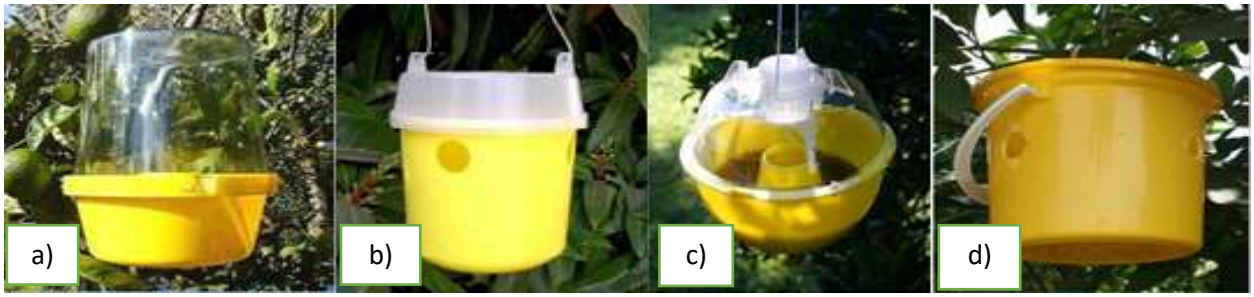


Figure 8- Different types of traps used to capture fruit flies: a) Mcphail, b) Tephri, c) Multilure and d) Lynfield. Source: Ekesi & Mohamed (2010).

Attractants

Male sexual attractants: They are characterized by being highly specific and are known to be highly effective in attracting flies over long distances. They are mainly for pheromones and are available both in liquid form (lasting two to four weeks in the field) and in the form of polymeric solids with controlled release formulation (they can last more than 6 weeks when installed at a minimum interval that varies from 50 to 100 meters).

Food attractants: They attract both male and female fruit flies, as they are non-specific, and are known to have low efficiency when compared to male sexual attractants. They also attract non-target insects and are available in both liquid and dry synthetic forms. Longevity in the field of proteins in liquid form is generally between one to two weeks while attractants in capsule form can last four to six weeks. Whatever its physical state, the minimum distance between traps varies from 10 to 30 meters (Enkerlin *et al*., 2025).

Monitoring through food attractants is considered important as it is directly related to the primary instinct of these insects, whose females need protein compounds to reach sexual maturation (Shelly *et al*., 2020).

In large-scale monitoring, the most used traps are the McPhail type with hydrolyzed proteins as an attractant. Jackson-type traps are the most used when you want to capture a specific species of fruit flies, using a specific sexual pheromone as an attractant, such as Trimedlure, which exclusively attracts males.

Cost is an important factor to be considered in fruit fly monitoring programs, especially those involving low-income producers, carrying out studies involving the use of traps made from alternative material (plastic bottles) is extremely relevant, as these results can serve as a basis for recommending more viable alternative technologies for monitoring the pest (Kean *et al*., 2024).

2.9.2. **General aspects of palm trees and the importance of palm sap in fruit fly monitoring**

The palm tree can be found in tropical and sub-tropical countries. Palm tree is the common name for plants in the family *Arecaceae*, formerly known as *Palmae* or *Palmaceae*, which is in the order *Arecal* (Eiserhardt *et al*., 2011). Palm sap is the liquid which is extracted from the inflorescence of palm species including *Borassus aethiopum*, *Elaeis guineensis*, and *Phoenix spp*. Fresh palm sap is sweet, oyster white and translucent in color, with an almost neutral pH. It can be used for fruit fly monitoring as a fermenting liquid bait (Abraham *et al*., 2023). The volatile molecules created during natural fermentation are what make it appealing; they have a potent smell that resembles the fruit-associated cues that tephritid flies (such as *Bactrocera, Ceratitis,* and *Anastrepha* species) take advantage of. Freshly tapped palm sap is high in minerals and carbohydrates (mostly sucrose, glucose, and fructose) that quickly ferment in the presence of lactic acid bacteria and yeasts. Ethanol, acetic acid, and other volatiles are produced during fermentation and are known to attract fruit flies, both male and female. Palm sap also contains proteins which is needed by the fruit flies especially the females for maturation of their eggs. According to some field tests conducted, palm sap can be used as an inexpensive, locally accessible bait in McPhail traps or basic bottle traps to monitor populations of *B. dorsalis, C. capitata, C. cosyra,* and other economically significant fruit flies (Cugala *et al*., 2016; Abraham *et al*., 2023).

2.9.3. Cane molasses and its application in fruit fly attraction

Cane molasses is the thick, dark, water-soluble syrup left after the last crystallization step in sugarcane processing. Chemically, it's dominated by sugars, typically with sucrose as the main component and appreciable amounts of reducing sugars (glucose and fructose) plus minerals (ash), organic acids, and trace nitrogenous compounds. It's mildly acidic (around pH 5 in many commercial lots), highly viscous, and hygroscopic. Because it is inexpensive, energy-dense, and readily fermented by yeasts and bacteria, molasses is widely used as a carbon source in food, feed, and fermentation industries (El-Gendy *et al*., 2013) Composition varies with cane variety and processing, but a representative analysis reported approximately 68% sucrose, 18% glucose, and 13% maltose in the sugar fraction, with 11% ash and pH 5 (El-Gendy *et al*., 2013). These traits matter for trapping where by sugars and their fermentation products release volatile cues (acids, alcohols, ammonia-related compounds) that can attract adult tephritid fruit flies seeking carbohydrate and protein before reproduction

(Lasa & Williams, 2021). Female tephritids are typically most responsive to “food-type” volatiles that signal accessible nutrients. This is because aqueous molasses provides readily available sugars and flies often respond to sweet solutions, especially when protein is limiting early in adult life. Also when diluted and exposed, molasses ferments quickly, emitting acetic acid, ethanol, and when nitrogen is present ammonia and related volatiles. Ammonia plus amines (e.g., putrescine) and organic acids form the backbone of many of the most effective synthetic food lures *(Jenkins et al.,* 2011).

Molasses has been used as a liquid attractant in traps where solutions (typically 5–10%) have been field tested in McPhail type traps. Results are mixed and species and context-dependent. In Uruguayan orchards, 6% sugarcane molasses placed in McPhail traps captured far fewer females of *C. capitata* and *Anastrepha fraterculus* than commercial protein or ammonia-based lures i.e., molasses alone was not an effective mass-trapping attractant there (Delgado *et al.*, 2022). By contrast, earlier work in Brazil did find sugarcane molasses (“melado de açúcar”) at about 7% among the more efficient low-cost attractants for *Anastrepha* spp. under those conditions (Lemos *et al*., 2002). Molasses solutions can work, but performance is variable and often inferior to hydrolyzed protein or modern ammonia/amine lures (Jenkins *et al*., 2011; Alves *et al*., 2019; Delgado *et al*., 2022).

2.9.4. Torula yeast as a monitoring bait for fruit flies

Torula yeast (autolyzed *Candida utilis*) is one of the most preferred food-based lures in the fruit fly monitoring procedure. In the process of its fermentation in water, it releases ammonia and other volatiles that are powerful attractants to both male and female tephritids. In order to preserve the bait and unify the release, most commercial pellets are pre-mixed with borax (FAO/IAEA, 2018; Hanna *et al.*, 2019). Comparative studies back up the reliability of torula. In West Africa, it was able to trap more flies than either BioLure or NuLure in three different mango plots (Hanna *et al*., 2019). There are also some experiments which displayed its superiority over synthetic sachet lures (Shelly *et al.*, 2022). Nevertheless, its extent of effectiveness varies with species and habitat and in some cases, other methods could be more appropriate. Normally, torula is made by dissolving one pellet of 5g in 100ml of water (Enkerlin *et al*., 2025) and placed in McPhail-type traps which are usually at 1–1.5 m in the shaded canopy. One major problem with longevity is that the attractiveness always declines after 1–2 weeks, therefore, regular renewal is required (FAO/IAEA, 2018). Still, in a

few guava orchards aged torula caught more *Anastrepha suspensa* than that of frequently renewed bait, indicating context-specific dynamics (Torres-Quezada *et al*., 2021). Generally, torula yeast should be regarded as a reliable baseline lure in fruit fly surveillance programs especially if the female biased sampling and the presence of mixed species are considered. The rationale behind international guidelines (FAO/IAEA, 2018;USDA-APHIS, 2024) still recommending it is that it is easy to use and performs consistently well.

3.0. MATERIALS AND METHODS

3.1. Description of the study area

The study was carried out at a guava orchard (Lat. -26.0867, Long. 32.38998) in Umbeluzi Agrarian Station, Boane district, Maputo province for seven months, starting from March 2025 up to October 2025. The site was selected basing on the dominance of guava trees which are some of the preferred hosts by fruit flies (José *et al*., 2013) and because they were at the fruiting stage and therefore, were expected to be hosting fruit flies.

Boane district is located in Maputo province, 45 km from Maputo city. The district is bordered to the north by the district of Moamba, to the west and southwest by the district of Namaacha, to the south and southeast it borders the district of Matutuine and finally to the east by the city of Matola (INE, 2020) (figure 9). Other fruits within the vicinity of the orchard included mangoes, tropical almond, oranges and bananas which are also important hosts of fruit flies.

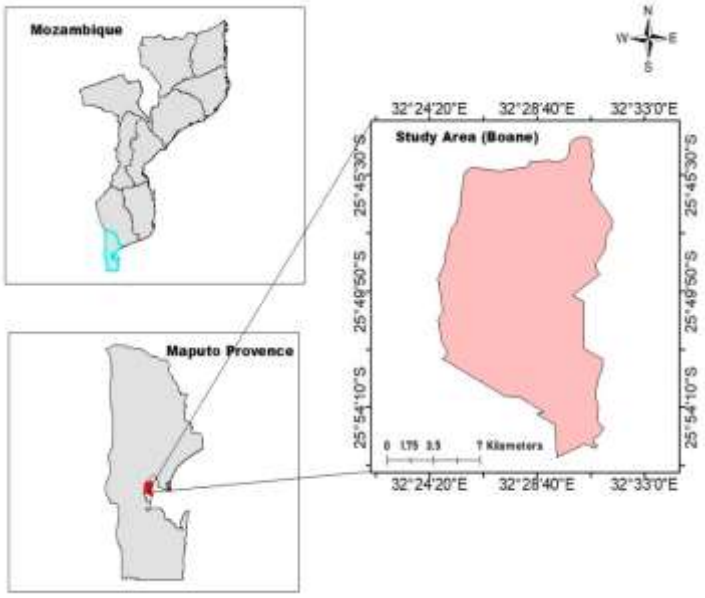


Figure 9- Map showing the location of Boane District in southern Mozambique. Source: Designed by author.

3.2. Sampling procedures

3.2.1. Description of treatments

The experiment was conducted in a Randomized Complete Block Design (RCBD) with 4 treatments (baits) and 4 replications (blocks). Within the guava orchard four blocks were selected and identified as block 1, 2, 3, and 4, separated for at least 50 m from each other. The GPS coordinates for each block were (26°05′12.12″ S, 32°23′23.93″ E; and 24 m a.s.l), (26°02′36.24″ S, 32°22′15.85″ E; and 8 m a.s.l), (26°02′38.04″ S, 32°22′19.31″ E; and 8 m a.s.l) and (26°02′40.92″ S, 32°22′22.04″ E; and 8 m a.s.l) for block1, block2, block3 and block 4 respectively. At each block, 4 guava trees were selected randomly and marked as tree 1, 2, 3 and 4, at least 20 meters apart from each other for placing the traps containing the treatments (Ekesi *et al.*, 2014; Nanga Nanga *et al*., 2022; Enkerlin *et al*., 2025).

The four treatments were: molasses, palm sap, torula (positive control) and water (negative control). In the field, each treatment was placed in Tephri traps labelled M_i, $P_{i,}$ T_i, and W_i for molasses, palm sap, torula and water respectively. Around 250 ml of the attractive solution were used per trap/week (Ekesi & Billah, 2006; Bortoli *et al*., 2016; Bota *et al*., 2020), as follows.

- Molasses, a byproduct of sugar refining rich in fermentable sugars, was prepared by diluting 100 ml of molasses with 900 ml of clean water to make a 10 % solution of molasses. The same procedure was used by (Alves *et al*., 2019). Molasses were obtained from sugar factory located in Xinavane (acucareira de xinavane) (Manhica district, Maputo province) in bottles of 20Litres.
- Palm sap was obtained from the inflorescence of the palm tree (*Phoenix reclinata*), (Hai *et al*., 2024). Fresh Palm sap was used and it was chosen because it is readily available in Mozambique. It was got from the local vendors (at Incoluane, Gaza province) and was kept fresh by keeping it in a deep freezer.
- An aqueous solution of torula yeast was prepared by suspending one pellet of torula yeast (5g; Scentry Biologicals Inc., Billings, MT, USA) in 100 ml of clean water (Shelly *et al*., 2022; Enkerlin *et al*., 2025).
- For water, fresh and clean tap water was put in the tephri traps and used as a negative control.

3.2.2. Trap placement

A tephri trap was placed in each of the four selected trees per block with four different treatments. Traps were set up in each selected tree within the tree canopy, approximately 1.5 to 2 m above the ground surface and preferably in shaded locations (Ekesi *et al*., 2014; García-Mendoza *et al*., 2024).Trap holes or entrances were left free of leaves and tree branches to allow easy access for fruit flies and prevent entry of ants (Cugala *et al*., 2008; Nanga Nanga *et al.*, 2022) (figure 10). The trap holding string was impregnated with Vaseline to prevent entry of ants and preying on the attracted fruit flies (Billah & Afreh-Nuamah, 2012).

Figure 10- Installation of traps in the field.

3.2.3. Traps inspection and attractants replacement

All traps were inspected once a week. The captured insects were removed and separated from the liquid attractants using a sieve, where the suspension was poured and the captured insects were rinsed with water and placed in plastic vials containing 70% alcohol (Santos *et al*., 2022; García-Mendoza *et al*., 2024) duly labeled according to the block, attractant, date and week of collection (Figure 11). After collecting the samples, the traps were washed with water, the attractants were replaced with fresh ones and the position of the traps was changed clockwise to avoid the influence of position (Ekesi *et al.*, 2009; Vayssières *et al.*, 2015). Used

attractants were disposed off by pouring them away at a distant location to prevent re-attracting fruit flies to non-trap areas, which could reduce trap effectiveness and create false monitoring results (FAO/IAEA, 2018).

Subsequently, all collected insects were taken to the laboratory of Entomology at the Faculty of Agronomy and Forestry Engineering (FAEF), in Maputo. In the laboratory, all fruit flies were separated from other captured individuals based on their general characteristics (wing venations). All fruit fly specimens collected were washed, counted, and recorded.

Figure 11- Procedures during traps servicing: A; Collection of trapped insects B; preserving trapped insects in alcohol.

3.3. Guava fruits sampling

Fruits were sampled every week in the four experimental blocks to estimate the infestation indices of fruit flies in the orchard. A total of up to 20 fruits were randomly collected per block every week, which included both the fruits from the ground and those from the tree, depending on availability. Fruits were collected, put into labeled containers, and transported to the FAEF Entomology Laboratory for incubation (Figure 12a). Fruits were counted, weighed and then incubated in groups of at least five fruits in mesh-top plastic containers lined with moist sterilized sand under laboratory room conditions of temperature and relative humidity (Figure 12b). Fruits collected from the ground were incubated separately from the

ones collected from the trees. The containers were inspected twice every week to harvest any pupae (Nankinga *et al*., 2014; Vayssières *et al*., 2015). The pupae were harvested by use of a sieve to remove the soil and remain with the pupae (Figure 12c). They were counted and placed in plastic vials lined with moist paper for humidity. The larvae which had not yet developed into pupae were placed back in the plastic container with soil for pupation. Harvesting of pupae went on until there was no pupae recovered for 2 consecutive times. Then, the fruits were dissected to check for any larvae or pupae which might have failed to come out of the fruits (Ekesi & Billah, 2006).The plastic vials containing the pupae were covered with perforated cloth for aeration and kept at laboratory room temperature until the adults emerged or for 2 weeks (Figure 12d). Then, the emerged adults were left in the vials until they died for full development of adult characteristics (colour). The adults were counted and separated by genera, sexed basing on the presence of the ovipositor for the females, before they were identified to species levels.

Figure 12- Procedures in the laboratory: a); collected fruits, b) fruits incubated in plastic containers, c) harvesting of pupae, and d) harvested and counted pupae kept in plastic vials for emergence into adults.

3.4. Identification of the species of fruit flies

In the FAEF Entomology Laboratory, fruit fly specimens were identified to species levels basing on visual observation of morphological characteristics and comparing them with identification keys described by (Ekesi & Billah, 2006; De Meyer *et al*., 2012) with the aid of an electric magnifying glass and comparison with specimens already identified (figure 13). Also electronic identification keys were used as described by Virgilio *et al*. (2014). For more precise identification, the specimens were sent to fruit fly taxonomist specialists' based at

Royal Museum for central Africa, Brussels, Belgium. The fruit flies samples from each species were separated by their sex by observing the ovipositor on the female and counted.

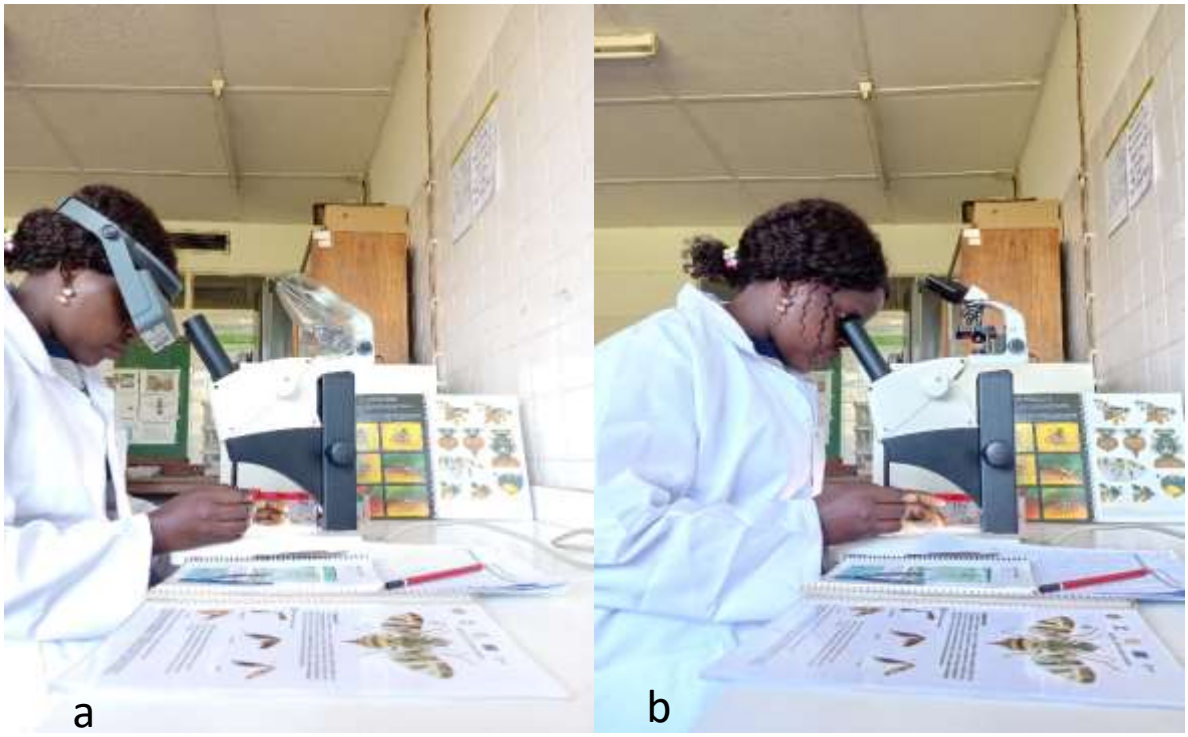


Figure 13- Identification of fruit flies: a) identifying the sex, and b) species identification.

3.5. Determination of variables

3.5.1 **Estimation of the absolute and relative abundance of fruit fly species**

The absolute abundance of fruit fly species captured in each treatment was estimated based on the total number of individuals of each species attracted in each treatment. This variable has been used in various studies to understand population size and dynamics of fruit flies in mango orchards (Ekesi *et al.*, 2009; Vayssières *et al.*, 2015). Relative abundance was estimated as the percentage ratio between the number of individuals of each species found in each type of treatment, and the total number of individuals of all species found for the same treatment. (Formula 1) This approach has been similarly employed in the evaluation of fruit fly monitoring techniques and the efficacy of different attractants in diverse mango-growing regions (Ekesi *et al.*, 2009; Hanna *et al.*, 2019).

Formula 1 $Ab = \frac{n}{N} * 100$

Where:

Ab = Relative Abundance;

N = Number of fruit fly's specimens of the reference species attracted in a given treatment;

N = Total number of flies captured in the same treatment of the reference species.

3.5.2. Determination of sex ratios

In order to determine the sex ratios of fruit flies captured in the different treatments, all adult flies were carefully examined and separated by sex basing on the presence of the ovipositor in females. For each treatment, the total number of males and females of each species was recorded, and the sex ratio was expressed as the percentage proportion of males to females. This procedure was done for each fruit fly species in each treatment independently (Howse *et al*., 2024).

3.5.3. Estimation of population density of fruit fly species during the study period and the population fluctuation in relation to fruit availability and climate variables

Species data collected from each treatment was reported using the variable; "mean Number of Fruit Flies per Trap per Day" (FTD) (formula 2) which describes the adult population size of the attracted fruit fly species at the sampling sites as described by Ekesi & Billah (2006) and FAO/IAEA, (2018) given by:

Formula 2: FTD = $\frac{F}{T*D}$

Where:

F = Number of fruit flies captured in the trap that received the treatment Z

T = Number of installed traps that received Z treatment;

D = Average number of days of exposure of traps in the field.

According to Cugala *et al.* (2008) and FAO/IAEA, (2018), the Fruit flies/Trap/Day (FTD) is an index that indicates the size of the adult population of a given species in time and space (spatial-temporal distribution) and the level of infestation of fruit flies in the location of catch. Depending on the FTD value of each species of fruit fly in a given location, that location can be classified as:

- FTD > 1 infested area;
- 1 < FTD > 0 area of low prevalence

- FTD = 0 pest free area

The meteorological data used to explain the fluctuation of fruit fly species (temperature, precipitation and relative air humidity) was obtained from the National Meteorological Institute (INAM) and data for the nearest weather station was used. Host fruit availability was estimated and recorded based on Fournier method with a fruiting intensity index of 0,1,2,3,4 for no fruits, very few, moderate, high and full fruiting respectively as adapted from Chapman *et al*. (2005) and justified by Santos *et al.* (2021).

Guava fruits development stages were also registered. Other fruits considered host for fruit flies available at the study area were also registered, to assess their relationship with the fruit flies population variations.

A correlation was done between the FTD of the most abundant fruit fly species with the climate variables and fruit host availability (fruiting intensity index) in order to find out their relationship with the population density with fruit flies. The climate variables were: minimum temperature (Tmin), maximum temperature (Tmax), average temperature (Tavg), relative humidity and precipitation. The weekly averages of these variables were recorded and correlated with the average weekly FTD of the most abundant fruit flies species in order to determine and explain the relationship.

3.5.4 Estimation of the pupae and adult infestation indices of guava fruits from the orchard

The infestation indices were estimated by calculating the number of pupae per fruit, number of pupae per kilogram of fruits, number of adults per fruit and number of adults per kg of fruits (Duyck *et al*., 2004; Raga *et al*., 2017) using the following formulae;

Formula 3; Pupae infestation index (pupae/fruit) = $\frac{total\ number\ of\ pupae\ harvested}{total\ number\ of\ fruits\ incubated}$

Formula 4; Pupae infestation index (pupae/kg) = $\frac{total\ number\ of\ pupae\ harvested}{total\ kilograms\ of\ fruits\ incubated}$

Formula 5; Adults infestation index (adults/fruit) = $\frac{total\ number\ of\ emerged\ adults}{total\ number\ of\ fruits\ incubated}$

Formula 6; Adults infestation index (adults/kg) = $\frac{total\ number\ of\ adults\ emerged}{total\ kilogramsr\ of\ fruits\ incubated}$

When calculating the infestation indices, the overall infestation indices of the total of both the fruits collected from the ground and those collected from the trees were calculated. However the different fruit sources were incubated separately.

3.5.5. Correlation between trapped fruit flies and those that emerged from incubated fruits

The weekly mean FTD data were paired with corresponding emergence data from fruits, and Pearson's correlation coefficient was calculated to assess the relationship between the two datasets, following a method similar to that described by Billah & Afreh-Nuamah (2012). The correlation was made between the mean weekly fruit flies per trap (FTD) of the most abundant fruit fly species attracted in torula and the mean weekly emerged fruit fly per kg of the same fruit fly species that emerged from the incubated guava fruits. The correlation analysis helped to evaluate whether trap catches could serve as reliable indicators of fruit infestation levels in the field, taking into consideration that food baits attract fruit flies from short distances.

A regression analysis was later conducted to examine the relationship between the mean weekly FTD (independent variable) and the number of emerged flies per kilogram (dependent variable).

3. 6. Data analysis

All statistical analyses were carried out using R software (R Core Team, 2025). The variable FTD was calculated for the first 12 weeks when the trap catches were high enough to detect a statistical significance (Jenkins *et al*., 2011). Analysis of variance (ANOVA) was conducted on the data. Since the assumptions of ANOVA were violated , i.e., homogeneity of variances and normality of residuals, a logarithmic transformation [log(x+0.5)] was carried out in order to stabilize variances and render the data standardized (Khan *et al*., 2021). Mean separation was performed using Tukey's Honest Significant Difference (HSD) test at the 5% level of significance.

The population fluctuation of *Bactrocera dorsalis* counted over the study period was computed by adding the count each week from all the baits and calculating the mean weekly FTD. The mean weekly FTD was plotted against time in weeks to visualize the trend by use of a line graph. Also a line graph for mean weekly FTD of the flies captured in each treatment against time was plotted to visualize the trend in each treatment independently.

The correlation between trapped flies and host availability together with the climate variables was determined by calculating the Pearson correlation coefficient.

In order to estimate the correlation between the FTD from traps and adults/kg from the incubated fruits, a Pearson correlation coefficient was calculated. Correlation was computed applying the cor() function and statistical significance was tested applying the cor.test() function that provided a p-value and 95% confidence interval of the correlation estimate.(Crawley, 2012). A regression analysis was performed to examine the relationship between mean weekly fruit flies/ trap/ day (FTD) as the independent variable and the number of emerged flies per kilogram of fruit as the dependent variable. Model assumptions, including normality of residuals and homoscedasticity, were checked prior to interpretation of results.

4.0. RESULTS

4.1. Absolute and relative abundance of the different fruit fly species and the sex ratio

Throughout the study period (25 weeks), a total of 2,844 fruit flies were attracted to the various baits (treatments) of which 1,670 were females and 1,174 were males. Torula attracted the highest number of fruit flies (1563) as the positive control, followed by palm sap (978), molasses was the third in attracting fruit flies (299) while water came last as the negative control (4) (table 1).

Table 1: Total number of fruit flies attracted in each attractant and their sex

Treatment	Molasses	Palm sap	Torula	Water	Grand total
Total number of fruit flies	299	978	1563	4	2,844
Number of females	181	534	955	0	1,670
Number of males	118	444	608	4	1,174

There were three genera of fruit flies identified, namely *Bactrocera* (2,570 flies), *Ceratitis* (37 flies) and *Dacus* (237 flies). The genus *Bactrocera* had *Bactrocera dorsalis* identified, and it was the most abundant species with a total of 2,570 flies corresponding to a relative abundance of 90.37%. Genus *Dacus*, had five species identified, namely *Dacus bivittatus* (136, 4.78%), *Dacus frontalis* (53, 1.86%), *Dacus punctatifrons (*18, 0.63%), *Dacus vertebratus* (28, 0.98%) and *Dacus ciliatus* (2, 0.70%). For *Ceratitis* the following species were identified: *Ceratitis quilicii* (16, 0.56%), *Ceratitis rosa* (10, 0.35%), *Ceratitis capitata* (8, 0.28%), *Ceratitis punctata* (2, 0.07%) and *Ceratitis cosyra* (1, 0.04%) (table 2).

Table 2: The different species of fruit flies and their abundances in each treatment.

SPECIES	TREATMENT								
	Molasses		**Palm sap**		**Torula**		**Water**		**Grand total**
	Total (A/A)	**R/A (%)**	**Total (A/A)**	**R/A (%)**	**Total (A/A)**	**R/A (%)**	**Total (A/A)**	**R/A (%)**	
Bactrocera dorsalis	252	84.28	903	92.33	1,413	90.40	2	50.00	**2,570**
Dacus bivitatus	27	9.03	11	1.12	98	6.27	0	0.00	**136**
Dacus punctatifrons	1	0.33	8	0.82	8	0.51	1	25.00	**18**
Dacus frontalis	17	5.69	26	2.66	9	0.58	1	25.00	**53**
Dacus vertebratus	2	0.67	24	2.45	2	0.13	0	0.00	**28**
Dacus ciliatus	0	0.00	1	0.10	1	0.06	0	0.00	**2**
Ceratitis quilicii	0	0.00	1	0.10	15	0.96	0	0.00	**16**
Ceratitis rosa	0	0.00	2	0.20	8	0.51	0	0.00	**10**
Ceratitis capitata	0	0.00	1	0.10	7	0.45	0	0.00	**8**
Ceratitis punctata	0	0.00	1	0.10	1	0.06	0	0.00	**2**
Ceratitis cosyra	0	0.00	0	0.00	1	0.06	0	0.00	**1**
Total	299	100	978	100	1563	100	4	100	**2,844**

KEY: A/A-Absolute abundance, R/A-Relative abundance.

In general more females were attracted to the different treatments. In the genus of *Bactrocera* and *Ceratitis* more females were attracted in all the treatments apart from water, which captured only male flies. For flies belonging to genus *Dacus*, more males were attracted to the different treatments apart from *Dacus ciliatus* which were only female flies (table 3and 4).

Table 3: Number of female and male fruit flies in each treatment

SPECIES	**TREATMENT**							
	Molasses		**Palm sap**		**torula**		**water**	
	F	M	F	M	F	M	F	M
Bactrocera dorsalis	178	74	512	391	904	509	0	2
Dacus bivitatus	0	27	4	7	31	67	0	0
Dacus punctatifrons	0	1	1	7	2	6	0	1
Dacus frontalis	3	14	7	19	4	5	0	1
Dacus vertebratus	0	2	5	19	1	1	0	0
Dacus ciliatus	0	0	1	0	1	0	0	0
Ceratitis quilicii	0	0	1	0	14	1	0	0
Ceratitis rosa	0	0	1	1	8	0	0	0
Ceratitis capitata	0	0	1	0	7	0	0	0
Ceratitis punctata	0	0	1	0	1	0	0	0
Ceratiti cosyra	0	0	0	0	0	1	0	0

KEY: F-female, M-male

Table 4: Percentage of female and male fruit flies in each treatment

SPECIES	**TREATMENT**							
	Molasses		**Palm sap**		**torula**		**water**	
	F (%)	**M (%)**	**F (%)**	**M (%)**	**F (%)**	**M (%)**	**F (%)**	**M (%)**
Bactrocera dorsalis	70.63	29.37	56.70	43.30	63.98	36.02	0.00	100
Dacus bivitatus	0.00	100	33.36	63.64	31.63	68.37	0.00	0.00
Dacus punctatifrons	0.00	100	12.50	87.50	25.00	75.00	0.00	100
Dacus frontalis	17.65	82.35	26.92	73.08	44.44	55.56	0.00	100
Dacus vertebratus	0.00	100	20.83	79.17	50.00	50.00	0.00	0.00
Dacus ciliatus	0.00	0.00	100	0.00	100	0.00	0.00	0.00
Ceratitis quilicii	0.00	0.00	100	0.00	93.33	6.67	0.00	0.00
Ceratitis rosa	0.00	0.00	50.00	50.00	100	0.00	0.00	0.00
Ceratitis capitata	0.00	0.00	100	0.00	100	0.00	0.00	0.00
Ceratitis punctata	0.00	0.00	100	0.00	100	0.00	0.00	0.00
Ceratiti cosyra	0.00	0.00	0.00	0.00	0.00	100	0.00	0.00

KEY: F-female, M-male

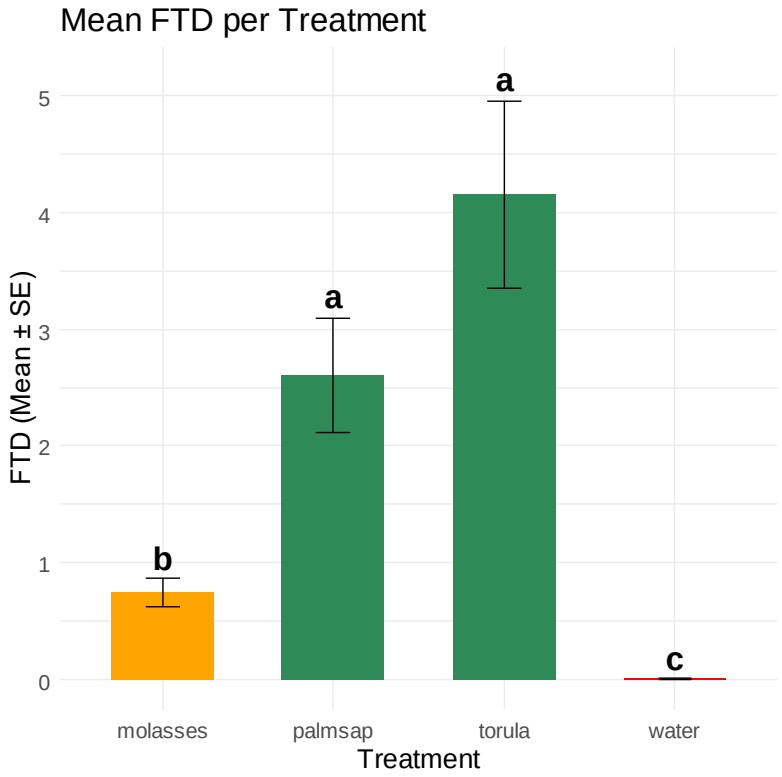
4.2. Population density of fruit fly species in each treatment

This was estimated by calculating the fruit flies per trap per day (FTD) of the most abundant fruit fly species, *Bactrocera dorsalis.* The population density of the dominant species *B. dorsalis*, showed highly divergent levels across bait treatments over the entire study period. There was highly significant effect of the treatment on the FTD; **(**$F_{(3, 187)} = 53.96$, $p < 0.001$**).**

The positive control, torula yeast, had the highest FTD (4.15±0.804) of *B. dorsalis*, confirming its position as a good standard attractant. The second was palm sap as a locally available bait with a mean FTD of 2.610±0.491. Molasses came third, with an FTD of 0.747±0.119. Water, the negative control, captured the least (FTD: 0.006±0.004) with very minimal attraction.

Statistical groupings according to post hoc Tukey's test for all the treatment showed that palm sap and Torula did not differ significantly from one another (group "a"), implying that palm sap was as effective as the commercial bait in attracting *B. dorsalis*. Molasses (group "b") was significantly different from palm sap and Torula, being of moderate but lower

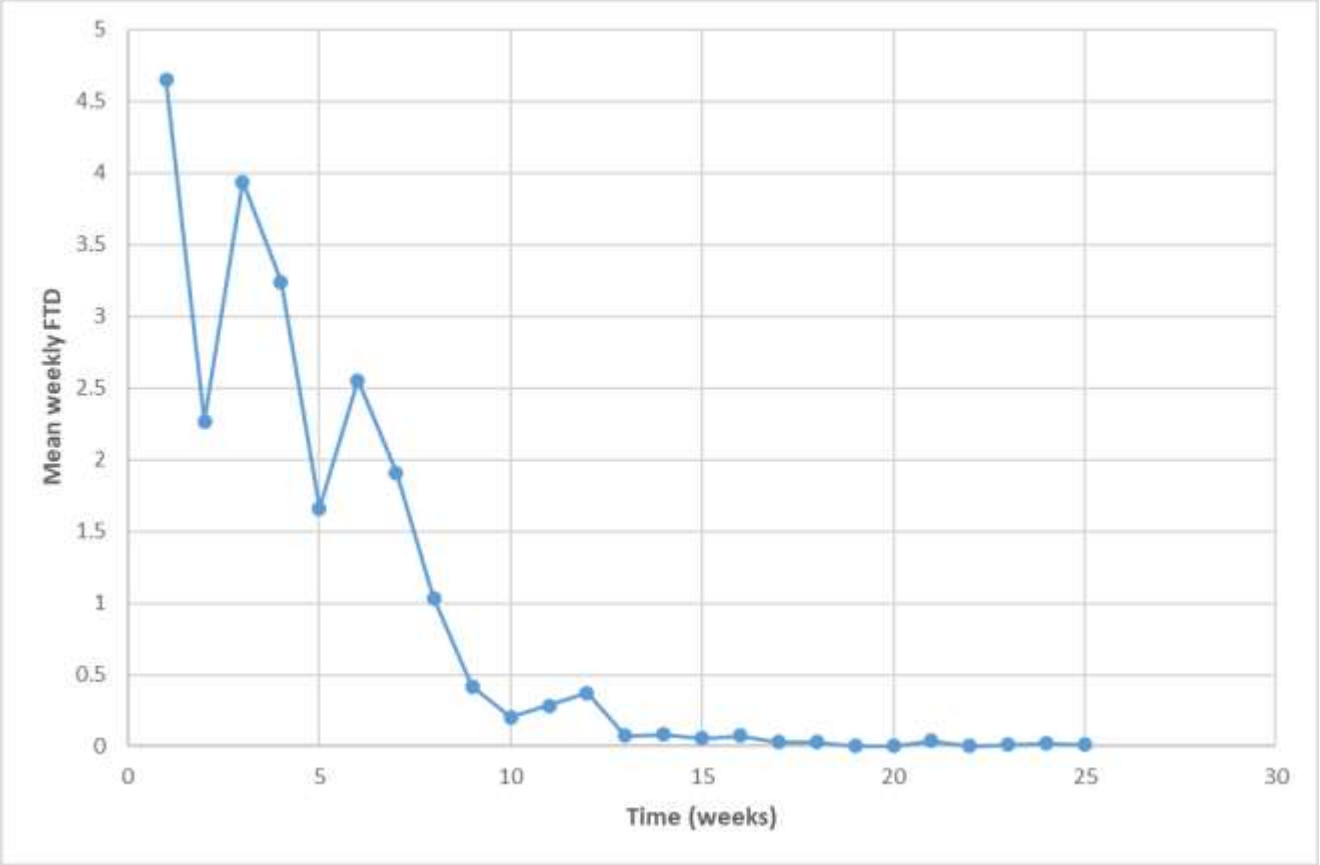
attractiveness. Water (group "c") was significantly less attractive than all the remainder of the treatments as would be expected (Graph 1).



Graph 1: **Mean FTD of *Bactrocera dorsalis* for the sampling period, in each treatment.** Treatments with bars with the same letter are not statistically different from each other

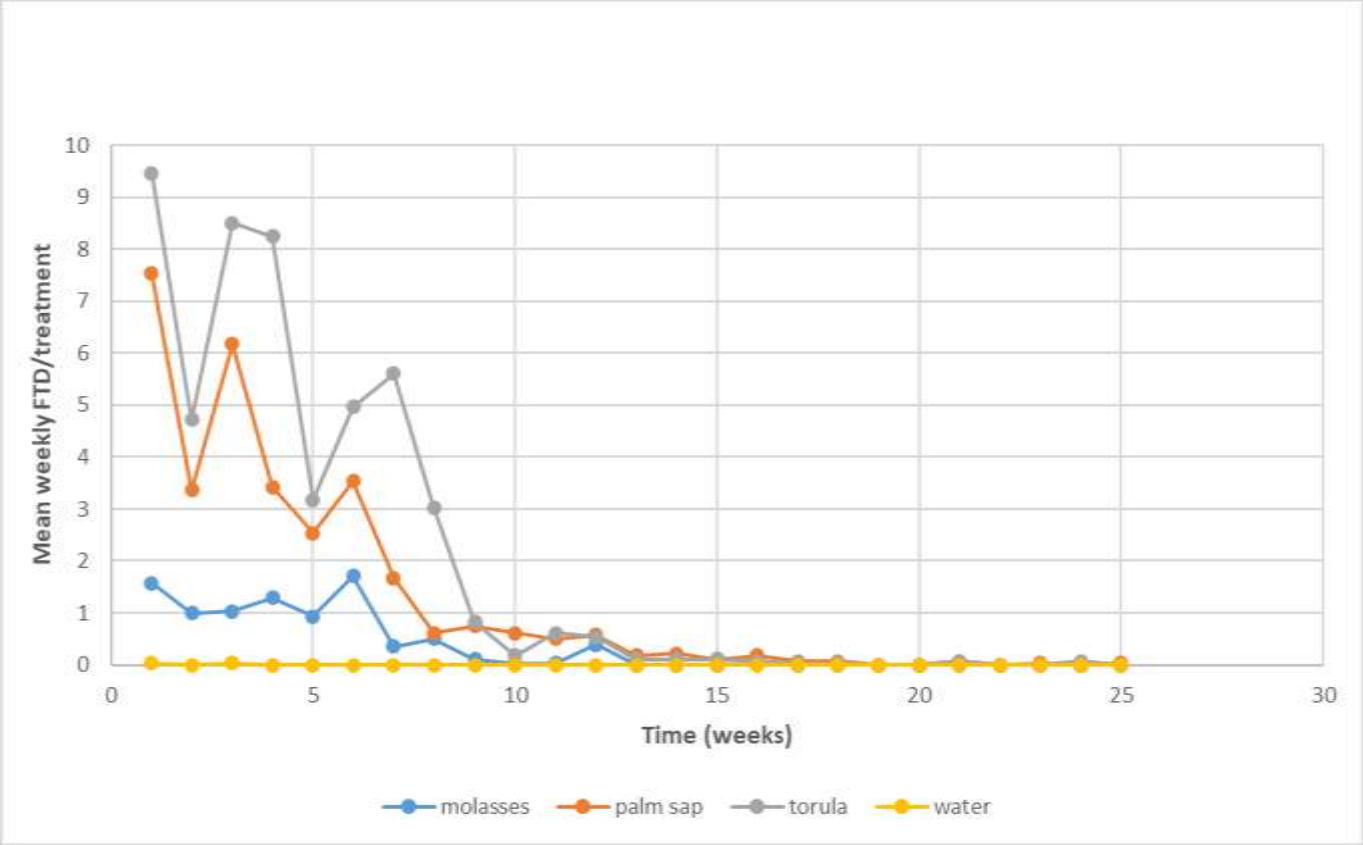
4.3. *B. dorsalis* population fluctuations in respect to fruit availability and climate variables

Population trend demonstrated a clear declining trend with time (Graph 2). The peak of the fruit fly population was caught in the first week of observation, and this coincided with the initial stage of fruit maturation of guavas, a time period known to have high abundance of fruit flies. The first peak population reflects that the fruit fly population community was already well established in the orchard and was attributed to favorable conditions like sufficient number of ripe fruits, favorable microclimate, and availability of breeding sites.



Graph- 2: **Population fluctuation of *Bactrocera dorsalis* with time.**

After the initial week, fruit fly catches generally continued to decline but with fluctuations in the following weeks. This was evident for both the general catches for all the traps and also for the independent treatments (Graph 3).



Graph- 3: **Mean weekly FTD/treatment of *Bactrocera dorsalis* with time (weeks).**

It can be seen from the graph that for each treatment the mean weekly catches were highest in the first week of the study and then kept on decreasing as the study period in weeks increased, apart from water which almost captured zero (0) flies throughout the study period.

The analysis of the relationship between the number of fruit flied trapped and climate factors and host fruit availability showed that host fruit availability, temperature and relative humidity had a significant positive association with fruit fly trap density (FTD), while precipitation did not have a significant association (Table 5).

Table 5: Correlation between the weekly FTD of *Bactrocera dorsalis* and host fruit availability and the climate variables.

Variable	Correlation (r)	95% Confidence Interval	p-value	Significance
Tmin	0.779	0.555 – 0.898	4.48e-06	*** (highly significant)
Tmax	0.499	0.130 – 0.747	0.011	* (significant)
Tavg	0.754	0.511 – 0.885	1.36e-05	*** (highly significant)
Precipitation	0.303	–0.104 – 0.624	0.141	ns (not significant)
R/ Humidity	0.515	0.151 – 0.757	0.008363	** (highly significant)
Fruit availability	0.895	0.774 –0.953	1.492e-09	*** (highly significant)

The fruit host availability had the strongest positive correlation (0.895) followed by the minimum temperature (Tmin) (0.779). The average temperature (Tavg) also showed a strong positive correlation with FTD, with a coefficient of 0.754, while maximum temperature (Tmax) was moderately and significantly related to FTD, with a correlation coefficient of 0.499. The relative humidity had a moderate association with the FTD. In contrast, precipitation had only a weak and non-significant positive correlation with FTD, with a coefficient of 0.303.

These results indicate that fruit host availability and temperature, especially the minimum and average daily temperatures, together with relative humidity have a greater association with the number of fruit flies when comparing with the rainfall.

4.4. Infestation indices of the fruits

A total of 820 guava fruits were collected throughout the study period for incubation. These included 456 fruits weighing 29.568kg from the ground and 364 fruits weighing 22.013kg from the trees. A total of 12,867 pupae emerged from the fruits with 6154 from the fruits collected from the ground and 6713 from the fruits collected from the trees. A total of 10,928 adult fruit flies emerged, with 5,607 females and 5,321 males. The infestation indices were calculated and recorded. (Table 6).

Two genera of fruit flies were recovered from the incubated fruits. These were *Bactrocera* and *Ceratitis*, with *Bactrocera dorsalis* being the only species of genus *Bactrocera* and the most abundant species of all the emerged flies while *Ceratitis* had 3 species. Flies of

Bactrocera dorsalis were 10,914 flies (99.87%) and the remaining (0.12%) were: *Ceratitis capitata* (2), *Ceratitis quilicii* (8), and *Ceratitis rosa* (4).

Table 6: Summary of totals of pupae, adults, females and males emerged from the fruits and infestation indices of fruit flies in guavas

Fruit source	Total number of fruits	Total weight (kg)	Number of pupae	Emerged adults	*Bactrocera dorsalis*	females	males	Pupae/fruit	Pupae/kg	Adult/fruit	Adult/kg
Guava (ground)	456	29.568	6154	5120	5115	2719	2401	13.40±1.09	210.00±16.6	11.30±0.94	175.00±13.7
Guava (from tree)	364	22.013	6713	5808	5799	2888	2920	17.10±1.60	287.00±28.3	14.90±1.34	248±23.1
Total (overall)	820	51.581	12,867	10,928	10,914	5,607	5,321	15.08±0.95	245.06±16.1	12.91±0.81	208.46±13.3

4.5. Correlation between trapped flies (*B. dorsalis*) and *B. dorsalis* infestation index.

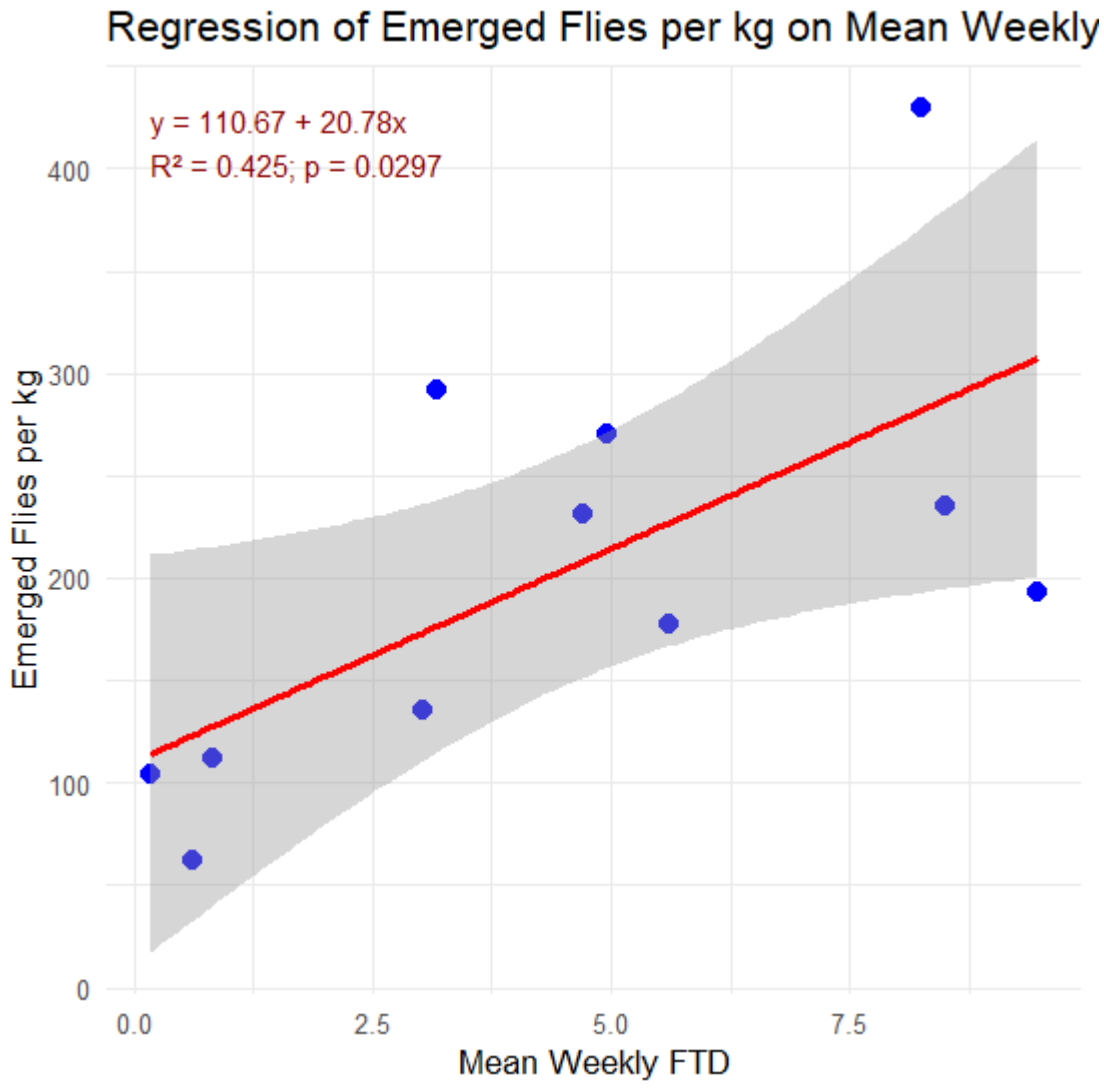
There was a statistically significant positive correlation between adult flies caught in traps and the adult flies emerged from fruits per kilogram ($r = 0.652$, $t = 2.58$, $df = 9$, $p = 0.0297$). This correlation coefficient indicates a moderately high correlation and indicates that a rise in the captures of the traps was associated with an increase in *B. dorsalis* infestation level. The 95% confidence interval for the correlation coefficient (0.0856–0.8999) also confirmed that the relation was consistently positive but with differential strength of association. These findings constitute empirical evidence to support the contention that trap catches can be utilized as a valid proxy for infestation level estimation in the field, justifying their application in monitoring fruit fly population changes in the orchard environment.

The regression model of a simple linear regression analysis was found to be statistically significant, $F_{(1,9)} = 6.66$, $p = 0.0297$, which indicates that the population density of fruit flies in the field, as shown by mean weekly FTD significantly predicts the number of emerged flies per kilogram of fruit.

The regression equation derived from the analysis is as follows:

Emerged flies per kg = 110.67 + 20.78 × Mean weekly FTD.

This equation suggests that for every one-unit increase in the mean weekly FTD, the number of emerged flies per kilogram increases by approximately 20.78. The model accounts for 42.5% of the variation in the number of emerged flies per kilogram ($R^2 = 0.425$, adjusted $R^2 = 0.361$), indicating a moderate positive association between the two variables. This is represented in graph 4



Graph-4: Regression of emerged flies/kg of *Bactrocera dorsalis* on mean weekly FTD of the same species of fruit flies attracted in torula.

5.0. DISCUSSION

Bactrocera dorsalis was identified as the most abundant species trapped in all the food baits. This is consistent with many studies which reported dominance of the invasive *B. dorsalis* over the native fruit fly species in Africa ever since its invasion into Africa (Ekesi *et al*., 2009; Grechi *et al*., 2022; Ndayizeye *et al*., 2024). This is because this species is more aggressive, has a higher reproductive rate and has more hosts than the native species (Ekesi *et al*., 2009; CABI, 2020).

The findings also showed distinctly characterized sex-specific trends of fruit fly catches to the baits. For the *Bactrocera* and *Ceratitis* species, higher numbers of female fruit flies were captured than male ones. This is in agreement with earlier research that females of the two genera have greater nutritional requirements, specifically protein and carbohydrate, in support of oogenesis and prolonged flight (Shelly *et al*., 2020;Shelly, 2021; Delgado *et al*., 2022). Fermenting food lures like palm sap and torula yeast thus yield energy and microbial metabolites eliciting female feeding reactions leading to trap catches being female-biased. In contrast to this, the reverse was true for the species of *Dacus*, where more males were caught than females using all the food baits. The pattern is consistent with the results from Shelly *et al*. (2017) which showed that food baits including torula, attracted more males of *Zeugodacus cucurbitae* flies than the females. However the results do not agree with other studies in which more females were attracted than males (Siderhurst & Jang, 2010; Royer *et al*., 2014).This could be because there might have been more male flies in the field than females. Also it is known that guavas are not good hosts for fruit flies in genus *Dacus* and hence fewer females were expected in the field because of less breeding sites (Katiyar *et al*., 2000). It is also consistent with the flies in the dacine ecology where males tend to utilize microbially fermented carbohydrate-based resources in order to attain quick energy turnover during mate searching and lekking (Drew, 1987).

According to the results, palm sap was found out to be as effective as the commercial food bait, torula, and therefore it presents a low-cost, viable alternative overall, and especially in the context of resources being limited. These results align with Abraham *et al*.(2023) who found out that palm sap could be used as a cheap alternative in management of fruit flies in Ghana. The high attractiveness by palm sap to fruit flies during this experiment is due to its natural chemical composition and fast fermentation rates. Fresh palm sap, when collected directly from the tree, is rich in soluble sugars mainly sucrose, glucose, and fructose and

proteins (Salvi & Katewa, 2012) which provide an immediately available source of energy for tephritid fruit flies. Such sugar-rich substrates play a crucial role in sustaining the flight activity, longevity, and reproductive potential of adult fruit flies (Delgado *et al*., 2022), Previous studies have demonstrated that carbohydrate and protein rich food sources significantly enhance mating success, fecundity, and survival in tephritid species, underscoring their importance as potent feeding stimulants (Royer *et al*., 2014.; Delgado *et al*., 2022). Apart from the composition of sugar, palm sap quickly becomes fermented by microorganisms during harvest, which is largely due to naturally occurring yeasts. This results in the release of volatile metabolites like ethanol, acetic acid, and other esters of chemical mimetic signals that mimic ripening or fermenting fruit crucially significant ecological host fruit fly location cues. Furthermore, palm sap includes essential amino acids, vitamins, and minerals that facilitate active microbial growth and continuous volatile development (Makhlouf-Gafsi *et al*., 2016). Such nutritional adequacy guarantees that fermentation continues, keeping the bait's appeal during extended trapping intervals hence increasing its effectiveness.

For the population fluctuations of fruit flies, the greatest weekly mean FTD catches were during the first week of trapping, which coincided with the time of maximum fruit ripening. The catches then fell steadily due to the diminishing fruit availability. This is due to the general host fruit phenology dependency of tephritid populations as was well illustrated in earlier works (Bota *et al*., 2020; Khan *et al*., 2021; Awarikabey *et al*., 2023). At times of fruit availability, females will actively pursue oviposition targets and males will bunch around host fruits to fight for mates, leading to reliable trap catches. On the other hand, as fruits deteriorate, flies either disperse to new hosts or their numbers decline due to fewer breeding substrates. The intimate association of host fruiting patterns with fruit fly abundance has significant implications for pest management. Producers tend to incur highest risk of infestation at times of peak ripening, necessitating greater control efforts and monitoring during this phase. Timing management interventions to coincide with fruiting cycles enables producers to achieve maximum suppression of fruit flies while minimizing unnecessary use of pesticides.

The correlation analysis revealed that host availability and temperature variables, particularly minimum and average temperatures, were strongly associated with fruit fly trap catches, while maximum temperature showed a moderate association and precipitation was weakly

correlated. Temperature has a direct effect on the metabolic processes, ability to reproduce, and survival of tephritid fruit flies. When temperatures are within their acceptable range, higher temperatures increase metabolic rates and speed up development, leading to more active adults and quicker population growth. For instance, Beer *et al*., (2021) found out that *B.dorsalis* had significant positive correlation with minimum temperature and maximum temperature in India and Yu *et al.*, (2022) found that favorable temperature ranges enhanced the population growth of *Bactrocera dorsalis*.

A strong positive relationship with the host fruit availability is because the fruit flies use them as source of food and breeding site. A moderate positive correlation between relative humidity and FTD is consistent with the findings from Jm *et al*. (2024) and Gm & Zp (2020). This is because higher relative humidity likely increases fruit fly numbers because it reduces desiccation, extends adult lifespan and fecundity, enhances flight and trap responsiveness, and creates more favorable host micro habitats (Winkler *et al*., 2020). However these results disagree with Beer *et al*. (2021) who found out that relative humidity was negatively correlated with *B. dorsalis* population in bitter gourds in India. The weaker association between precipitation and fruit fly catches observed in this study aligns with the findings of Ekesi *et al*. (2016), who reported that rainfall plays an indirect role by influencing host fruit availability rather than directly affecting fruit fly activity. However, some studies emphasize precipitation as a key driver of fruit fly population dynamics, particularly in areas where fruit availability is highly seasonal and dependent on rainfall (Mwatawala *et al*., 2006). The weaker influence of rainfall in the current study could therefore be attributed to the availability of alternative host plants throughout the season, which buffers fruit fly populations against rainfall fluctuations. Overall, the results reinforce the importance host fruit availability in contributing to the population of fruit fly population. The results also show temperature as the dominant climatic factor shaping fruit fly population dynamics, with rainfall exerting more variable and context-dependent effects. These findings are consistent with the broader ecological understanding that fruit flies are highly temperature-sensitive pests, and they emphasize the need to integrate climate factors into forecasting and management programs.

The average number of pupae found in this study (15.08±0.95 pupae per fruit; 245.06±16.10 pupae per kilogram) suggests significant larval growth within the collected fruits. Surveys based on incubation show varying results depending on the host plant and location. For

instance, in southern Benin, the average number of pupae per kilogram ranged from about 1.7 to 92.7, depending on the host species (Vayssieres *et al*., 2011). Similarly, field studies on mangoes in Kenya found highly variable infestation levels, with fly numbers per kilogram ranging from 3.0 to 97.2, based on site and elevation (Ekesi *et al.*, 2006). Therefore, factors like the type of host, fruit size, and ripeness are key reasons for differences in the number of pupae per fruit and per kilogram across studies (Araujo *et al*., 2019). The high numbers of pupae and emerged adults from the fruits suggest high infestation intensity and confirm that guavas are a preferred host for *B. dorsalis* (José *et al.*, 2013). From a management point of view, these findings emphasize the importance of keeping orchards clean. Fallen fruits act as reservoir of, the developing stages of fruit flies and act as a source of infestation if left unattended (Vargas *et al*., 2015; Deconninck *et al*., 2024). As a result, combining sanitation practices with other strategies like using protein baits and introducing natural predators can lead to a more effective way of controlling fruit fly populations. These recommendations for management are consistent with integrated fruit-fly control strategies used in African agricultural ecosystems, where high infestation levels and high emergence from incubated fruits have been previously documented (Ekesi & Billah, 2006; Vayssieres *et al*., 2011).

For the correlation of trapped flies and emerged flies from the fruits, the results of this study showed a moderate but statistically significant positive correlation between the number of fruit flies captured in traps and the number of adult flies emerging per kilogram of fruit ($r = 0.652$, $p = 0.0297$). In simple terms, this means that when more flies were caught in the traps, there tended to be more flies developing inside the fruits as well, suggesting that trap catches can serve as a practical indicator of infestation levels. This finding aligns with previous studies. For example, Vayssières *et al*. (2009) and Wen-Hua *et al*. (2023) observed that higher trap catches of fruit flies corresponded to higher fruit infestation in mango and guava orchards respectively, and they were able to use trap counts to predict infestation risk. Similarly, Manrakhan *et al*. (2017) reported that in citrus orchards, male-lure traps provided early signals of fruit fly activity, while food-based traps captured females and more closely reflected actual fruit infestation, particularly during fruit ripening. The guidelines from FAO/IAEA (2018) also emphasize that trap indices, such as flies per trap per day, are widely used as proxies for population pressure in integrated pest management programs, even though they may not capture every aspect of infestation perfectly. Long-term studies in different regions, including Cameroon (Nanga Nanga *et al*., 2022) and Ethiopia (Mihretie *et al*., 2024), similarly show that seasonal peaks in trap catches often correspond to peaks in adult

emergence from fruit, highlighting the reliability of trap data as a monitoring tool. However, as noted by Querino *et al*. (2014), trap effectiveness can be influenced by environmental conditions, host availability, and landscape factors, which may explain some of the variability around the observed correlation. Overall, these findings reinforce that while trap catches are not a perfect predictor, they provide a valuable and practical method to estimate fruit fly infestation in orchards, supporting timely decision-making in pest management.

The simple linear regression analysis showed a significant positive link between the average weekly fruit trap density (FTD) and the number of flies that emerged from each kilogram of fruit. The statistical model was significant, suggesting that changes in trap catches can effectively explain differences in the level of fruit infestation. The coefficient of determination, indicates that about 42.5% of the variation in the number of emerged flies per kilogram of fruit is explained by the average weekly FTD, implying that the model has moderate predictive ability. The positive regression coefficient of 20.78 means that for each unit increase in mean weekly FTD, there is an increase of roughly 20.78 flies emerging per kilogram of fruit. This shows that the activity of fruit flies captured in traps is related to the level of infestation in the field. However, the remaining unexplained variation suggests that other factors, such as the maturity of the fruit, differences in crop varieties, environmental conditions and hosts and fruit flies surrounding the orchards could also play a role and were not considered in this model. These results agree with earlier research, such as that by Wen-Hua *et al*. (2023) which also found that higher trap catches are linked to more fruit infestation. Overall, the study confirms that mean weekly FTD is a reliable indicator of fruit fly emergence and can be a helpful tool for making decisions about pest management strategies within integrated pest management (IPM) programs. However, it is clear that area wide management programs instead of localized ones, are more likely to provide effective control of fruit flies.

6.0. CONCLUSION

- *Bactrocera dorsalis* was the most abundant species, consistent with its status as an invasive species. Generally more females of *Bactrocera* and *Ceratitis* were captured by the different treatment while more males of *Dacus* were captured than females. Water captured only male flies.
- This study demonstrated that palm sap is as effective as Torula yeast in attracting fruit flies, confirming its potential as a low-cost alternative for resource-limited farmers.
- Fruit fly population density was highest in week one, coinciding with the peak of fruit maturation and ripening. The population later decreased steadily with decrease in fruits available. The population density of *bactrocera dorsalis* was statistically positively correlated to fruit availability, minimum temperature, average temperature, maximum temperature and relative humidity, but not statistically correlated to average rainfall.
- Guavas collected from the orchard had high infestation indices, indicating high infestation of fruit flies in the orchard.
- Higher mean weekly FTD corresponds to higher numbers of emerged flies per kilogram of fruit.

7.0. RECOMMENDATIONS

1. Adopt palm sap as a locally available, affordable and sustainable bait for monitoring and controlling fruit flies, particularly in smallholder systems where commercial baits are unaffordable.
2. Intensify monitoring during peak fruit ripening, when fruit fly populations are highest and crops face the greatest infestation risk
3. Incorporate fruit phenology and climate variables into IPM programs, ensuring that control measures (e.g., bait sprays, orchard sanitation, mass trapping) are synchronized with fruiting periods for maximum effectiveness.
4. Timely harvesting of mature and ripe fruits before oviposition takes place.
5. Adopt the field sanitation consisting regular removal and destruction of fallen fruits to reduce potential breeding sites.

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APPENDICES

Appendix1- Mean weekly Fruit fly / Trap/ Day (FTD) and SE

```
> data=read.table("bactrocera.txt",h=T)
>
>
> library(ExpDes)
> ## Adding FTD
> # Add FTD (Fruit Fly per Trap per Day) column
> data$FTD <- data$count / 7
>
>
> # View the updated data
> head(data)
  week    treat rep count       FTD
1    1 molasses   1     7  1.000000
2    1 molasses   2     0  0.000000
3    1 molasses   3    21  3.000000
4    1 molasses   4    16  2.285714
5    1  palmsap   1    81 11.571429
6    1  palmsap   2    20  2.857143
>
> library(dplyr)
>
> # Calculate mean FTD, SE per bait
> summary_df <- data %>%
+   group_by(treat) %>%
+   summarise(mean_FTD = mean(FTD),
+             sd_FTD = sd(FTD),
+             n = n(),
+             se_FTD = sd_FTD/sqrt(n))
> print(summary_df)
# A tibble: 4 × 5
  treat    mean_FTD sd_FTD     n  se_FTD
  <chr>       <dbl>  <dbl> <int>   <dbl>
1 molasses  0.747    0.821     48 0.119
2 palmsap   2.61     3.40      48 0.491
3 torula    4.15     5.57      48 0.804
4 water     0.00595 0.0288    48 0.00416

>
```

Appendix2- ANOVA and Post ANOVA Tukey's test results Fruit fly/Trap/Day (FTD)

```
> library(ExpDes)
> # Run RCBD analysis on FTD
> rbd(treat = treat,block = rep,resp =data$FTD,quali = T,mcomp = "tukey")
------------------------------------------------------------------------
Analysis of Variance Table
------------------------------------------------------------------------
            DF      SS      MS     Fc      Pr>Fc
Treatament   3  503.95 167.983 17.866 3.2000e-10
Block        3  293.46  97.821 10.404 2.3297e-06
Residuals  185 1739.46   9.402
Total      191 2536.87
------------------------------------------------------------------------
CV = 163.21 %

------------------------------------------------------------------------
Shapiro-Wilk normality test
p-value:  7.290262e-16
WARNING: at 5% of significance, residuals can not be considered normal!
------------------------------------------------------------------------

------------------------------------------------------------------------
Homogeneity of variances test
p-value:  0.9993378
According to the test of oneillmathews at 5% of significance, the variances can be considered homocedastic.
------------------------------------------------------------------------

Tukey's test
------------------------------------------------------------------------
Groups Treatments Means
a        torula          4.154762
a        palmsap         2.607143
 b       molasses        0.7470238
 b       water   0.005952381
------------------------------------------------------------------------
------------------------------------------------------------------------
> ### Log transformation of FTD data to normalise residuals
>
> data$log_FTD <- log(data$FTD + 0.5)
> # View updated data
> head(data)
  week    treat rep count       FTD    log_FTD
1    1 molasses   1     7  1.000000  0.4054651
2    1 molasses   2     0  0.000000 -0.6931472
3    1 molasses   3    21  3.000000  1.2527630
4    1 molasses   4    16  2.285714  1.0245043
5    1  palmsap   1    81 11.571429  2.4908414
6    1  palmsap   2    20  2.857143  1.2110903
> ## ANOVA
> # Load ExpDes
> library(ExpDes)
>
> # RCBD analysis on log-transformed FTD
> rbd(treat = treat,block = rep,resp = data$log_FTD,quali = T, mcomp = "tukey")
------------------------------------------------------------------------
Analysis of Variance Table
------------------------------------------------------------------------
            DF      SS      MS     Fc      Pr>Fc
Treatament   3  80.467 26.8223 53.959 0.0000e+00
Block        3  15.624  5.2080 10.477 2.1261e-06
Residuals  185  91.960  0.4971
Total      191 188.051
------------------------------------------------------------------------
CV = 273.62 %

------------------------------------------------------------------------
Shapiro-Wilk normality test
p-value:  0.07102274
According to Shapiro-Wilk normality test at 5% of significance, residuals can be considered normal.
------------------------------------------------------------------------

------------------------------------------------------------------------
Homogeneity of variances test
p-value:  0.8595913
According to the test of oneillmathews at 5% of significance, the variances can be considered homocedastic.
------------------------------------------------------------------------

Tukey's test
------------------------------------------------------------------------
Groups Treatments Means
a        torula          0.9981619
a        palmsap         0.6921466
 b       molasses        0.02305693
  c      water   -0.6826757
------------------------------------------------------------------------
```

```
> ### Fitting RCBD model using aov() to get the complete p, value
> model <- aov(log_FTD ~ treat + rep, data = data)
>
> # 3. ANOVA table
> anova_tab <- summary(model)
> print(anova_tab)
             Df Sum Sq Mean Sq F value   Pr(>F)
treat         3  80.47  26.822   53.96  < 2e-16 ***
rep           3  15.62   5.208   10.48 2.13e-06 ***
Residuals   185  91.96   0.497
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
>
>
> # 5. Tukey HSD for post hoc with letters
> library(agricolae)
> tukey <- HSD.test(model, "treat", group = TRUE)
> print(tukey$groups)
             log_FTD groups
torula    0.99816185      a
palmsap   0.69214659      a
molasses  0.02305693      b
water    -0.68267575      c
>
```

Appendix 3- R Output of correlation of fruit fly population density with fruit availability and climate variables.

```
> data <- read_excel("fmultiple correlation.xlsx")
>
> # Inspect the first few rows
> head(data)
# A tibble: 6 × 7
    FTD  tmin  tmax  tavg  prcp fruit_availability humidity
  <dbl> <dbl> <dbl> <dbl> <dbl>              <dbl>    <dbl>
1  32.6  23.0  30.4  26.3  1.7                    4     76.0
2  15.9  22.8  29.5  25.7  1.49                   4     80.5
3  27.6  22.0  29.3  25.4  0.7                    4     77.9
4  22.7  19.4  28.3  23.6  0.74                   4     73.2
5  11.6  18.9  27.2  22.6  0.78                   3     76.1
6  17.9  20.1  27.0  23.1  4.07                   3     78.2
>
> # Calculate correlation matrix between FTD and climate variables
> cor_matrix <- cor(data[, c("FTD", "tmin", "tmax", "tavg", "prcp","fruit_availability","humidity")], use = "complete.obs")
>
> # Print correlation matrix
> print(cor_matrix)
                         FTD      tmin       tmax      tavg       prcp
FTD                1.0000000 0.7790202  0.4992224 0.7537661  0.3032316
tmin               0.7790202 1.0000000  0.7648163 0.9809334  0.2157184
tmax               0.4992224 0.7648163  1.0000000 0.8532975 -0.1659192
tavg               0.7537661 0.9809334  0.8532975 1.0000000  0.1022756
prcp               0.3032316 0.2157184 -0.1659192 0.1022756  1.0000000
fruit_availability 0.8954978 0.8551636  0.6086821 0.8266862  0.2199013
humidity           0.5154447 0.7216646  0.4199771 0.6501683  0.3079739
                   fruit_availability  humidity
FTD                         0.8954978 0.5154447
tmin                        0.8551636 0.7216646
tmax                        0.6086821 0.4199771
tavg                        0.8266862 0.6501683
prcp                        0.2199013 0.3079739
fruit_availability          1.0000000 0.5824375
humidity                    0.5824375 1.0000000
>
```

```
> # Significance testing of correlations between FTD and climate variables
>
> # FTD vs Tmin
> test_tmin <- cor.test(data$FTD, data$tmin, use = "complete.obs")
> cat("\nFTD vs Tmin:\n")

FTD vs Tmin:
> print(test_tmin)

        Pearson's product-moment correlation

data:  data$FTD and data$tmin
t = 5.9586, df = 23, p-value = 4.48e-06
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
 0.5546049 0.8977960
sample estimates:
      cor
0.7790202

> # FTD vs Tmax
> test_tmax <- cor.test(data$FTD, data$tmax, use = "complete.obs")
> cat("\nFTD vs Tmax:\n")

FTD vs Tmax:
> print(test_tmax)

        Pearson's product-moment correlation

data:  data$FTD and data$tmax
t = 2.7631, df = 23, p-value = 0.01107
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
 0.1296700 0.7470012
sample estimates:
      cor
0.4992224

>
> # FTD vs Tavg
> test_tavg <- cor.test(data$FTD, data$tavg, use = "complete.obs")
> cat("\nFTD vs Tavg:\n")

FTD vs Tavg:
> print(test_tavg)

        Pearson's product-moment correlation

data:  data$FTD and data$tavg
t = 5.501, df = 23, p-value = 1.358e-05
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
 0.5107572 0.8852403
sample estimates:
      cor
0.7537661
```

```
> # FTD vs Precipitation
> test_prcp <- cor.test(data$FTD, data$prcp, use = "complete.obs")
> cat("\nFTD vs Precipitation:\n")

FTD vs Precipitation:
> print(test_prcp)

        Pearson's product-moment correlation

data:  data$FTD and data$prcp
t = 1.5261, df = 23, p-value = 0.1406
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
 -0.1044092  0.6236403
sample estimates:
      cor
0.3032316

>
> # FTD vs fruit_availability
> test_fruit_availability <- cor.test(data$FTD, data$fruit_availability, use = "complete.obs")
> cat("\nFTD vs fruit_availability:\n")

FTD vs fruit_availability:
> print(test_fruit_availability)

        Pearson's product-moment correlation

data:  data$FTD and data$fruit_availability
t = 9.6495, df = 23, p-value = 1.492e-09
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
 0.7743685 0.9533104
sample estimates:
      cor
0.8954978


> # FTD vs humidity
> test_humidity <- cor.test(data$FTD, data$humidity, use = "complete.obs")
> cat("\nFTD vs relative humidity:\n")

FTD vs relative humidity:
> print(test_humidity)

        Pearson's product-moment correlation

data:  data$FTD and data$humidity
t = 2.8847, df = 23, p-value = 0.008363
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
 0.1510850 0.7565005
sample estimates:
      cor
0.5154447
```

Appendix- 4 R output of correlation between trapped fruit flies and emerged fruit flies

```
> ## importing the data
>
> # Step 1: Read the data
> data <- read.table("bactrocera torula correlation.txt", header = TRUE, sep = "\t")
>
> # Step 2: View the first few rows
> head(data)
  meanweeklyftd emerged.flies.per.kg
1      9.464286             192.8941
2      4.714286             230.8175
3      8.500000             235.4830
4      8.250000             429.9407
5      3.178571             292.1126
6      4.964286             270.4019
> # Step 3: Calculate correlation
> correlation <- cor(data$meanweeklyftd, data$emerged.flies.per.kg, use = "complete.obs", method = "pearson")
> print(paste("Correlation coefficient:", round(correlation, 3)))
[1] "Correlation coefficient: 0.652"
>
> # Step 4: Pearson correlation test
> cor.test(data$meanweeklyftd, data$emerged.flies.per.kg, method = "pearson")

        Pearson's product-moment correlation

data:  data$meanweeklyftd and data$emerged.flies.per.kg
t = 2.5797, df = 9, p-value = 0.02971
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
 0.08559136 0.89990222
sample estimates:
      cor
0.6519905
```

Appendix 5- R output of regression of trapped fruit flies with emerged fruit flies

```
> # Regression Analysis: Emerged Flies per kg vs Mean Weekly FTD
>
> # ---  Load the data ---
> data <- read.table("bactrocera torula correlation.txt", header = TRUE, sep = "\t")
>
> # ---  Explore data ---
> str(data)
'data.frame':   11 obs. of  2 variables:
 $ meanweeklyftd       : num  9.46 4.71 8.5 8.25 3.18 ...
 $ emerged.flies.per.kg: num  193 231 235 430 292 ...
> head(data)
  meanweeklyftd emerged.flies.per.kg
1      9.464286             192.8941
2      4.714286             230.8175
3      8.500000             235.4830
4      8.250000             429.9407
5      3.178571             292.1126
6      4.964286             270.4019
>
> # ---  Fitting the linear regression model ---
> model <- lm(emerged.flies.per.kg ~ meanweeklyftd, data = data)
>
> # ---  Display regression summary ---
> summary_output <- summary(model)
> print(summary output)

Call:
lm(formula = emerged.flies.per.kg ~ meanweeklyftd, data = data)

Residuals:
    Min      1Q  Median      3Q     Max
-114.45  -50.82  -15.36   39.38  147.83

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept)    110.667     44.028   2.514   0.0331 *
meanweeklyftd   20.781      8.056   2.580   0.0297 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 83.5 on 9 degrees of freedom
Multiple R-squared:  0.4251,    Adjusted R-squared:  0.3612
F-statistic: 6.655 on 1 and 9 DF,  p-value: 0.02971


> # Extract key values
> intercept <- coef(model)[1]
> slope <- coef(model)[2]
> r2 <- summary_output$r.squared
> adj_r2 <- summary_output$adj.r.squared
> p_value <- summary_output$coefficients[2, 4]
>
> # --- Print regression equation and key metrics ---
> cat("\n----------------------------------------\n")

----------------------------------------
> cat("Regression Equation:\n")
Regression Equation:
> cat("Emerged Flies per kg = ", round(intercept, 3), " + ", round(slope, 3),
+     " × Mean Weekly FTD\n", sep = "")
Emerged Flies per kg = 110.667 + 20.781 × Mean Weekly FTD
> cat("R-squared =", round(r2, 3), "\n")
R-squared = 0.425
> cat("Adjusted R-squared =", round(adj_r2, 3), "\n")
Adjusted R-squared = 0.361
> cat("P-value (for slope) =", round(p_value, 4), "\n")
P-value (for slope) = 0.0297
> cat("----------------------------------------\n\n")
```