FIELD EVALUATION OF THE FRUIT FLY FOOD BAIT, SUCCESS APPAT® (GF-120), AND WASTE BREWERS' YEAST (WBY) AGAINST FRUIT FLIES (DIPTERA: TEPHRITIDAE) IN MANGO ORCHARDS

BY

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DECLARATION

This is to certify that this thesis is the result of research undertaken by Copperfield Kwami BANINI, and that except for references to work of other researchers that have been duly acknowledged, this thesis in whole or in part has not been presented for any other degree elsewhere.

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I dedicate this work to my Beloved wife, Dzifa Banini (Mrs.); my children, Fafali, Jennifer and Dzidzorm Kelly.

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LIST OF ACRONYMS

ABL	Accra Brewery Limited
AFFI	African Fruit Fly Initiative
APHIS	Animal and Plant Health Inspection Service
BSG	Brewers' Spent Grain
DDVP	Dimethyl 2, 2-Dichloro Vinyl Phosphate
EU	European Union
F/T/D	Flies per Trap per Day
FAO	Food and Agriculture Organisation
GEPC	Ghana Export Promotion Council
GPS	Global Positioning System
IAEA	International Atomic Energy Agency
ICIPE	International Centre of Insect Physiology and Ecology
IPM	Integrated Pest Management
ISSER	Institute of Statistics, Social and Economic Research
ITFC	Integrated Tamale Fruit Company
MAT	Male Annihilation Technique
ME	Methyl Eugenol
MOFA	Ministry Of Food and Agriculture
MRLs	Maximum Residue Levels
NGO	Non Governmental Organisation
PPRSD	Plant Protection and Regulatory Services Directorate
RCBD	Randomised Complete Block Design

SIT	Sterile Insect Technique
TA	Terpinyl acetate
TML	Trimedlure
US$	United States Dollar
USAID	United States Agency for International Development
WBY	Waste Brewers' Yeast

ABSTRACT

The efficacy of Waste Brewers' Yeast (WBY) + Imidacloprid (Akape®) (insecticide) as food bait was compared with the novel fruit fly food bait, commercially available as SUCCESS APPAT® (GF-120) in the field as attractants for the management of fruit flies in mango orchards at the Coastal Savanna ecological zone for two major seasons (2010/2011 and 2011/2012). Randomised Complete Block Design was used and a meter square of foliage of every tree in the WBY and GF-120 plots was spot-treated with about 50-60 mls coarse spray mix of the two products weekly. Control plots received no application or treatment. The population dynamics of the fruit flies were monitored on weekly basis with three different lures, Methyl eugenol (ME), Terpinyl acetate (TA) and Trimedlure (TML) in improvised plastic bottle traps in each plot. Prior to treatment application, baseline survey was carried out for three weeks to determine the fruit fly species and fly density levels in the three study sites (Ayenya 1, Akorley 1 and Akorley 2). After 6-8 weeks of treatment, 30 matured fruits were sampled from each plot, weighed and incubated on sterilised sand to determine their levels of infestation by flies. This was repeated at the end of the fruiting season, and for the first and second seasons. A total of 22,652 organisms were collected during the study period, out of which 22,355 were fruit flies and 297 non-target organisms. The fruit flies constituted 98.69%, while the non-targets were 1.31%. The pre-treatment periods for season one (SO) and season two (ST) recorded 8,621 and 13,734 fruit flies, respectively. . Four fruit fly species, belonging to two genera, were identified in the collections. These were *Bactrocera invadens* Drew, Tsuruta and White (Africa Invader fly), *Ceratitis cosyra* Walker (Mango fruit fly) *Ceratitis capitata* (Wiedemann) (Mediterranean fruit fly), and *Ceratitis ditissima* Munro (West Africa citrus fly). Total fly catches were significantly different for the various lures,

with Methyl Eugenol traps recording the highest (1285.67 ± 118.41) at Ayenya 1. However, there were no significant differences between trap catches of TML and TA traps. The relative fly densities (number of flies per trap per day, F/T/D) ranged from 0.007-10.192 and 0.004-11.666 flies per trap per day in first and second seasons respectively. The highest number of puparia was recovered from the Control plots which recorded 163 and the least was from WBY treated plots 63 and the GF-120 recorded 84. The only non-tephritid species that emerged was identified to be *Carpophilus bipustulatus* (Heer) (Coleoptera: Nitidulidae). The highest infestation level (1.0) was recorded by the Control; followed by GF-120 (0.67) and WBY (0.54). This resulted into fruit infestation reduction levels of 33% and 46% by GF-120 and WBY, respectively compared to the Control plot. WBY in its crude form was equally effective and attracted the same fruit fly species as the standard SUCCESS APPAT® (GF120) though in varied proportions.

CHAPTER ONE

GENERAL INTRODUCTION

Mango, *Mangifera indica* L. is a tropical crop which is said to have originated from South-East Asia. Production of the crop worldwide increased by nearly 50% since 1993, and makes up to 50% of all tropical fruits produced worldwide (Stefan *et al.*, 2003).

Much of this new production occurred outside the traditional centres of mango culture, in South and Central America, Africa and Australia, and a significant proportion of the new mango production has been for export markets (Galan, 1993), In Asia, it has been considered to be the "king of fruits" (Purseglove, 1972), and it is currently ranked fifth in total production among major fruit crops worldwide, after banana, citrus, grapes and apples (FAO STATDATA, 1997).

The world production of mangoes in 1997 was estimated to be over 21,740 million metric tonnes and in 2005 it was 28,510 million metric tonnes (Evans, 2008). Out of this, Africa produced 1.673 million tonnes in 1997 (FAO STATDATA, 1997) and 2.5 million tonnes in 2005, accounting for about 10% of fresh fruits and 11% of processed mango.

In Ghana, total land area under production of the crop was estimated to be about 4,166.7 ha in 2006 and 6,360 ha in 2008 with the largest farm measuring about 416.7 ha (Adongo, 2006, MoFA, 2010). Production of the fruit is said to have increased from about 1,200 metric tonnes in 2007 to about 2,000 metric tonnes in 2008 (Quartey, 2008). It is estimated that about 824 and 858 metric tonnes of fruits were exported in 2007 and 2008 which earned the country US$ 998,000 and US$ 522,000 respectively (MoFA, 2010). There has been rapid increase in mango production in

recent years due to its expansion into new growing areas. The demand for mango in Ghana far exceeds the supply. It is also targeted as a potential non-traditional export crop expected to earn the highest foreign exchange for the country, taking over from pineapple and probably replacing cocoa (Quartey, 2008). This indicates that it is an important source of income, employment and foreign exchange to the country. Economically, it is one of the most attractive sectors owing to the relatively high value of the products.

Globally, there is an enormous growing demand for mangoes. This demand has risen to an annual average of 10% and was expected to rise further by 8% by the close of 2008 (Quartey, 2008). Although more than 500 mango cultivars exist, Mukherjee (1997) indicated that only a few are important for international trade. These include 'Haden', 'Irwin', 'Kent', 'Palmer', 'Sensation', 'Tommy Arkins', 'Keitt', which have reddish blush fruits and are less fibrous. These are firm and more suited for long-distance transportation than other cultivars (Sauco, 2004).

Mango is the only fruit imported in significant quantities by both the developed and developing countries. In Ghana, mango is the second most important tropical fruit after pineapple traded internationally (MoFA, 2010). Its importance as a food and cash crop in small holder communities has been well recognised by successive governments. While this sector presents many opportunities for rural economies and improved livelihoods for smallholders, several factors constrain its production, notable among them is the attack by insect pests.

About 260 species of insects and mites have been recorded as major and minor pests of mango worldwide. Of these arthropod pests, 87 are fruit feeders, 127 foliage feeders, 36 feed on branches and trunk (Pena and Mohyuddin, 2000). They also listed the major pests of mango as stone weevils, tree borers, mango hoppers and fruit flies

but Ekesi and Billah (2006) suggested that none has gained greater attention than the fruit flies. Some of the fruit flies (Diptera, Tephritidae) belong to the genera *Dacus* Fabricius; *Ceratitis* Bezzi; *Bactrocera* Macquart and *Trirhithrum* Bezzi (White and Elson- Harris, 1992; Thompson, 1998). The tephritid fruit fly, *Bactrocera invadens* (Drew, Tsuruta and White) and other species such as *Ceratitis cosyra*, (Walker) *C. capitata,* (Wiedemann) caused direct damage in Benin ranging from 17% at the beginning of April to 80% at the end of June (Vayssieres *et al.*, 2005).

Fruit flies attack both ripe and unripe fruits by laying eggs under the epicarp of these fruits. The eggs hatch into larvae and feed on the fruit tissue resulting in the rotting of fruits and premature fruits drop (Afreh- Nuamah, 2007). They damage horticultural produce throughout tropical and sub-tropical countries and various parts of the world. The devastation caused by these arthropod pests results in the loss of fruits and vegetables for export markets or trade disruption.

Quarantine restrictions of produce reduce export access to lucrative markets in Europe, the Middle East, South America and USA, where the insects are regarded as quarantine pests. With the current world emphasis on quality standards, fruits for local and export markets are to be free from insects that blemish them either by feeding, scratching or ovipositing in the pulp. This development, if not managed properly, can directly cause high losses in value and monetary terms. Only fruit flies, seed weevils and some lepidopterans actually penetrate the fruit pulp and seed (Pena and Mohyuddin, 1997).

Justification

Prior to detection of *B. invadens* in the sub-Saharan Africa, *Ceratitis* spp. (Macheay) was reported to damage between 20-30% of some fruit crops (Lux *et al.*, 2003b). In

Ghana, crop losses due to this species were estimated between 60-85% (Billah *et al*., 2006), depending on crop variety and the season. *B. invadens* is one of the most destructive fruit fly species in the horticulture production in the world. Ghana is poised to become a bigger exporter of horticulture crops namely mango, papaya and vegetable crops. This dream might not be realised or achieved owing to the destructive nature of fruit flies. It is also likely to affect the development of the export market.

Wih (2008) reported that Ghana began exporting some fruits especially mangoes to the EU in 2004 with a total of 177 mt which was the country's largest export of fresh produce. In 2005, however, a ban was placed on Ghanaian mangoes to the South Africa market due to the detection of *B. invadens* in Ghana that year. In November 2010, authorities in the Republic of Lebanon, (Ministry of Agriculture) prohibited the importation of fresh fruits from the African continent- including Ghana due to detection of fruit fly larvae in some mango fruit imports (V. Suglo, Director, PPRSD, Accra, 2010 personal communication). These fruits are considered as principal and secondary providers of fruit flies.

In desperation, growers indiscriminately used all kinds of chemical products in an attempt to control the pests. Some made cocktails of products to control the pest but to no avail. This desperate action has serious environmental consequences, increase the production cost and further cause reduction in their profit margin. This could lead to high levels of pesticide residues in harvested fruits.

This situation may be worsened due to the strict maximum residue level (MRL) set by the EU. It is therefore essential to equip farmers with economically viable, sustainable and environmentally-sound and friendly techniques for the management of the pest. It

is imperative therefore, to develop alternative management methods/ strategies that can be put together as a package in an integrated manner that can also fit into the practices of the farmers to reduce their reliance on chemical pesticides.

A commercial product, GF120, which is a broad-spectrum bait plus insecticide of low mammalian toxicity, based on metabolites of actinomycete *Saccaropolyspora spinosa* (Mertz and Yao, 1990) is being used by farmers to manage the fruit flies in many mango producing countries, including Ghana. It is commercially available as 'Success Appat®' manufactured by Dow AgroSciences and is reported to be accepted globally for use in Organic production systems. However, the high cost of the product to farmers prohibits its use. Thus, the need to find a cheaper and locally accessible products for use by farmers.

In this study, GF-120 was used as the standard alongside a local product, Waste Brewer's Yeast (WBY). WBY is an industrial by-product from the brewery which was reported to be used as food bait to attract insect pests in some countries but not in Ghana. It is locally available and affordable and it could serve as an alternative to GF-120 which has to be imported with hard-earned foreign exchange.

It is important that these two products are evaluated under local cropping conditions before they can be recommended for the growers. This could be incorporated into an Integrated Pest Management (IPM) strategy for sustainable mango production in Ghana.

Objectives

The main goal of the study was to evaluate Waste Brewers' Yeast (WBY) in the field as a management option for fruit flies in mango orchards and possible incorporation into an IPM programme.

The specific objectives were:

i. To compare the performance of WBY+ insecticide as killing agent and GF-120 against fruit flies in mango orchards,

ii. To determine the efficacy of WBY+ insecticide against fruit flies in mango orchards

iii. To assess species composition of fruit flies in mango orchards

iv. Compare the relative fruit fly densities in mango orchards, and

v. To determine fruit infestation levels of fruits by fruit flies in mango orchards

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Mango

2.1.1 Origin of mango

The centre of origin and diversity of the genus *Mangifera* is firmly established as being in Southeast Asia (Mukherjee, 1997). The origin of *Mangifera. indica* has however, been a matter of speculation for many years. According to Seward (1912), as cited by Mukherjee (1997), fossil record provides few clues, as only a single fossil bearing the imprint of a leaf of *M. pentandra* has ever been found. Fossil leaf impressions from North-Eastern India (Assam) were identified by Seward (1912) as cited Mukherjee (1997), as being the present day *M. pentandra*; however, the identification remains doubtful, since it is not always easy to identify the different species even from fresh leaves. *M. indica* is believed to have first appeared during the Quaternary period (Mukherjee, 1951b). Blume (1850) considered that mango might have originated from several related species, primarily located in the Malay Archipelago.

On the basis of ancient accounts of travelers and the written historical record, it was believed for many years that mango must have originated in India. It has been cultivated for at least 4000 years and over 1000 varieties are recognized (Mukherjee, 1953). This is said to spread outward from India to the Southeast Asia and thence to the New World and Africa.

2.1.2 Distribution of mango

The global spread of mangoes and their cultivation outside their original centres of domestication probably did not occur until the beginning of the European voyages of discovery and colonialisation in the fifteenth and sixteenth centuries (Mukherjee, 1997). Earlier, the Buddhist monks according to Morton (1987) are believed to have taken the mango on voyages to Malaya and eastern Asia in the 4th and 5th Centuries B.C. The Persians are said to have carried it to East Africa about the 10th Century A.D. It was commonly grown in the East Indies before the earliest visits of the Portuguese who apparently introduced it to West Africa early in the 16th Century and also into Brazil (Morton (1987). Mango is now cultivated commercially throughout the tropics and in many subtropical areas. It is grown at the equator and at latitude of 35-37^0 N in Southern Spain (Mukherjee, 1997). According to Knight and Schnell (1993), introduction of superior germplasm from abroad followed by selection of improved cultivars adapted to local conditions is now underway in many areas.

2.1.3 Botany of mango

Mango belongs to the genus *Mangifera*, consisting of numerous species of tropical fruiting trees in the flowering plant family Anacardiaceae. The mango tree is erect 10-30m high, with a broad, rounded canopy which may, with age, attain 30-38m in width, or a more upright, oval, relatively slender crown (Morton, 1987). In deep soil, the taproot descends to a depth of 6m, the profuse, wide-spreading, feeder root system also sends down many anchor roots which penetrate for several meters. The tree is long-lived, some specimens being known to be 300 years old and still fruiting (Morton, 1987; Mukherjee, 1997). The leaves are evergreen, alternate, simple, 15–35cm (5.9–14 in) long and 6–16cm (2.4–6.3in) broad; when the leaves are young they are orange-pink, rapidly changing to a dark glossy red, then dark green as they mature

(Wikipedia, 2011). The midrib is pale and conspicuous and the many horizontal veins distinct. Full-grown leaves may be 10-32cm long and 2-5.4cm wide.

2.1.4 Flowers

The inflorescence is a terminal panicle which appears over the entire tree or in only one portion of the tree at any one time. Each panicle branches 3-4 times and consists of 1000 or more, mostly male and occasionally hermaphrodite flowers (Mukherjee, 1997). The flowers are produced in terminal panicles 10–40 cm long; each flower is small and white with five petals 5–10 mm long, with a mild sweet odour. The fruit takes three to six months to ripen. Hundreds and even as many as 3,000 to 4,000 small, yellowish or reddish flowers, 25% to 98% male, the rest hermaphroditic, are borne in profuse, showy, erect, pyramidal, branched clusters 6-40 cm high (Morton, 1987).

2.1.5 Fruits

The mango fruit is a large fleshy drupe, containing edible mesocarp and highly variable with respect to shape and size. Chlorophyll, carotenes, anthocyanins and xanthophylls are all present in the fruit. Although chlorophyll disappears during ripening, the anthocyanins and carotenoids increase with maturity (Lakshminaraya, 1980).

2.1.6 Mango cultivars

One of the keys to improving mango production is the identification of cultivars which have good characteristics like flavour, colour and low fibre content and which will grow under local conditions and be acceptable in the market. Many cultivars have been imported from India, Australia, the West Indies, Brazil, and the United States and these have spread to secondary production areas as indicated by (Mukherjee,

1997). Some of the common mango cultivars that are of interest in areas other than their places of origin, with descriptions intended to help differentiate them are as follows (Knight, 1997):

2.2.0 Mango production in Ghana

2.2.1 Mango cultivars in Ghana

Cultivars of mango introduced earlier have been documented as Peter, Blackman, Kinsington, Devine, Julie Celon 1 and 2, Jaffna, and Rupae. Later, some new ones were also introduced from Miami (Florida, USA) in the mid-sixties as bud wood (Abutiate, 1987). These included, Earlygold, Eldon, Florigon, Jacquelin, Palmer, Ruby, Springfels, Sunset, Zill, Keitt, Haden, Yellow Bombay, Irwin and Alphonso. Keitt and Kent cultivars are the major ones being cultivated for export in Ghana with Haden, Palmer, Tommy Atkins and Julie, respectively following in order of descending importance.

2.2.2 Climatic conditions of mango production

Mangoes are mainly cultivated in tropical (25^0N, 25^0S) and subtropical (35^0 N, 35^0 S) areas of the world, although limited production occurs in warm temperate/ subtropical, i.e. Mediterranean type areas as well (Crane *et al*., 1997). The ideal areas for mango production according to Chacko (1986) are those with a cool and or dry period prior to flowering followed by abundant soil moisture and moderate hot temperature (30^0-33^0C). Knight (1997) also indicated that the crop is best adapted to warm tropical monsoon climate, with a pronounced dry season followed by rains. The diversity of climates and soils where successful mango production occurs attests to the inherent adaptability of the species and technology improvements in cultural practices throughout the world (Crane *et al*., 1997).

Climate, mainly temperature and availability of water are the predominant environmental factors which influence commercial mango production through their effect on the frequency, intensity, duration and time of vegetative growth, flowering (Chacko 1986; 1989; Whiley, 1993; Schaffer *et al*., 1994; Núñez and Davenport, 1995) and disease incidence (Johnson *et al.*, 1989; Ploetz, 1994). Rain, heavy dews or fog during the blooming season are deleterious, stimulating tree growth but interfering with flower production and encouraging fungus diseases of the inflorescence and fruit (Morton, 1987). Strong winds during the fruiting season may cause many fruits to fall prematurely. Fruit of the best quality is usually produced in such areas, but specific races are known to fruit in humid regions (Knight, 1997).

2.2.6 Nutritional value of mango

The mango fruit has a high nutritive value and it is the most popular fruit of the orient and has not only been called King of the fruits, but also "a ball of tow soaked in turpentine" (Samson, 1986). Mango is rich in a variety of phytochemicals (Ajila and Prasada Rao, 2008) and nutrients. Mango contains amino acids, carbohydrates, fatty acids, minerals, organic acids, proteins and vitamins. The fruit pulp is high in prebiotic dietary fiber, vitamin C, polyphenols and provitamin A carotenoids (nutritiondata.com). Ripe mango contains moderate levels of vitamin C, but is fairly rich in provitamin A and vitamins B_1 and B_2. Vitamin D is not present in a significant quantity (Mukherjee, 1997). During the ripening process, the fruit is initially acidic, astringent and rich in ascorbic acid (vitamin C). Acidity is cultivar – related but reduces during ripening (Fang, 1965) while free sugars, including glucose, fructose and sucrose which generally increases during ripening. Fruit acidity is primarily due to the presence of malic and citric acids. In addition, oxalic, malonic, succinic,

pyruvic, adipic, galacturonic, glucuronic, tartaric, glycolic and mucic acids are also present. Mukherjee (1997) indicated that sucrose is the principal sugar of ripe mango. The composition of the edible portion of the fruit is shown in the Table 2. 1.

Table 2.2 Composition of raw edible portion of Mango (per 100 g)

Nutrient	Concentration
Energy	65.0 kcal = 273 kj
Protein	0.510 g
Carbohydrate	15.2 g
Fibre	1.80 g
Vitamin A	389 µg RE
Vitamin B1	0.058 mg
Vitamin B2	0.057 mg
Niacin	0.717 mg NE
Vitamin B5	0.134 mg
Folate	14.0 µg
Vitamin B12	-
Vitamin C	27.7 mg
Vitamin E	1.12 mg
Calcium	10.0 mg
Phosphorus	11.0 mg
Magnesium	9.00 mg
Iron	0.130 mg
Potassium	156 mg
Zinc 0.040 mg	0.270 g
Total fat	0.270 g
Saturated fat	0.066 g
Cholesterol	-
Sodium	2.00 mg

Source: Pamplona and Roger, (2007)

2.2.7 Uses of Mango

Mango is an important component of the diet in many less developed countries in the subtropics and tropics. Mango is generally sweet, although the taste and texture of the flesh varies across cultivars, some having a soft, pulpy texture while the flesh of others is firmer, or may have a fibrous texture. Ripe mangoes are typically eaten fresh; however, they can have many other culinary uses.

Approximately 1% of mango production is utilised for processing for juice, nectars, preserves (including chutney), fruit leather, frozen pulp and as a favouring for baked goods, ice cream, yoghurt, (Mukherjee, 1997). The fruit can be used for various purposes in all stages of development, from the tiny imperfectly set fruits, to the fully mature ones. At the first windfall stages, the fruit is gathered for pickles and chutney, coming as it does as the first material after the dry season. The tender green fruits are also chopped up for use in lieu of tamarind in various dishes where an acid flavour is desired. The tender leaves are used for salads. No other fruit compares in flavour with the mango when ripe. No part of the fruit is wasted. Even the seed is used for the extraction of starch, and the peels have been used as a source anacardic acid. Mango wood is a low quality timber, and the bark of the tree is an important source of tannins for curing leather (Mukherjee, 1997).

2.2.8 Mango production in the world

In 2005, world production of mango was estimated at 28.51 million metric tons. The Food and Agriculture Organisation (FAO) of the United Nations estimated worldwide production at more than 33,000,000 metric tonnes (36,000,000 tons) in 2007. Between 1996 and 2005, production grew at an average annual rate of 2.6% (Evans, 2009). Mango accounts for approximately half of all tropical fruits produced worldwide (Wikipedia, 2010). The aggregate production of the top 10 countries (Table 2.2) is responsible for roughly 80% of total world production (FAOSTAT 2007).

Table 3.2 World's top 10 mango producers, 1996–2005

Countries	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2003–2005
	(1,000 metric tons)										(%)
India	11,000	11,000	10,230	9,780	10,500	10,060	10,640	10,780	10,800	10,800	38.58
China	2,074	2,410	2,562	3,127	3,211	3,273	3,513	3,571	3,582	3,673	12.90
Thailand	1,181	1,198	1,088	1,462	1,633	1,700	1,700	1,700	1,700	1,800	6.20
Mexico	1,189	1,500	1,474	1,508	1,559	1,577	1,523	1,362	1,573	1,679	5.50
Indonesia	783	1,088	600	827	876	923	1,403	1,526	1,438	1,478	5.29
Pakistan	908	914	917	916	938	990	1,037	1,035	1,056	1,674	4.48
Brazil	593	508	469	456	538	782	842	1,254	1,358	1,000	4.30
Philippines	898	1,005	945	866	848	882	956	1,006	968	985	3.53
Nigeria	656	689	731	729	730	730	730	730	730	730	2.61
Egypt	203	231	223	287	299	325	287	319	375	380	1.28
Others	3,248	3,230	3,347	3,656	3,597	3,731	4,001	4,327	4,242	4,308	15.34
World Total	**22,733**	**23,773**	**22,584**	**22,584**	**24,730**	**24,973**	**26,634**	**27,609**	**27,822**	**28,508**	**100.00**
Source: FAOSTAT 2007.											

India is the largest producer of mangoes, accounting for 38.6% of world production from 2003 to 2005. During that period, India's mango crop averaged 10.79 million metric tons, followed by China and Thailand at 3.61 million metric tons (12.9%) and 1.73 million metric tons (6.2%), respectively. Other leading mango producers during the 2003 to 2005 period included Mexico (5.5%), Indonesia (5.3%), Pakistan (4.5%), Brazil (4.3%), and Philippines (3.5%) (FAOSTAT, 2007).

In Africa, mango has become domesticated due to germinating discarded seeds in the wild in most areas. Many African mangoes, because they are produced from seedlings, bear fruits that are strongly flavoured and fibroid. Fruits are seasonal and are consumed locally with a small quantity being exported. Where high-quality improved cultivars are grown, some exportation, primarily to Europe, does occur. Many African exporting countries include Kenya, Malagasy, Mali, Senegal, Congo, Burkina Faso, Cote D'Ivoire and the Southern African countries (Rice *et al*., 1987).

Although currently only 3% of the world production of mango is traded globally, it still represents a noticeable increase over the quantities traded 20 years ago. In terms of distribution, Mexico, Brazil, Peru, Ecuador, and Haiti supply the majority of mango imports to the North American market. India and Pakistan are the predominant suppliers to the West Asian market. The Philippines and Thailand supply most of the Southeast Asian market. The European Union mainly buys mangoes from South America and Asia (Evans, 2009). In 2005, world exports of mangoes reached 912,853 metric tons, totaling US $543.10 million (FAOSTAT 2007). For the 2003 to 2005 period, Mexico and India dominated the export trade with shares of 22.6% and 20.3%, respectively, followed by Brazil (13.2%) and Pakistan (6.9%). Other major exporters (Table 2.3) include the Netherlands (major re-exporter), Peru, Ecuador, the Philippines, Thailand, and China.

Table 2.4 World's top 10 mango exporting countries, 1996–2005

Countries	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2003–2005
	(1,000 metric tons)										(%)
Mexico	148	187	209	204	207	195	195	216	213	195	22.64
India	27	45	47	38	39	46	42	179	156	223	20.25
Brazil	24	23	39	54	67	94	104	138	111	114	13.18
Pakistan	18	25	39	41	48	52	48	60	82	49	6.94
Netherlands	21	25	17	37	34	43	33	58	51	69	6.42
Peru	11	6	11	20	21	27	35	40	60	58	5.71
Ecuador	0	2	7	0	26	34	30	38	41	40	4.31
Philippines	40	45	53	35	40	39	36	38	36	25	3.61
Thailand	8	9	10	10	9	11	9	8	33	2	1.55
China	12	7	9	10	5	5	15	22	10	4	1.31
Others	80	104	87	103	132	121	127	126	127	135	14.08
World Total	**391**	**478**	**529**	**552**	**628**	**666**	**673**	**923**	**920**	**913**	**100.00**
Source: FAOSTAT, 2007											

World imports of mangoes increased from 397,623 metric tons in 1996 to 826,584 metric tons in 2005. As the number one importer of mangoes during the 2003 to 2005 period, the United States imported 271,848 metric tons, or approximately one-third of total mango imports accounting for 32.7% of the total imports during the same period (FAOSTAT 2007).

The Netherlands within the same period imported 88,300 metric tons of mangoes (10.6%), but most of this was redistributed throughout the European Union. Other major importing redistributors of mangoes are the United Arab Emirates (6.8%) and

Saudi Arabia (5.3%), with most of these imports being redistributed within the Middle East. Mango imports to China have been declining due to increased domestic production. For example, China imported 57 metric tons in 2004 and only 19 metric tons in 2005. Other noticeable importers (Table 2.4) include Bangladesh and the United Kingdom (4.6% each), Germany (4.1%), France (4.1%), and Malaysia (3.6%) (Evans, 2009).

Table 2. 4 World's top 10 mango importing countries, 1996–2005

Countries	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2003–2005**
	(1,000 metric tons)										(%)
United States	171	187	197	219	235	238	263	278	276	261	32.70
Netherlands	25	34	35	63	62	70	71	91	76	98	10.62
United Arab Emirates	28	37	48	48	42	46	52	62	58	51	6.82
Saudi Arabia	10	16	14	9	28	36	35	40	42	51	5.32
China	36	40	47	33	33	34	38	47	57	19	4.91
Bangladesh	5	9	0	11	21	21	14	43	37	36	4.63
United Kingdom	16	18	18	23	22	27	24	32	37	47	4.63
Germany	13	17	17	24	23	25	28	32	33	37	4.11
France	18	23	22	31	26	26	27	32	35	35	4.09
Malaysia	14	6	21	1	20	27	31	26	45	19	3.59
Others	61	68	66	84	114	106	101	142	148	173	18.58
World Total	398	454	486	545	628	656	684	825	843	827	100.00

Source: FAOSTAT 2007.

The most popular export mango cultivars continue to be Kent, Tommy Atkins, Haden, and Keitt, which have fruits with a red blush, and are less fibrous, firmer, and more suited for long-distance transportation than other types of cultivars (Sauco, 2004). The green cultivars, such as Ataulfo and Amelie, are only now being widely accepted in the international market. Other cultivars gaining popularity in the international market include Alphona, Dudhpeda, Kesar, Sindhu, Pairi, Desi, Chaunsa, Langra, and Katchamita. Most of the newer cultivars are coming from India and Pakistan (Evans, 2009).

Over the last decade, prices for most mango varieties have decreased by about 5% as the fruit becomes more available worldwide, but prices could increase with proper promotional efforts (Evans, 2009).There is evidence that the processed mango fruit market is increasing (Sauco 2004). Processed fruit products include mango juice, pickled mangoes, mango chutney, mango pulp, mango paste, mango puree, dried mango fruit, mango slices in brine, and mango flour. India is the main exporter of processed mangoes, followed by Pakistan, Brazil, and Zimbabwe. Major importers include the United Arab Emirates, Saudi Arab, Kuwait, the United States, the United Kingdom, and Canada (Evans, 2009).

2.2.3 Commercial mango production in Ghana

Mango is not indigenous to Ghana but is very popular and a known tree crop throughout the country now. It used to be a smallholder crop mostly produced on subsistence level but now it has gained recognition as a major horticultural export crop. It thrives well mostly in the northern savanna regions, transitional zone in the Ejura (Ashanti region), Kintampo and Wenchi districts of the Brong Ahafo Region, Hohoe and Kpando Districts in the Volta Region and the coastal savanna or the Accra

Plains (Dangme East and West, South Tongu, Yilo and Manya Krobo districts). Some mangoes can be produced in the forest zones but qualitatively they do not meet the export standards. From a very modest beginning, engineered by Ghana Export Promotion Council (GEPC) identified a niche in mango cultivation as far back in the nineties. A USAID's sponsored food security programme supported the dissemination of planting materials in the south, which afforded Ghanaian farmers opportunity to have grafted varieties for commercial mango farming (Adongo, 2006).

Since the creation of this awareness, mango production has been rapidly gaining grounds for domestic consumption, processing and export markets. It is estimated that about 6,937 acres of land are planted to mango in Ghana with 5,637 acres representing 81.3% of the total acreage, planted to various varieties in the Southern part of Ghana (MOFA, 2010). Production of mango in Ghana has increased over the years from about 1,200 metric tonnes (mt) in 2006 to about 2,000 mt in 2007 (GEPC, 2007). Mango production in the Northern savanna Zone is fast expanding due to the support provided by the Integrated Tamale Fruit Company (ITFC), an NGO which is promoting organic production of the crop for poverty alleviation and improved rural livelihood among farmers in this zone. The demand for Ghana's mango far exceeds the supply currently as both exporters and processors travel to the neighboring countries such as Burkina Faso and Togo in search of mango fruits.

2.2.4 Importance of mango in Ghana

Mango fruits are mostly eaten fresh but in the last few years, some are now being processed into juice and other products. Initially, it used to be grown for domestic market but has now become an important source of income and foreign exchange for most African countries including Ghana. Improvement in fruit productivity and quality will also enhance food safety and security, employment opportunities and the

national economy at large. It is being advocated that value addition to the fruits as concentrate, juice and pulp would go a long way to increase the value of fresh fruits in stock and also create much needed employment for the teeming youth in the production areas.

2.2.5 Constraints to mango production in Ghana

The major constraints are not limited only to mango production, but all commercial fruits being produced in Ghana. These must bottlenecks such as arthropod pests and diseases, lack of storage facilities; quality packaging and pack houses; limited choice of mango varieties suitable for export; lack of certified regulated nurseries, unavailability of well structured marketing channels, non adoption of agronomic practices, unfavourable weather conditions and others. Out of these, pests and diseases have been reported to be the main production constraints. Fruit flies, mango stone weevil and anthracnose have been recognized as very destructive. These barriers must be surmounted if Ghana is to penetrate into the highly lucrative international mango markets.

2.3 Grades and standards

Satisfying customers underpins quality assurance which aims to produce a product of the desired standard, encouraging regular, larger and more frequent purchases, and brand. There are various standards that have been established for appearance and quality of fruit on the international market (Mukherjee, 1997). As export markets become increasingly competitive, responsive quality assurance can be the vital strategy for maintaining and expanding market niche (Johnson and Coates, 1991; Askar and Treptow, 1993; Lindror and Prussia, 1993; Bunt and Piccone, 1994). Currently, the mango export market is based for the most part upon ‘Keitt’, ‘Kent’,‘Haden’and ‘Tommy Atkins’(Mukherjee, 1997). According to United Nations

ECE Standard FFV-45, mango fruit should be intact, firm, fresh in appearance, sound (produce affected by rotting or deterioration which make it unfit for consumption is excluded), clean, practically free from any visible foreign matter, free from black stains or trails that extend under the skin, free from marked bruising, practically free from pests, free from damage caused by low temperature, free from abnormal external moisture, free of any foreign smell and taste. The UN/ECE mango standards categorise mangoes into three classes:

i. Extra class for mangoes of superior quality and free of defects;
ii. Class I mangoes are good quality, with slight defects of skin and shape; and
iii. Class II mangoes that do not qualify for inclusion in the higher classes, but satisfy the minimum requirements.

Mangoes shipped to the crucial USA and Japanese markets from areas with Mediterranean fruit fly infestations must be vapour heat treated prior to shipping (Mukherjee, 1997).

2.4 Major insect pests of mango

Mango, like most fruit tree crops, is usually attacked by two or three key pests, several secondary pests and a large number of occasional pests in localised areas where it is grown (Pena and Mohyuddin, 1997). Worldwide lists of pests of mango have been published by Laroussilhe (1980), Tandom and Verghese (1985) and Veerish (1989). 260 species of insect and mites have been recorded as minor and major pests of mango, of which 87 are fruit feeders, 127 are foliage feeders, 36 feed on the inflorescence, 33 inhabit buds, and 25 feed on branches and the trunk (Pena and Mohyuddin, 1997). Obeng-Ofori, (2007) confirms that the key insect pests of mango are fruit flies, seed weevils, tree borers and mango hoppers but added Thrips (*Selenothrips rubrocintus*) Giard (Thysanoptera: Thripidae), mango mealybug

(*Rastrococcus invadens*) William (Hemiptera:Pseudococcidae), Black ants (*Crematogasteri* spp.), Sucking bugs (*Anoplocnemis curvipes)* (F.) (Hemiptera: Coreidae) and Spiraling white flies *Aleurodicus dispersues* Russel (Hemiptera:Aleyrodidae), as some arthropod pest species of mangoes in West Africa. With current world emphasis on quality fruit for local consumption and export, insect pests that blemish fruit by feeding, scratching or ovipositing in the pulp or seed can cause high losses.

2.4 Fruit flies

Fruit flies (Diptera: Tephritidae) are among the most economically important groups of insects in the Afro-Tropical Region. They cause millions of dollars of damage to fruits and vegetables, and are a major constraint to commercial and subsistence farming in the region (De Meyer and White, 2004). Fruit flies cause both direct and indirect losses. Direct damage is mainly caused by the oviposition punctures made by the females in the fruit skin when laying eggs. White and Elson-Harris (1992), revised the taxonomy of fruit flies, reported that 48 species of fruit flies attack mango. Various species of fruit fly cause damage to fruit and other plant crops. In order to distinguish them from the Drosophilidae, the Tephritidae are sometimes called peacock flies, in reference to their elaborate and colourful markings.

In recent times, a new invasive species of fruit fly *Bactrocera invadens* Drew, Tsuruta and White (Diptera: Tephritidae) is the most damaging species all over Africa (ICIPE, 2007). In 2003, the *B. invadens* originating from Asia was detected in Kenya and was reported to be spreading across tropical Africa (Lux *et al.*, 2003). This pest has since been detected in Tanzania (Mwatawala *et al.*, 2004), Benin (Vasssieres *et al.*, 2005) and Ghana (Billah *et al.*, 2005). Prior to the invasion of Sub-Sahara Africa by *B.*

invadens, the major pest of mango was *C. cosyra* (Walker) whose average damage ranged from 20-30% (Lux *et al.*, 2003).

2.4.1 Classification of fruit flies

Fruit flies belong to the order Diptera and family Tephritidae. Globally, Lux *et al.* (2003) indicated that 4,257 fly species are known and about 1,400 species develop in fruits. Out of these, White and Elson-Harris (1992); Thompson, (1998) reported that about 250 species already are, or may become pests by inflicting severe damage to fruits of economic value. In Equatorial Africa, there are about 915 species from 148 genera, out of which 299 species develop in either wild or cultivated fruits (Lux *et al.*, 2003). They belong mainly to four genera which are *Dacus, Ceratitis, Trirhithrum and Bactrocera* (White and Elson-Harris, 1992; Thompson, 1998). Currently, the major species which have invaded the African continent are the Melon fly, *B. cucurbitae* (Coquillet), the African invader fly; *B. invadens*, the Peach fruit fly; *B. zonata* (Saunders) and *B. latifrons* (Hendel) (Ekesi and Billah, 2009).

2.4.2 General biology and life cycle of fruit flies

Fruit flies are holometabolous thus they undergo complete metamorphosis. Adult flies become sexually matured 4-10 days after emergence. Mating begins when they become sexually matured. Soon after mating, the female fruit flies insert white banana-shaped eggs beneath the skin of the fruit using the ovipositor to pierce to the depth of about 2-5 mm (Ekesi and Billah, 2009). Depending on the species, eggs are laid in clusters of 3-8 on mature green and ripening fruits. Some species may even lay eggs in fruitlets. Eggs hatch within 3-12 days depending on the environmental conditions (especially temperature) into tiny whitish maggots which bore into the pulp tissue and make the feeding galleries (Figure 2.1**).** The fruit subsequently rots or becomes distorted. The young larvae leave the necrotic region and move to healthy

tissue, where they often introduce various pathogens and hasten fruit decomposition. When the infested fruit is immature, the fruit ripens prematurely and is unfit for marketing. The larvae when fully grown, measures about 7-8 mm and drops to the ground (under the tree) and enter the soil where they pupate. The puparia which are brown or black and 4-12mm long are buried 2-5 cm beneath the soil of the host plants. The pupal stage can last from 10-20 days depending on climatic conditions. Winged adults emerge and infest the fruits again where the females require a protein source for egg maturation (Pena and Mohyuddin, 1997).

Fig. 2.1. Generalised life cycle of Tephritid fruit flies (Source: Ekesi & Billah, 2009)

2.4.3 Economic importance of fruit flies

The economic importance of fruit flies in any fruit and vegetable production systems has been in focus for a very long time. The economic impact of fruit flies includes not

only the direct losses of yield and increased cost of production, but also the losses of export markets and/or additional expenditures incurred on construction and maintenance of fruit treatment and eradication emanating from strict quarantine regulations imposed by the importing countries (APHIS, 1988). Nearly 250 fruit fly species are of economic importance and are distributed widely in temperate, sub-tropical and tropical regions of the world (Christenson and Foote, 1960). Fruits and vegetables are the most important crops attacked, including mango, citrus, guava, apples, tomatoes, cucurbits and many others, and seed crops such as sunflower and safflower are also affected (Ekesi and Billah, 2006). Lux *et al.* (2003) indicated that out of 1.9 million tonnes of mangoes produced in Africa annually, about 40% is lost due to fruit flies. Infestation rates, however, vary among countries and seasons ranging from 5% to 100%. Syed *et al.* (1970a) reported that up to 30% of mango fruits were attacked by *B. dorsalis* in July and August. Mohyuddin and Mahmood (1993) reported that mango fruits are attacked in central Punjab in July peaking in August when 35% of the fruits were damaged by *B. dorsalis* and *B. zonata.* In Pakistan, Stonehouse *et al.* (1998) estimated the annual farm-level losses due to fruit flies to be US$ 200 million. During the 2006 crop year in Benin, Vayssieres *et al.* (2009) estimated losses at17% in early April and exceeded 70% in mid-June and by the middle of the crop year, over 50% losses occurred in mango orchards. In Ghana, the current estimate of fruit fly abundance is not available. However, the flies are reported to cause 44-100% fruit damage in citrus plantations in Eastern region when not controlled (Afreh-Nuamah, 1985; 2007 and Akosten-Mensah, 1999).

In recent times, the new invasive species of the fruit fly (*Bactrocera invadens*) Drew, Tsuruta and White is the most damaging species all over Africa (ICIPE, 2007).

Although fruit flies are commonly thought of as pests, some species are valuable agents for the biological control of weeds (White and Elson-Harris, 1992). Most species that have been used or tested for biological control belong to the subfamily Tephritinae and attack plants of the family Asteraceae. A comprehensive list of these species has been provided by (White and Elson-Harris, 1992).

2.4.4 Important fruit flies of mango

The African Fruit Fly Initiative (AFFI) (2007) in East Africa maintained that heavy losses are incurred by both the farmers and the exporters whose mango shipments with these quarantine pests are intercepted and destroyed at the entry points in the European markets. This necessitated AFFI to initiate programmes to drastically reduce the infestation of the pests on their hosts in the producing countries. In view of this development, Vayssieres *et al.* (2005) studied the various mango infesting fruit flies in Benin and revealed that four species are of major economic importance in the mango orchard. This was confirmed by Ekesi and Billah (2006) and Obeng-Ofori (2007) and listed the major fruit fly species that are likely to attack mango in the sub-region (Table 2.5).

Table 2. 5 Important fruit flies of mango

Name of species	Country
Bactrocera invadens Drew, Tsuruta and White	Benin, Nigeria, Mali, Sierra Leone, Ghana, Guinea, Senegal
Ceratitis cosyra (Walker)	Benin, Cote d'Ivoire, Nigeria, Mali, Sierra, Ghana
C. quinaria (Bezzi)	Guinea, Togo, Benin
C. silvestrii Bezzi	Benin, Ghana, Mali, Nigeria, Cote d'Ivoire, Guinea
C. fasciventris Bezzi	Benin, Ghana, Cote d'Ivoire, Guinea, Togo
C. anonae Graham	Benin, Ghana, Cote d'Ivoire, Guinea, Togo
C. capitata (Wiedemann)	Benin, Ghana, Cote d'Ivoire, Guinea, Togo
C. ditissima (Munro)	Benin, Ghana, Cote d'Ivoire
C. punctata (Wiedemann)	Benin, Ghana, Nigeria, Cote d'Ivoire, Guinea, Togo, Liberia, Senegal, Burkina Faso, Niger,
C. rosa Karsch	Mali, Nigeria

Source: (Vayssieres *et al.*, 2005; Ekesi and Billah, 2006; Obeng-Ofori, 2007)

2.4.5 Status of fruit fly management in Africa

Management of fruit flies in Africa is problematic. This stems from the fact that farms vary considerably in size and seldom grouped into uniform production blocks. These production units are scattered among areas with wild and abandoned trees that serve as breeding sites for a host of pests including fruit flies. The rare attempts to manage fruit flies are usually based on blanket pesticide sprays which are mostly not approved for use on the crop. Most farmers make concoctions of more than one pesticide products in desperation to totally control fruit flies. The approach yielded no fruitful results due to lack of basic knowledge about fruit flies biology and management strategies (Lux *et al.,* 2003). The current level of development of fruit production, especially its low productivity, fragmentation and general technological simplicity, greatly limits the options for economically sound fruit fly management (Lux *et al.,* 2003).

2.5 Management of fruit flies

Fruit flies can be managed through two- tier strategies. These are integrated and eradication approaches. The integrated approach deals with controlling fruit fly populations in order to reduce yield losses and the eradication approach on the other hand aids in eliminating fruit flies through an area-wide action in order to create certified 'fruit fly-free' zones (Lux *et al.,* 2003). The integrated approach combines many compatible methods to achieve its objective. The components of this strategy include regulatory control, cultural and sanitation methods, chemical control, biological control, mechanical protection, male suppression, early warning systems, field monitoring and host-plant resistance (Ekesi and Billah, 2006; Ekesi and Billah, 2009). This can individually be practiced by farmers.

2.5.1 The integrated approach

This strategy is also referred to as the Integrated Pest Management (IPM) approach. It combines many compatible methods for growing healthy crop and also protects the environment. Vargas *et al.* (2010) indicates that the use of single techniques to reduce or eradicate fruit flies from an area where they are well established has proven insufficient in many cases, and consequently, most successful programmes have resorted to the use of multiple suppression techniques.

2.5.2 Regulatory/ Quarantine control

This is a pest control strategy established by an act of parliament or has legal backing of a country. Import and export laws have to be enacted to establish standards for a wide range of agricultural products. It seeks to establish a network of inspection stations at major ports of entry and gives authority to organise border quarantines, to inspect all agricultural products, and to restrict entry of any infested goods. The import and export of infested plant material without post-harvest treatment, from one area or country to other non-infested place, according to Dhillon *et al.* (2005) is the major mode of the spread of insect pests. The spread can be blocked or prevented through tight quarantine and treatment of fruits at the import and export ports. Most of the fruits and vegetables imported or exported for example, must receive some form of fumigation, heat treatment, cold treatments, insecticidal dipping, controlled atmosphere storage, or radiation exposure (Collin *et al.*, 2007) before they are released from quarantine. Armstrong *et al.* (1995) suggested that cold treatment (1.1± 0.6 ºC) for 12 days disinfested Hawaiian starfruit, *Averrhoa carambola* of tephritid eggs and larvae. Import controls carried out in airports in France since1993 on tropical fruits have revealed the presence of 12 non-European and one European species of Tephritidae, (Bayart *et al.*, 1997). These post-harvest treatments are

designed to kill whatever pest species may be present without affecting taste or quality of the produce.

2.5.3 Cultural control and sanitation methods

Field activities that are performed as part of the normal production system in order to produce quality and healthy fruits also help to reduce insect pest populations in the orchards. Poorly managed or abandoned orchards can result in buildup of fruit fly populations. Fruits that have fallen either prematurely or dropped due to infestation are regularly collected (twice a week for the entire season) under the trees. These fruits are buried in pits (0.46cm) (Klungness *et al.,* 2005) which are dug and later covered with earth to prevent the larvae in these fruits from pupating in the soil.

On the other hand, these fruits are collected in black polythene bags and are left in the sun for a few days for the larvae in the fruits to be killed by the heat generated within the bags. This helps to break the reproduction cycle and population increase (Dhillon *et al.,* 2005). Early harvesting and general orchard sanitation helps to evade fruit fly infestation in the production of fruits (Ekesi and Lux, 2006). Early harvesting according to Ekesi and Lux (2006), is not effective in mango as some fruit fly species like *B. invadens* and *C. cosyra* are capable of infesting even immature or mature green mangoes.

2.5.4 Chemical control

Until recently, in order for pest control in mango orchards to achieve good yields with top quality fruits, mango growers relied on regular pesticide applications. This led to increased costs, the reduction of natural predator and parasitoid populations that helped to control the insect pests, increased pest resistance to insecticides, pesticide residues in the fruits and environmental pollution. Chemical control of fruit fly is

relatively ineffective (Dhillon, *et al.*, 2005). However, insecticides such as malathion, dichlorvos, phosphamidon and endosulfan are moderately effective against fruit fly (Agarwal *et al.*, 1987). In a study of chemical alternatives to malathion for the control of *C. capitata* in Spanish citrus orchards, Urbaneje *et al.*, (2009) obtained high Mediterrean fruit fly mortalities. Lambda-cyhalothrin, however, caused the lowest mortality and showed novel disabling effects on surviving Mediterrean fruit fly adults. The oriental fruit fly, for example, has been shown in laboratory studies to develop resistance and cross-resistance to carbamate, organophosphorus, and pyrethroid insecticides (Hsu *et al*., 2004; Hsu and Feng, 2006). In 2002, resistance to organophosphate treatments was also documented in field populations of fruit fly in Taiwan (Hsu and Feng, 2002). In some cases, overuse of insecticides resulted in resurgence of other pest population. Russell (1999) also cautions that most pesticides are more toxic to parasites and other beneficial fruit flies.

2.5.5 Bait spraying

The risk posed by malathion to humans and other vertebrates has been extensively studied (Environmental Protection Agency, 2000) in the United States and showed that the potential impact of large-scale applications of malathion on the structure of insect communities is less well understood. For example, malathion is an active ingredient in bait sprays applied for control or eradication of tephritid fruit flies, like the Mediterranean fruit fly (medfly), *C. capitata* (Environmental Protection Agency, 1998). During the 1998 medfly eradication programme in Florida, malathion was used, combined with the corn protein hydrolysate bait, Nu-Lure®. This mixture was applied at a rate of 2.4 fluid ounces malathion and 9.6 fluid ounces Nu-Lure® per acre every 7-10 days in regions where med fly was detected (Michaud, 2003). During this

programme, many beneficial insects, particularly parasitoids, were shown to be more susceptible to malathion than fruit flies (Purcell *et al*., 1994).

Another application for malathion-based fruit fly baits is in citrus production which enables farmers to comply with the "Caribbean Fruit Fly-Free Protocol" for fresh fruit export certification in Florida (Florida Division of Plant Industry, 2002).

The potential for development of fruit fly resistance to malathion in response to broadcast sprays over large areas, such as has been observed for the oriental fruit fly, *B. dorsalis* (Hendel) in Taiwan (Hsu and Feng, 2000) is a further impetus for seeking bait sprays with alternative active ingredients. A bait spray consists of protein bait mixed with suitable insecticide. Fruit flies (both males and females) are attracted to the hydrolysed protein as ammonia emanates from this source (Ekesi and Billah (2006). For these fly species, protein baits (those with hydrolysed proteins, which consist of amino acids or peptides) have some attractiveness, but the attractiveness of and feeding propensity on various baits differ (Moreno and Mangan, 1995; Fabre *et al*., 2003; Vargas *et al.*, 2003; Vargas and Prokopy, 2006), and feeding responses to baits among species also vary (Barry *et al.*, 2006, Vargas and Prokopy, 2006). Bait sprays have also been tested against temperate *Rhagoletis* (Diptera: Tephritidae) flies. The effectiveness of this reduced-risk insecticidal bait against tephritid flies in Hawaii has been recently demonstrated by Peck and McQuate, (2000), Vargas *et al*. (2001), McQuate *et al*. (2005a, 2005b), Prokopy *et al.* (2003, 2004), Jang *et al*. (2008), and Piñero *et al*. (2009, 2010). Consequently, foliar applications of this product may spare predatory or parasitic insects that do not consume leaves or other plant parts.

2.5.6 GF-120

GF-120 bait is a combination attractant, feeding stimulant, and spinosad insecticide for control of fruit fly (Tephritidae) populations. The bait was formulated to attract multiple fruit fly species and to use the minimum concentration of an environmentally compatible toxicant for ultra-low volume (2–4 l/ha) application. Spinosad is a combination of spinosyn compounds that are purified from the soil actinomycete, *Saccharopolyspora spinosa* Mertz (Thompson *et al*., 2000). It was discovered and developed for use as a foliar spray and as an insect control product over a 17-year period from 1984 to 2001 by which time it had been registered in 50 countries on over 250 crops (Dow AgroSciences, 2001). The bait is referred to as Solbait and is based on Solulys, a spray-dried enzymatically hydrolysed protein that is produced from the industrial processing of corn for recovery of sugars and oil. Other additives including feeding stimulants, adjuvants, auxiliary attractants and conditioners are described in Moreno and Mangan (2002). GF-120 includes further proprietary refinements that improve the overall effectiveness.

A historic review of the development and basic chemical characteristics of spinosad is given in Thompson *et al*. (2000).The bait is marketed as a concentrate that is diluted in the field with water. It attracts the flies, induces them to feed on the drops, and are killed by stomach poison (Mangan *et al*., 2006). The GF-120 formula is registered as organic by US Department of Agriculture and international organic registries (Organic Materials Review Institute, 2002). GF-120 has been shown to have no effect on honey bees in field applications (Rendon *et al.*, 2000). Experimental evidence has also shown that GF-120 has minimal or no effect on non-target beneficial insects (Burns *et al.*, 2001; Vargas *et al*., 2001; Michaud, 2003), while the Malathion-NuLure bait has been shown to have negative impacts on beneficial and pollinating insects in

treated zones (Harris *et al.*, 1980; Troetschler, 1983; Hoelmer and Dahlsten, 1993). Additional advantages of the GF-120 compared to malathion baits are that no protective cover-all clothing is required for applicators and post-spray re-entry periods are only 4 h (Specimen Label GF120 Naturalyte, 2003) compared to a minimum of 12 h for Malathion. Fruit flies are managed in many areas using GF-120 (Yee, 2007). It can be used on backyard and abandoned trees, which are usually infested and are potential sources of flies in managed orchards. According to Yee and Chapman (2005), GF-120 was used to suppress larval populations when sprayed on single trees. Further, they asserted that GF-120 is the only bait that has been tested for its effects on both attracted responses and control of fruit flies. The spinosad-containing bait has proven effectiveness against *B. cucurbitae* (Jang *et al.*, 2008), *C capitata* (Vargas *et al.*, 2010), and *B. dorsalis* (Piñero *et al.*, 2009a) and consequently has become the primary tool for area-wide suppression of tephritid fruit flies in the Hawaiian Islands (Vargas *et al.*, 2008). Factors such as rainfall (Piñero *et al.*, 2009a) and phytotoxicity (DeLury *et al.*, 2009) may influence the efficacy or utility of foliar applications of insecticidal baits.

2.5.7 Waste Brewers' Yeast

Brewers' spent grain (BSG) is the insoluble residue of barley malt resulting from the manufacture of wort/beer. Although it is the main by-product of the brewing industry, it has received little attention as a marketable commodity and is mainly used as animal feed. Chang (2009) tested several yeasts and yeast products in adult diets for medfly, *C. capitata* (Wiedemann), oriental fruit fly *B. dorsalis* (Hendel), and melon fly *B. cucurbitae* (Coquillett) and in larval liquid diet for mass-rearing *B. dorsalis.* Brewer's yeast, *Saccharomcyes cerevisiae*, and Torula yeast, *Candida utilis* are the two most commonly used yeasts in mass rearing fruit flies (Chang, 2009).

Brewers' yeasts contain all the essential microbial growth factors for both fruit flies such as high level of amino nitrogen, peptides, vitamins and minerals and are economical and good alternatives used for many types of fermentations including cultures and bioremediation (Chang, 2009). The WBY is reported to be rich in proteins, amino acids, water-soluble vitamins (B-complex vitamins). The B-complex vitamins in brewer's yeast include B1 (thiamine), B2 (riboflavin), B3 (niacin), B5 (pantothenic acid), B6 (pyridoxine), B9 (folic acid), and H or B7 (biotin). These constituents are needed in the diet for development of fruit flies and can also serve as source of food. Anghel (1991) also reported that it is a rich source of minerals**,** chromium**,** copper**,** zinc**,** and selenium. Chromium is an essential trace mineral that helps the body maintain normal blood sugar levels. In Malaysia, the protein source used in bait sprays is a yeast autolysate produced as a by-product of the brewing process in the production of stout. It is marketed under the name of 'Promar'. It has proven to be an excellent attractant for local species of fruit flies and does not cause phytotoxicity to plants (Vijaysegaran, 1989; Loke *et al*., 1992). In Australia, a formulation plant was established to convert yeast into autolysate which was used by the farmers to manage fruit flies (Lloyd and Drew, 1996). A similar plant was also reported to be established in 2001 in Vietnam and the product was registered under the trade name SOFRI Protein 10DD (yeast protein + fipronil insecticide). It also has excellent control of fruit flies in peaches, Barbados cherry, luffa and bitter gourd orchards which really enhanced income levels of the farmers.

2.5.8 Biological control

Following the establishment of the *C. capitata,* in other tropical regions, several explorations for its natural enemies were sought especially in Africa (Aboriginal home) of the pest in order to seek parasitoids which could effectively control the pest

in the invaded regions (Wharton, 1989). There is also considerable current interest in obtaining more effective parasitoids for biological control of fruit flies in the Neotropics (Messing *et al.*, 1996). Out of over 40 parasitoid species collected from Africa, only a few have so far been used to control *C. capitata* (Clausen *et al*., 1965; Wharton, 1989; Waterhouse and Sand, 2001). Table 2.6 shows the parasitoid species, their origin, where established and their host.

Exotic parasitoid species that were released for biological control of various Tephritidae and also recovered from *C. capitata* have been listed in Table 2.6 (Clausen *et al*., 1965; Wharton, 1989; Waterhouse and Sands, 2001). These include *Fopius arisanus* (Braconidae), *F. vandenboschi* (Braconidae), *Psyttalia incisi* (Braconidae) and *Diachasmimorpha tryoni (*Braconidae). More recently, a new parasitoid, *F. arisanus* has been included in the IPM programme of *B. cucurbitae* at Hawaii (Wood, 2001).

Table 2. 6 Parasitoids and their region of establishment

Family	Parasitoid species	Origin	Where established	Host
Braconidae	*Psyttalia concolor*	Tunisia	Mediterranean region	*Bactrocera oleae, Ceratitis capitata*
	Psyttalia humilis	South Africa	Hawaii, Bermuda	*C. capitata*
	Diachasmimorpha fullawayi	West Africa	Brazil, Hawaii, Fiji, Spain	*C. capitata*
Eulophidae	*Tetrastichus giffardianus*	West and South Africa	Hawaii, Brazil, Fiji, Spain	*C. capitata, Bactrocera* spp.
	Tetrastichus dacicida	Tanzania	Hawaii	*B. dorsalis, C. capitata*
Chalcididae	*Dirhinus giffardii*	Nigeria	Hawaii,	*B. dorsalis, C. capitata*
	Dirhinus anthracia	East and West Africa	Hawaii, Sri Lanka	*Bactrocera* spp, *C. capitata*
Diapriidae	*Coptera silvestrii*	West and South Africa	Hawaii	*C. capitata, C. anonae, C. giffardi, Trirhithrum nigerrimum*

Source: Clausen *et al*., 1965; Wharton, 1989; and Waterhouse and Sands, (2001)

Knipling (1992) observed that although a number of natural enemies have been tried in fruit fly biological control programmes outside Africa with some success, in most cases, the impact of the introduced parasitoids on *C. capitata* populations was rather limited. Recently, the potential of an inundative approach in the control of the Mediterranean fruit fly was successfully demonstrated on coffee in Hawaii (Vargas *et al.,* 2001). Several of these parasitoids according to reports proved capable of attacking the Mediterranean fruit fly larvae and hence were sent for further evaluation to the United States Department in Hawaii and Guatemala, and also to Republic of South Africa.

Parasitism in coffee fields by all parasitoid species combined as reported by Mohammed and Billah (2002) is over 50% at the peak of the season. However, for most of the year, parasitism rates were much lower, ranging from about 1% to 10%. This clearly indicates that the natural enemy populations of indigenous parasitoids, although capable of high parasitism rates at certain times during the year, are not able to suppress fruit fly population significantly. Parasitoids have a great potential for regulating the fruit fly populations. It has been reported that the use of these agents have been used successfully in the Central and South America; Australia; Hawaii; Fiji; Philippines, S. E. Asia, Costa Rica, etc.

2.5.9 Other Biological control agents

Other biological agents especially predators from the families Staphylinidae, Carabidae, Chrysopidae, Pentatomidae and several mite species are known to attack tephritids (Bateman, 1972). Marucci, (1955) studied the efficiency of two earwig species as predators on *B. dorsalis* (Hendel) in Hawaii. Ants were also reported to cause up to 38% mortality of *C. capitata* (Wong *et al.,* 1984). Similar groups of ants especially *Oecophilla longinoda* have also been reported as predators to the flies

(Ativor *et al.*, 2012). Poinar and Hislop (1981) also reported detection of Mediterranean fruit flies caused by the entomopathogenic nematodes *Neoaplectana* spp. (Rhabditida: Steinernematidae) and *Heterorhabditis* spp. (Rhabditida, Heterorhabditidae) in the laboratory. Beavers and Calkins (1984) showed that *Anastrepha ludens* (Loew) larvae were also susceptible to steinernematids and heterorhabditids. Lindegren *et al*., (1990) reported of field studies in Hawaii which exposed mature larvae of *C. capitata* to 500 infective juveniles cm^{-2} of *Steinernema feltiae* (Filipjev) in the soil resulting in 70% mortality of puparia.

In Bermuda, according to Clausen (1978) the lizard *Anolis graham* Gray (Sauria, Iguanidae) was introduced from Jamaica for the control of fruit flies, although its role in controlling the pest was not quantified. In addition, birds and rodents have also been reported to cause a high level of larval mortality by consuming infested fruits (Drew, 1987).

2.5.9.1 Pathogens

One of the first observations of a pathogen attacking fruit flies was made by Fujii and Tamashiro (1972), who reported an infection by the protozoan pathogen, *Nosema tephritidae* (Microspora, Nosematidae) on *B. Dorsalis* and *C. capitata* in Hawaii. Several isolates of *Bacillus thuringiensis* (Berliner) have also been evaluated in the laboratory and in the field against larvae of *B. oleae* (Gmelin) and adults of *A. ludens* (Robacker *et al*., 1996). Recently, the use of entomopathogenic fungi has received increasing attention, both in Europe and in the Americas (Castillo *et al*., 2001, Ekesi *et al*., 2002). Even though fungal pathogens are capable of controlling some species of fruit flies, Lux *et al*., (2003) suggested that they should be integrated with other IPM control tactics such as baiting, field sanitation and conservation of natural enemies.

2.5.10 Mechanical fruit protection

Individual fruits can be wrapped or bagged in newspaper or paper bags to prevent adult flies from laying eggs on the fruits. Bagging of fruits on the tree (3 to 4 cm long) with 2 layers of paper bags at 2 to 3 day intervals minimises fruit fly infestation and increases the returns from 40 to 58% (Fang, 1989a, b; Jaiswal *et al*., 1997). Ekesi and Billah (2006) asserted that bagging could be done at least a month before harvest. It is an effective method for the production of high valued fruits but can be laborious.

2.5.11 Male suppression

The use of chemicals, particularly male lures or parapheromones (Sivinski and Calkins 1986; Cunningham, 1989), to manipulate behavior for management purposes has been well-documented for fruit flies in the genus *Bactrocera*, most notably *B. dorsalis*. Methyl eugenol is widely used to detect incipient infestations of *B. dorsalis* (Chambers *et al*., 1974; Jang and Light, 1996). In addition, when mixed with a toxicant, methyl eugenol was used to eradicate island populations of this species in a procedure termed "male annihilation" (Steiner *et al*.1965, 1970). Although not frequently used against *B. dorsalis*, the sterile insect technique may be implemented in instances where male annihilation alone is ineffective or where environmental concerns preclude widespread use of methyl eugenol, which may attract non-target species and pose a threat to native insect populations (Dhillon, *et al.*, 2005).

Methyl eugenol has been shown to function as a precursor for the male sex pheromone in *B. dorsalis* (Nishida *et al.*, 1988, 1997).

2.5.12 Field monitoring and control with parapheromone lures

Monitoring of fruit flies in the field is very important in its management. It is done purposely for identification and the trends of population dynamics of fruit fly species.

This normally involves the use of high density of bait solutions consisting of a male lure combined with an insecticide as killing agent (usually malathion, and more recently fipronyl) to reduce the population of male fruit flies to such a low level that mating does not occur. This approach has been successfully used to control several species in Egypt, Rota Island and Japan. For example, cotton wool, pieces of wood and coconut husk blocks impregnated with methyl eugenol and malathion in plastic bottles are used by farmers in Ghana.

There are two main types of attractant used in fruit fly monitoring. These are para-pheromones or male lures and food baits. The lures can either be in liquid form, as well as polymeric plugs. Depending on the type, Ekesi and Billah, (2006) indicated that the lure may last for six weeks. The Para-pheromones attract and kill only male flies so that unmated females do not reproduce (Cunningham, 1989). The flies are attracted from relatively short distance; these monitoring traps are expected to represent a good estimate of populations present in the vicinity.

Dhillon, *et al.,* (2005) indicated that there is positive correlation between lure trap catches and weather conditions such as minimum temperature, rainfall and minimum humidity. Pawar *et al*., (1991), showed that the sex attractant lure traps are more effective than the food attractant tephritlures for monitoring the *B. cucurbitae.* A number of commercially produced attractants are available on the market, and have been found to be effective in controlling fruit fly species (Iwaizumi *et al*., 1991). Although, the protein baits, parapheromone lures, cue-lures and baited traps have been successful for the monitoring and control, the risk is the immigration of protein satiated females (Dhillon, *et al.,* 2005). Stonehouse *et al.,* (2004) suggested that this could be managed by increasing the distance these satiated immigrants must travel.

2.5.1.3 Host- plant resistance

Host plant resistance is an important component in integrated pest management programmes. This does not cause any adverse effects to the environment, and no extra cost is incurred to the farmers. Unfortunately success in developing high yielding and fruit fly resistant varieties have been limited (Dhillon, *et al.,* 2005). Insects may prefer one host to another for its suitability as a source of food, oviposition site and developmental site. Friend (1958) observed that host preferences in certain insect species were affected by the presence and/or absence of chemical compounds in their plant host. Dent (1991) reported that some plants may reduce growth, inhibit reproduction, alter physiology, delay maturation and induce various physical or behavioural abnormalities in phytophagous insects.

2.6. Eradication Approach

Eradication is conducted on an area-wide basis and has been described as the elimination of all individuals of species from a geographic area where reinvasion is likely to occur (Myers *et al.,* 1998). This approach deals with eliminating fruit flies to create certified 'fruit fly-free' zones. It is very costly and only justified when a highly productive industry is threatened. Eradication methods where blanket application of pesticides has been advocated might not be environmentally suitable since pollution of water bodies and non-target organisms may be affected. Methods such as the wide area management, sterile insect technique (SIT) or male annihilation technique (MAT) and Transgene based, embryo-specific lethality system are employed under this approach.

2.6.1 Area-wide management

An area-wide insect control programme is a long-term campaign against an insect pest population throughout its entire range with the objective of reducing the pest

population to non-economic status (Lindquist, 2000). The importance of area-wide integrated pest management for suppression and/or eradication of tephritid flies has been documented by Koyama *et al.,* (2004); Dhillon *et al.,* (2005); Mau *et al.,* (2007); Vargas *et al.,* (2007; 2008); and Jang *et al.,* (2008). The aim of wide area management is to coordinate and combine different characteristics of an insect eradication programme over an entire area within a defensible perimeter and the area must be subsequently protected against reinvasion through quarantine controls (Dhillon, *et al.,* 2005). It has been proven to be economically viable, environmentally sensitive, sustainable and has suppressed fruit flies below economic thresholds with the minimum use of organophosphate and carbamate insecticides (Wood, 2001). Vargas (2004) estimated that the programme reduced fruit fly infestation from 30 to 40% to less than 5% and reduced organophosphate pesticide use by 75 to 90%. The wide area management needs more sophiscated and powerful technologies in their eradication programme, such as insect transgenesis, which could be deployed over wide area and is less susceptible to immigrants. Above all, the use of the geographical information system has been used as a tool to mark site-specific locality of traps, host plants roads, land use areas and fruit fly populations within a specified operational grid (Mau *et al.,* 2003).

2.6.2 Sterile Insect technique or Male annihilation technique

The sterile insect technique is an important component of many area-wide integrated pests management programmes against tephritid fruit flies (Enkerlin, 2005). Regardless of the strategic goal of the control programme such as eradication and suppression, the success of the sterile insect technique hinges, to a large extent, on the field performance of the mass-reared, sterilised, and released insects (Calkins *et al.,* 1994). In this technique, sterile males are released in the fields for mating with the

wild females. Sterilisation is accomplished through irradiation, chemo-sterilisation, or by genetic manipulation. In sterile insect programmes the terms ‘sterility’ or ‘sterile insect' refer to the transmission of dominant lethal mutations that kill the progeny. The females either do not lay eggs or lay sterile eggs. For certain fruit fly species, most notably the Mediterranean fruit fly, *C. capitata*, released males must have the capability to locate mating aggregations (leks), synthesise and broadcast attractive pheromones, and perform complex courtship displays involving olfactory, visual, and acoustic signals (Hendrichs *et al*., 2002; Robinson *et al*., 2002). Unfortunately, processes inherent in mass production, such as genetic drift and intense artificial selection under crowded rearing conditions, may result in the release of sterile male fruit flies that have low sexual competitiveness relative to their fertile, wild counterparts (Leppla, 1989; Cayol, 2000). Such poor field performance may, of course, greatly reduce the cost effectiveness of sterile insect programmes.

A sterile insect programme is species specific, and is considered an ecologically safe procedure and has been successfully used in area-wide approaches to suppress or eradicate pest insects in entire regions such as the pink bollworm, *Pectinophora gossypiella* in California (Walters *et al*., 2000), the tsetse fly, *Glossina austeni* in Zanzibar (Vreysen, 2001), the New World screwworm, *Cochliomyia hominivorax* in North and Central America (Wyss, 2000), and various tephritid fruit fly species in different parts of several continents (Klassen *et al*., 1994). Although not frequently used, the sterile insect technique may be implemented in those instances where male annihilation alone is ineffective or where environmental concerns preclude widespread use of pesticides, which may kill non-target species and pose a threat to native insect populations.

2.6.3 Transgene-based embryo-specific lethality system

A transgene-based, female-specific expression method of a conditional dominant lethal gene (Handler, 2001; Horn *et al.*, 2002), has been well tested in *Drosophila melanogaster*, and might be transferable to other insect pest species (Heinrich and Scott, 2000; Thomas *et al*., 2000; Horn and Wimmer, 2003). Thus, the transgene-based dominant embryo lethality system can generate large numbers of competitive and vigorous sterile males, and can be used successfully in a sterile insect programme.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study sites

The experiment was carried out in the field and the laboratory. The field work was carried out in the Dodowa- Somanya stretch of the coastal savanna agro- ecological zone of Ghana. This locality is a major mango growing and trading area and has been involved in the promotion of this crop for some time now. The study was conducted at three different localities namely Ayenya No.I, Akorley No. I and Akorley No. II (Table 3.1). These areas are in the Dangme West and Yilo Krobo Districts of Greater Accra and Eastern regions respectively. One farm was chosen from each of these localities and geo-referenced for the field studies (Table 3.1). The orchards are 7.2, 10.5, 65.3 acres respectively and planted with two main varieties namely Keitt and Kent. These orchards were averagely eight years old with a planting distance of 6m x 6m. These areas were selected for this work based on its bimodal climatic conditions for the growing of the crop hence two cropping seasons experienced in a year.

The laboratory study was carried out at the Plant Protection and Regulatory Services Directorate (PPRSD) of the Ministry of Food and Agriculture (MOFA) at Pokuase in the Greater Accra region.

Table 3.1: Geo-referenced readings of study sites

Study site	GPS Reading		
	Latitude	Longitude	Altitude (m)
Ayenya No. I	05°56.994N	0°01.154W	51
Akorley No. I	6°00.536N	0°00.538E	29
Akorley No. II	6°00.562N	0°00.527E	30

3.2 Yilo Krobo and Dangme West Districts

The Yilo Krobo and Dangme West Districts are located in the coastal savanna agro-ecological zone of Ghana. The Yilo Krobo District is one of the twenty-one districts in the Eastern Region. It lies approximately between latitude 6° 00N and 0° 30N and between longitude 0° 30'and 1° 00'W. It covers an estimated area of 805sq.km, constituting 4.2 percent of the total area of the Eastern Region with Somanya as its capital. The Dangme West District is one of the ten Districts in the Greater Accra Region. It forms about 41.5% of the landmass of the Region and therefore the largest. The total land area is 1,442 sq km (144,201 ha), which consists of total cultivable land of 129,600 hectares and has a coastline stretch of about 37kms. The Dangme West District is situated in the Southeastern part of Ghana, lying between latitude 5° 45 south and 6° 05 North and Longitude 0° 05 East and 0° 20 West. The vegetation in these two districts is mainly coastal savannah with a small transitional zone along the foothills of the Akwapim-Togo mountain Range. The soil type is mainly of the heavy Akuse series with sandy and sandy-loams in certain areas. The rainfall pattern is bimodal and the main agricultural activities undertaken are livestock and crop production, fish production, fishing and fish processing and other agro-processing activities. Crops production includes maize, cassava, rice, tomatoes, garden eggs, okra, pepper, watermelon, sugarcane, banana, pineapple, pawpaw and exotic vegetables (for export). Tree crops grown are mainly mangoes with a few small- scale cashew plantations dotted in these areas.

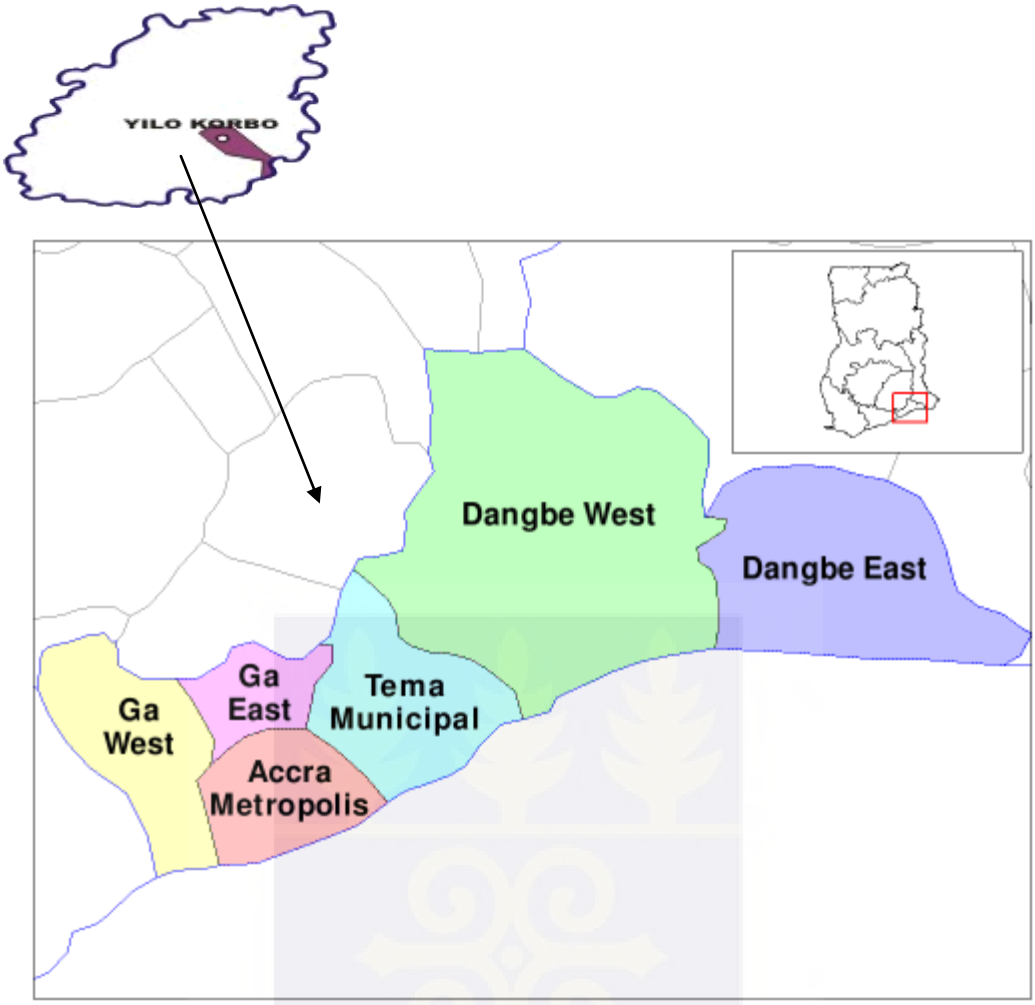

Fig. 3.1. Map of the study area (Yilo Krobo and Dangme West Districts).

3.3 Experimental layout

There were three treatments in each locality. In all, there were a total of nine plots for the experiment. The experimental design used for the layout was Randomised Complete Block Design (RCBD) with three replications (Appendix 2). The treatments were as follows:

- GF-120
- Brewers' Waste Yeast, and
- Control (farmer's Practice)

Fifty trees constituted a plot that was considered for one treatment at each locality. A total of 150 trees were used for the three treatments in one locality. Thus a total of 450

trees were required for the whole experiment. Three plots were randomly allocated at each of the three localities. These trees were tagged with different coloured ribbons to reflect the different treatments. Each treatment was clearly separated from each other by three rows of plants. Trapping with Methyl Eugenol, Terpinyl Acetate and Trimedlure was also carried out in each plot in order to monitor the population dynamics of the flies.

3.4 Trapping of male fruit flies and determination of species composition

Trapping started at the three experimental localities after six weeks of fruit formation. This was done in order to attract and catch only male species of fruit flies and also to determine and ascertain species composition of the flies as suggested by Ekesi and Billah, (2006). Three different attractants or lures (Plate 3.1 a, b, c) were used, namely, Methyl Eugenol (ME) (1, 2-Dimethoxy -4-(2-propenyl); Terpinyl Acetate (TA) (Methyl -4-hydroxybenzoate) and Trimedlure (TML) (Tert-butyl 4 (and 5)-chloro-2-methylcyclohexane-1-carboxylate) (White and Elson- Harris, 1992) were used in cylindrical plastic containers (Plate 3.2) which were locally produced for the purpose. These lures were in the slow-releasing polymeric plug form. The ME attracts *Bactrocera* and *Dacus* species, while TA and TML attract *Ceratitis* species (Ekesi & Billah, 2009). Insecticide, DDVP (Dimethyl Dichloro-Vinyl Phosphate) yellow in colour which was cut in strips of about 1-1.5 cm in length was placed at the bottom of each trap to kill attracted flies. Improvised plastic traps were used as receptacles for collection of the dead flies. The trap (Plate 3.2) is a cylindrical plastic container with three holes created around the uppermost level to serve as entrance of the insects. It has a lid through which a pin-hole was created for the passage of wire hanger which also carried the bait as it was suspended at the top within the container.

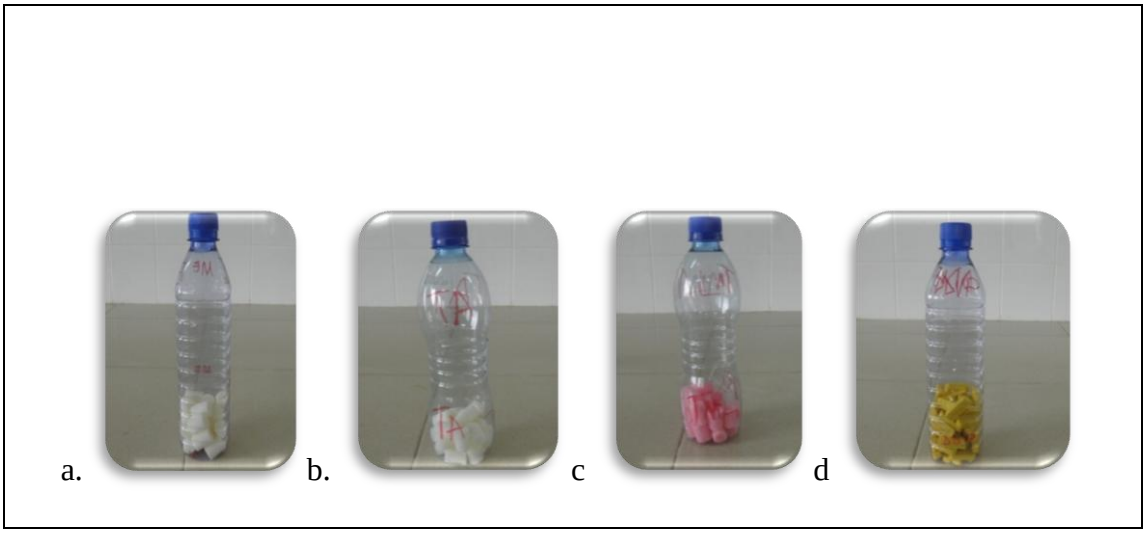

Plate 3.1. Lures used in the study. Methyl Eugenol (a), Terpinyl Acetate (b), Trimedlure (c) and Dimethyl Dichloro-Vinyl Phosphate (DDVP) (d).

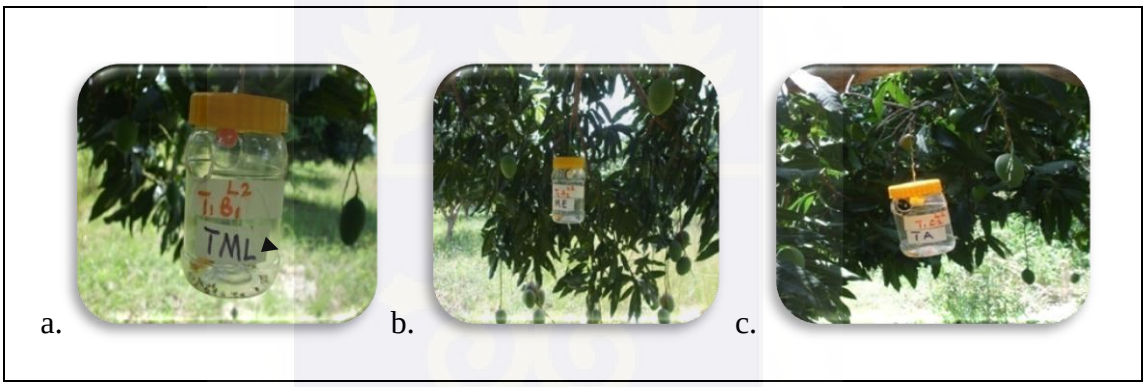

Plate 3.2 Improvised plastic traps with baits: Trimedlure trap (a), Methyl Eugenol (b) and Terpinyl Acetate (c).

Trap dimensions are: height 12.2 cm, height of lid, 2.0 cm and diameter 7.4 cm. The traps were rotated on a weekly basis in alternating fashion in the orchards. Two traps were used per lure, making it six traps per plot. A thin thread was fastened to the wire from the knotted end within the traps and the polymeric lure plugs tied at the opposite end of the thread. A total of 54 traps were set up on the three experimental sites. The traps (Plate 3.2) were suspended by wire hanger onto tree branches in semi-shaded spot in the upwind part of the canopy. A minimum distance of about 25-30 m was maintained between traps to minimise inter-trap interference (Ekesi and Billah, 2006).

The wire hangers were smeared with solid grease in order to prevent ants and other predators from harvesting the trap catches.

3.5 Baseline studies on fruit fly species presence and population dynamics

A baseline study was carried out in the three experimental areas from 28th October to 11th November, 2010 and 17th November to 8th December, 2011 for season one and two respectively. This was done by collecting and counting the catches from the traps for three conservative weeks without any treatment application. This pre-treatment trapping exercise was carried out before application of the treatments for the two major seasons. The traps were set up with the various lures and the killing agent as described above. This was carried out to determine the fruit fly species presence and their population dynamics in the chosen sites for the experiment. After the baseline studies (28th October 2010) for 3 weeks, the traps were monitored on weekly basis for four months i.e. throughout the experimental period (October 2010 to March 2011) and November 2011 to March 2012.

3.6 Treatments

3.6.1 Treatment application method and rates

A knapsack sprayer (Jacto®) fitted with cone nozzle and low spray pressure of two bars was to achieve high droplet size of 4-6mm diameter for efficient spray delivery. Two different sprayers were used for the respective treatment applications. These were boldly marked or written on to prevent interchanging during the course of application of treatments.

3.6.1.1 Application of GF-120

Two litres of GF-120 (Plate 3.3a) was measured using measuring cylinder and poured in a plastic bucket containing ten litres of water. This was vigorously stirred with a

piece of wood for proper mixing. The mixture was poured into a Jacto®) spraying machine and applied at the rate of 50-60 mls to $1m^2$ of foliage per tree. This procedure was repeated per week for the twelve weeks period of the experiment starting from 12th November, 2010 to 28th January 2011 during the minor season fruits. All the mango plants in the plot were treated. Applications of treatment were done early in the morning (0600-0900hrs) to prevent a possible spray drift. Applications were rotated around each tree inside the foliage at different spot (in the subsequent weeks) to avoid accumulation of bait and eventually increase the treated surface over time. Spraying was done inside the canopy so as to prevent photo-degradation of the product.

3.6.1.2 WBY and its preparation

The Waste Brewers' Yeast, a by-product of brewed beer, was acquired from Accra Brewery Limited (ABL) in Accra in sacks. The WBY was sun-dried for a number of days for good storage. It was then milled using corn mill (Appendix 3) to a fine powder and stored in an air-tight container to prevent moulding and contamination from micro-organism. The milled WBY was weighed (450g) on an electronic weighing scale (Plate 3.3b). The weighed WBY was poured into a plastic bucket containing ten litres of water and stirred vigorously for about five minutes. The bucket was covered with a lid and left for about 12hours (overnight). Afterwards, it was sieved with a strainer (Plate 3.3c) and the filtrate was poured into another knapsack spraying machine which was used as food bait as described for the GF-120. Fifty millilitres of Imidacoprid (insecticide) was added as killing agent. Imidacoprid is a systemic neonicotinoid insecticide produced by the German chemical firm Bayer CropScience and sold under such trade names as Gaucho, Admire, Merit, Advantage, Confidor, Provado, and Winner. In this experiment, Akape ® (local trade name) was

used. It works by interfering with the transmission of nerve impulses in insects by binding to specific nicotinic acetylcholine receptors. It is a product that is manufactured for use on soil, seed and foliar for the control of sucking insects. It was also applied at the same rate as the GF-120.

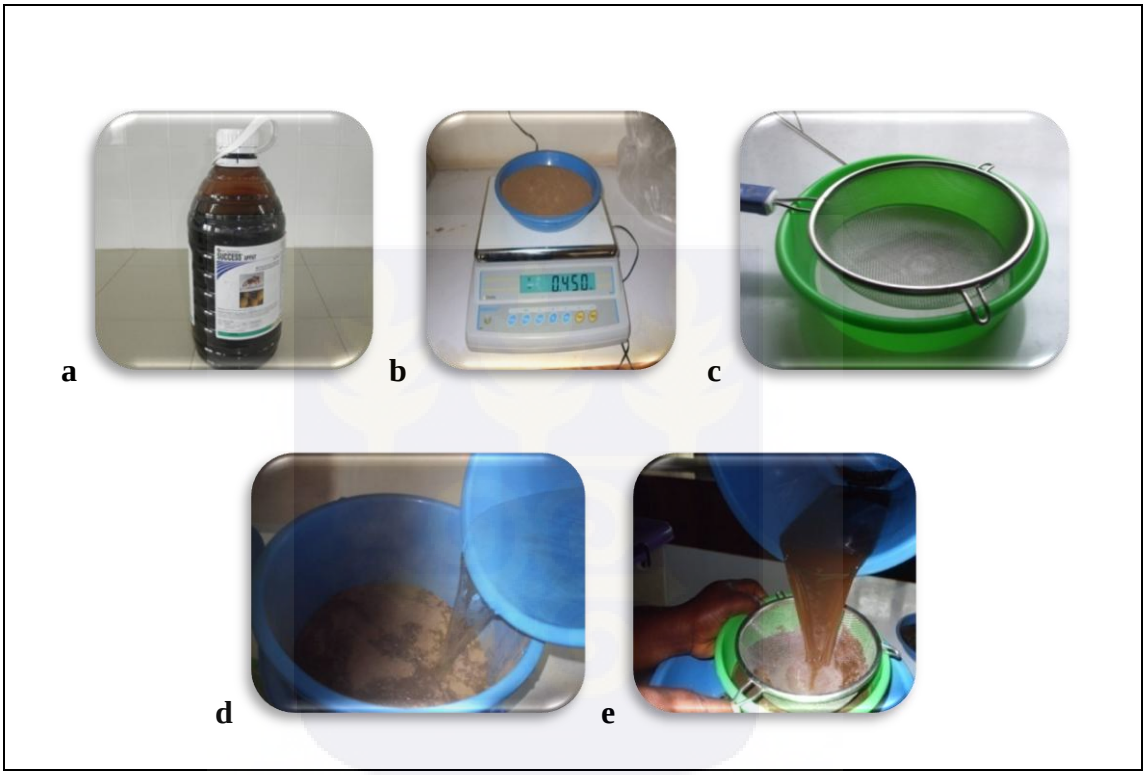

Plate 3.3. GF-120 (SUCCESS Appat®) in a 5-litre package container (a), Electronic scale (b), Strainers (c), water being added to WBY (d) and Straining of WBY (e)

3.6.1.3 Calibration of knapsack sprayer for bait (WBY) spraying

One of the two Jacto® knapsack sprayers was labeled WBY using a permanent marker which indicated its specific use. The sprayer was thoroughly inspected for any possible leakage and later water was added to the tank for calibration after which the bait was poured into the tank. The sprayer was pressurised by "an up and down" stroking of the lever of the sprayer while adjusting the nozzle of the sprayer to deliver

coarse droplets. The sprayer was calibrated for 10 seconds to deliver 50 millilitres of coarse droplets of the bait into a small graduated measuring cylinder.

3.6.1.4 Application of Waste Brewers' Yeast (WBY)

About 50ml of coarse droplets was delivered on one square metre of foliage in such a way that the bait drift did not hit the fruits on the trees. The spraying was done within the canopy to prevent the bait from being degraded by sunlight since it was an organic product. In all 150 mango trees from the three different WBY plots were sprayed with 7.5liters of WBY. Applications were rotated around each tree inside the foliage at different spot (in the subsequent weeks) to avoid accumulation of bait and eventually increase the treated surface over time.

3.6.1.5 Control treatment

The control was the treatment and activities of the farmer (farmer's practice). No chemical or treatment was used by the farmers for the control of the fruit flies in the three orchards. Fungicides were used for the management of fungi diseases especially anthracnose as has been their practice. However, trapping of the flies was carried out as described for the other plots.

3.7 Data collection

Trap collections were assessed on weekly basis into plastic collection vials and labeled in the field accordingly. The flies were later counted for every plot and preserved in 80% ethanol in the laboratory of PPRSD at Pokuase and stored in a dark place to prevent discolouration. This was recorded as flies per trap per day. This was a population index representing the average number of flies captured in one trap in one day that the trap was exposed to in the field (IAEA, 2003). The function of this population index is to have a relative measure of the size of the adult population in

these three localities within the experimentation period. This helped to compare fly populations among these three localities, determined population fluctuations during the period.

This was calculated using the formula:

Relative Density = F/T/D

Where F = Total number of flies collected

T = Number of traps used in study

D = Number of days traps were exposed in the field.

3.7.1 Identification of trap catches

The insects were identified using the taxonomic keys developed by the African Fruit Fly Initiative (AFFI) (Ekesi and Billah, 2009). All identified insects were sexed, counted and the results entered into a fruit fly trapping data collection sheet.

3.7.2 Fruit sampling and incubation

Fruits were sampled as described by Vayssiere *et al*. (2009). The first sampling was carried at the 7th week of treatment (24th December, 2010) and the second one four weeks thereafter. Thirty fruits were sampled at random from each plot. A total of 540 fruits were sampled for the two seasons of the experiment. The fruits were transported in sacks from the fields to the laboratory of PPRSD for incubation.

3.8 Sterilisation of sand for fruit incubation

Sand was collected from Nasaki River at Pokuase and washed in copious amount of water until all the dust and dirt particles were removed. The sand was then placed in an oven at 120◦C for 12 hours. The sterilized sand was allowed to cool after which it was spread onto polythene sheet.

3.8.1 Fruit incubation

For the two seasons, a total of one thousand and eighty (1,080) fruits were sampled from the three treatment plots at the three localities and weighed (593.57kg) and later incubated. The cumulative weight of the sampled fruits for season one and two were 286.78 kg and 306.79 kg, respectively. The fruits were placed on the heat-sterilized sand in plastic cages according to plots (Plates 3.4a and b). The room temperature during the incubation period ranged between 28^{o}C and 37^{o}C while the relative humidity for the same period was between 75% and 85%. The sand was inspected every other day (3 days) to remove all puparia present. Inspection was regularly done until no puparia were present in the sand. The puparia were then placed in bottles of diameter 8cm and height 17cm. The bottom of the bottles was lined with moist tissue paper. Each bottle was labeled with the plot number and locality of the experiment, date of collection and number of puparia.

(a)  (b) 

Plate 3.4 (a) Fruits on heat-sterilized sand **(b)**: Fruits put in cages

As the flies emerged from the puparia, they were released into bigger bottles with the lids made of gauze and contained fruit fly diet composed of yeast and sugar in the ratio 1:3. Water was also provided in the bottle. The flies were kept alive for four days to allow for the full development of taxonomic features before they were killed. A killing bottle was made from a glass jar. Ethyl acetate was soaked in cotton wool and

placed in the bottle. The base of the bottle was lined with tissue paper to prevent dead insects from having contact with cotton wool. The insects from the bigger bottle were transferred into the charged bottle. The killing bottle was closed with its lid after all the insects had entered to enable them die. The dead insects were emptied into plastic vials that had been appropriately labeled and preserved with 70% ethanol.

3.8.2 Infestation and damage levels

Fruit fly infestation and damage levels during the research period were determined by cutting the fruits with a shape knife. The infestation and damage of fruits were recorded and expressed as percentage damage. Calculating Infestation rate of fruit fly is given by: The number of puparia got from treated plot minus the Number of puparia got from Control plot.

The Difference in infestation: The infestation rate value of treated plot minus the infestation rate value of control plot. Calculating the percentage reduction in fruit infestation, the following formula was used:

The Percentage Reduction: $\frac{\text{Difference in infestation for treated plot}}{\text{Difference in infestation for control plot}} \times 100$

3.8.3 Effect of baits on other insects

All observed effects of baits on other insect pests were recorded. The same applied to effects of baits on other beneficial insects or organisms. A list of all the insects (both pests and beneficial) trapped was made. A list of species identified during the course of the study was generated. Besides this, the total number of insects collected from the traps at various localities was recorded.

3.8.4 Data analysis

Data were transformed using log (x + 1) to normalize the variance before analysing. Analysis of variance was performed using Generalised Linear Model (Proc GLM, SAS Inc. 2003) on the total number of different fruit fly species attracted by the different traps in mango orchard. When ANOVAs were significant, means were separated using Student-Newman-Keuls (SNK) test at P=0.05.

CHAPTER FOUR

RESULTS

4.1 Trap catches

During the study period, a total of 22,652 insect species were collected, of which 22,355 (98.69%) were fruit flies and 297 (1.31%) as non-target species. Four fruit fly species (*B. invadens, Ceratitis cosyra, C. capitata and C. ditissima)* belonging to two genera (Bactrocera and Ceratitis) were identified (Appendix 4).

In season one (SO) of the study period, a total of 14,035 insects were collected. During the period, 2,867 and 11,168 were collected for pre- treatment and treatment respectively with 121 non-target species. In season two (ST) a total of 8,509 insects were collected which comprised 5,895 in pre-treatment, 2,566 in treatment with 48 non-target species.

WBY plots recorded the highest baseline fruit flies captures of 1,091 while 752 flies were catches recorded for Control as the least in SO. For ST, GF120 plots had 2,409 captures being the highest as Control again recorded the least (1,360). During SO, WBY treated plots recorded the highest (4,131) captures in the treatment period and the least (3,445) by control plots. GF-120 treated plots had 1,075 being the highest captures during ST while control again recorded the least (698).

Table 4.1. Summary of catches in Methyl eugenol (ME), Trimedlure (TML) and Terpinyl acetate (TA) baited traps

Locality	Fruit fly species	Season One (SO) (Oct 2010-March 2011)				Season Two (ST) (Nov 2011- March 2012)			
		No. of flies	No. of traps	Exposure period (days)	Flies/ trap/ day	No. of flies	No. of traps	Exposure period (days)	Flies/ trap/ day
Ayenya 1 GF-120 Treated Plot	*B. invadens* (ME)	275	2	140	9.819	2449	2	105	11.661
	C. cosyra (TML)	5	2	140	0.311				
	C. capitata (TML)	87							
	C. cosyra (TA)	22	2	140	0.048				0.004
	C. capitata (TA)	2	2	140	0.007	1	2	105	0.004
		0	2	140	0	1	2	105	
Ayenya 1 WBY Treated Plot	*B. invadens* (ME)	2854	2	140	10.192	2450	2	105	11.666
	C. cosyra (TML)	104	2	140	0.371				
	C. capitata (TML)	45	2	140	0.161				
	C. cosyra (TA)	3	2	140	0.011	4	2	105	0.019
	B.invadens (TA)	0	2	140	0	1	2	105	0.004
Ayenya 1 Control Plot	*B. invadens* (ME)	2179	2	140	7.782	1346	2	105	6.409
	C. cosyra (TML)	293	2	140	1.046				
	C. capitata (TML)	37	2	140	0.132				
	C. cosyra (TA)	4	2	140	0.014				
	C. capitata (TA)	2	2	140	0.007	1	2	105	0.004
	B.invadens (TA)	0	2	140	0	1	2	105	0.004
Akorley 1 GF-120 Treated Plot	*B.invadens* (ME)	612	2	140	2.187	266	2	105	1.266
	C.cosyra (TML)	104	2	140	0.371				
	C. capitata (TML)	45	2	140	0.161				
	C. cosyra (TA)	26	2	140	0.092	32	2	105	0.152
	C. capitata (TA)	0	2	140	0	7	2	105	0.033

Akorley 1 WBY Treated Plot	*B. invadens* (ME)	769	2	140	2.746	131	2	105	0.623
	C. cosyra (TML)	88	2	140	0.314				
	C. capitata (TML	13	2	140	0.046				
	C. cosyra (TA)	22	2	140	0.078	28	2	105	0.133
	C. capitata (TA)	6	2	140	0.025	11	2	105	0.052
Akorley 1 Control Plot	*B. invadens* (ME)	582	2	140	2.078	255	2	105	1.214
	C. cosyra (TML)	12	2	140	0.042				
	C. capitata (TML)	3	2	140	0.011				
	C. cosyra (TA)	4	2	140	0.014	31	2	105	0.147
	C. capitata (TA)	3	2	140	0.011	8	2	105	0.038
Akorley 2 GF-120 Treated Plot	*B. invadens* (ME)	871	2	140	3.110	634	2	105	3.019
	C. cosyra (TML)	37	2	140	0.132				
	C. capitata (TML)	8	2	140	0.028				
	C. cosyra (TA)	22	2	140	0.078	189	2	105	0.900
	C. capitata (TA)	6	2	140	0.021	42	2	105	0.200
Akorley 2 WBY Treated Plot	*B. invadens* (ME)	854	2	140	3.050	131	2	105	0.061
	C. cosyra (TML)	41	2	140	0.146				
	C. capitata (TML	17	2	140	0.061				
	C. cosyra (TA)	35	2	140	0.125	28	2	105	0.133
	C. capitata (TA)	8	2	140	0.028	11	2	105	0.052
Akorley 2 Control Plot	*B. invadens* (ME)	1020	2	140	3.642	331	2	105	1.576
	C. cosyra (TML)	18	2	140	0.064				
	C. capitata (TML)	3	2	140	0.011				
	C. cosyra (TA)	32	2	140	0.114	61	2	105	0.290
	C. capitata (TA)	4	2	140	0.014	18	2	105	0.085

4.1.2 Fruit flies captures

The outcome of the trapping of flies for each season was expressed as number of flies per trap per day (F/T/D) (IAEA, 2003). The function of this index is to have a relative measure of the size of the adult population in a given space and time. This is a standard index that allows comparison of trap catches between different periods and geographical localities.

According to IAEA (2003), fruit fly density is the ratio of the number of flies per trap per day, that is,

$$\text{Relative Fly Density} = \frac{\text{Number of fruit flies captured}}{\text{No. of traps} \times \text{No. of days}}$$

During the pre-treatment period for SO, GF-120 plots recorded the highest *B. invadens* F/T/D value of 14.128 while 9.047 was recorded in the Control plots as the least. For SO treatment period, WBY plots recorded the highest *B. invadens* F/T/D figure of 13.590 while the lowest value, 2.771 was recorded by the control plots (Table 4.1).

The highest *B. invadens* value (11.666) for season two (ST) was recorded by WBY plots at Ayenya No. I and the lowest (0.623) was also by WBY plots at Akorley No. I. Control plots at Ayenya No. I had the highest and lowest F/T/D figures of 1.046 and 0.007 of *C. cosyra* catches respectively in TML plot and GF-120 plots during SO. During season two (ST), GF-120 plots had the highest F/T/D values (0.309) of *C. cosyra* captured at Akorley No. I in TA trap while both GF-120 and Control plots had the lowest value (0.004) also from TA traps at Ayenya No. I (Table 4.1).

GF-120 plots recorded the highest *C. capitata* F/T/D value of 0.161 for SO in TML trap captures at Akorley 1 and 0.007 being the least value for TA was recorded in Control plots at Ayenya No. I. For ST, GF-120 plots again had the highest (0.104) *C.*

capitata F/T/D value at Akorley 2 while 0.033 was recorded as the least value for TA traps at Akorley 1. GF-120 plots for TA recorded zero value for *B. invadens* during SO but in ST;GF-120, WBY and Control plots recorded the F/T/D value of 0.004 for TA traps at Ayenya No I.

4.1.3 Methyl Eugenol trap captures

The weekly trap catches for ME baited traps were recorded. During the pre-treatment trapping period, week 3 had the highest *B. invadens* catches of 283 for GF-120 plot with week 1 recording the least value (163) in SO (Fig 4.1). The trend changed during ST where week 1 had the highest value (1,135) and got reduced as the season progressed, with week 3 being the least (448). For SO, in the same plot, the highest catches (378) was recorded in week 11 while the least value (41) during the period was recorded in week 8. During the treatment period of ST, the highest *B. invadens* catches of 329 was recorded in week 1. This reduced weekly as the season progressed with the least catches (4) recorded in week 12 (Fig 4.1).

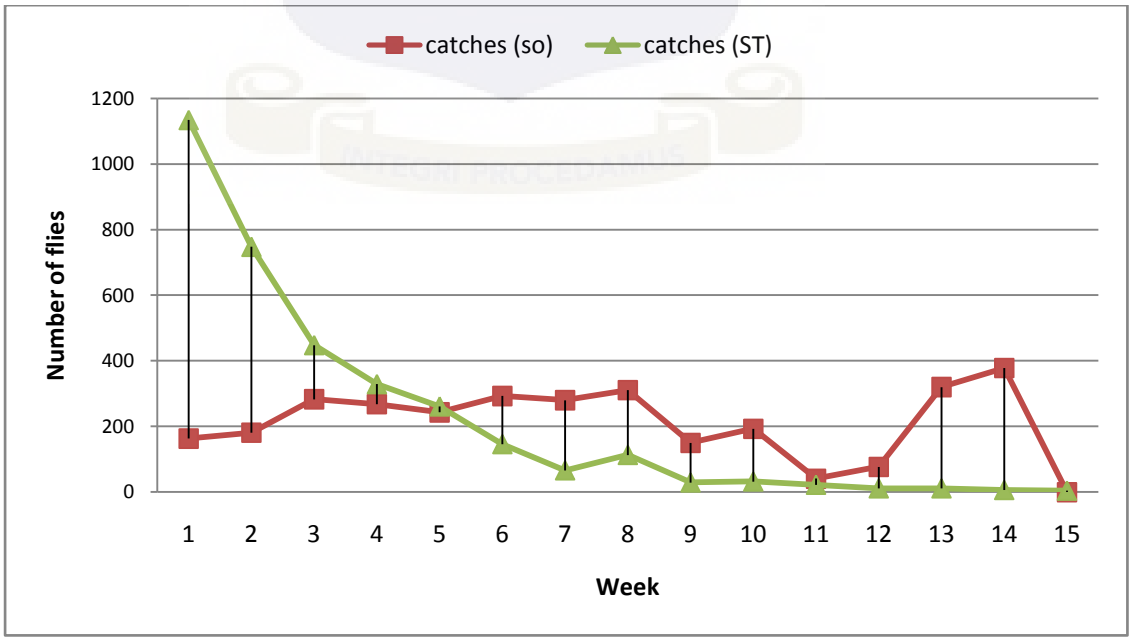

Fig 4.1: Trap catches for Methyl Eugenol

The WBY plots during the pre-treatment trapping period recorded the highest *B. invadens* catches (239) for ME in week 3 while the least value (90) was captured in week 1 of SO (Fig 4.2). During the treatment period, the highest *B. invadens* were trapped in week 5 (386) and gradually got reduced to 60 in week 8. During ST however, there was a shift from SO recordings. The highest catches (821) were trapped in week 2 for the pre-treatment and the lowest (463) in week 3 of ST (Fig 4.2). The treatment period recorded the highest *B .invadens* catches (383) in week 1 while the lowest (3) was in week 12.

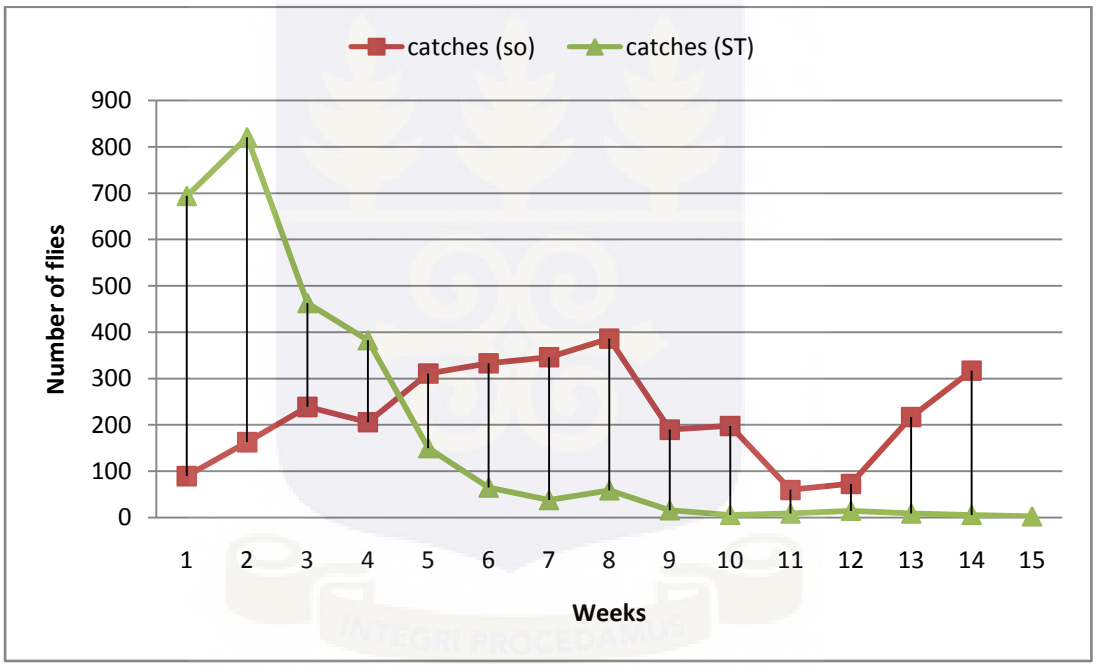

Fig 4.2: Trap catches for Waste Brewers' Yeast

Trap catches at the Control plots in SO recorded the highest (158) value in week 3 during the pre-treatment period while the least (90) was in week 1 and increased steadily (Fig 4.3). During the treatment period for SO, the highest catch (368) was recorded in week 2, thereafter reduced gradually with the least (52) in week 8. The ST in these plots began with high trap catches (523) in week 2 during the pre-treatment period but there was a significant reduction in week 3 (294) which was the least (Fig

4.3). However, week 1 of the treatment recorded the highest value (334) and the least (4) in week 12.

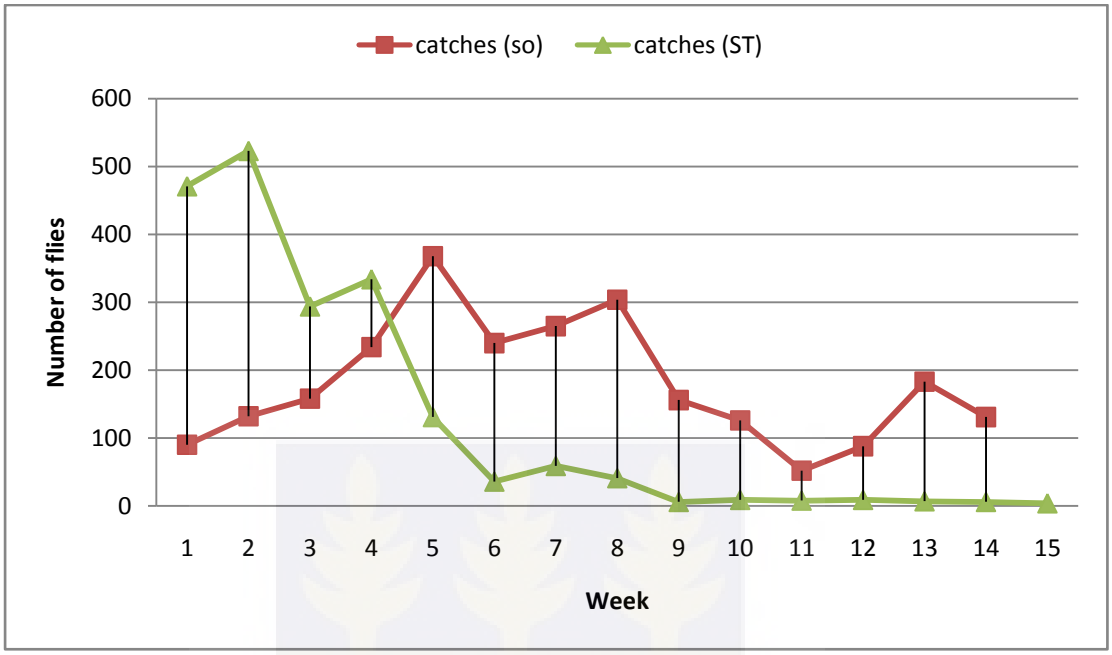

Fig. 4.3: Trap catches for Control

The highest trap catches of *B. invadens* in the three study sites was recorded at Ayenya 1 (Fig. 4.4) with WBY plots (2854) in SO and the least (131) at Akorley 1 in ST. However, a total of 14,034 *B. invadens* were trapped at Ayenya 1 alone while Akorley 1 and II recorded 2,615 and 3,899 during the study period respectively (Fig 4.4).

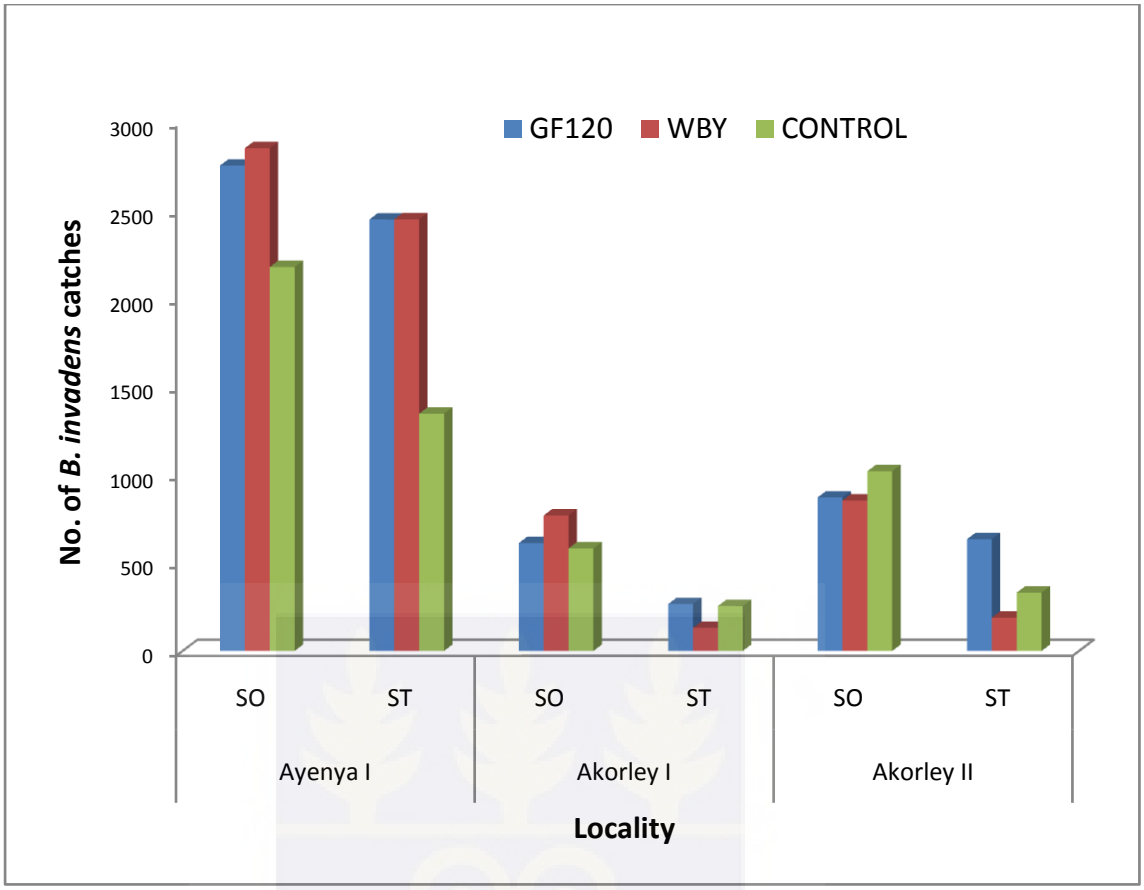

Fig. 4.4: *B. invadens* catches with ME baited traps

4.1.4 Trimedlure trap catches (fruit fly)

There were 138 trap catches in week 1 and this had been the highest value for the GF-120 plots. This value reduced consistently over the weeks till no (zero) fly was caught in weeks 7, 8, 10, 11 and 12. Akorley 1 recorded the highest trap catches (149) and the least (44) at Akorley 2 for GF-120 treated plots during the study period (Fig 4.5).

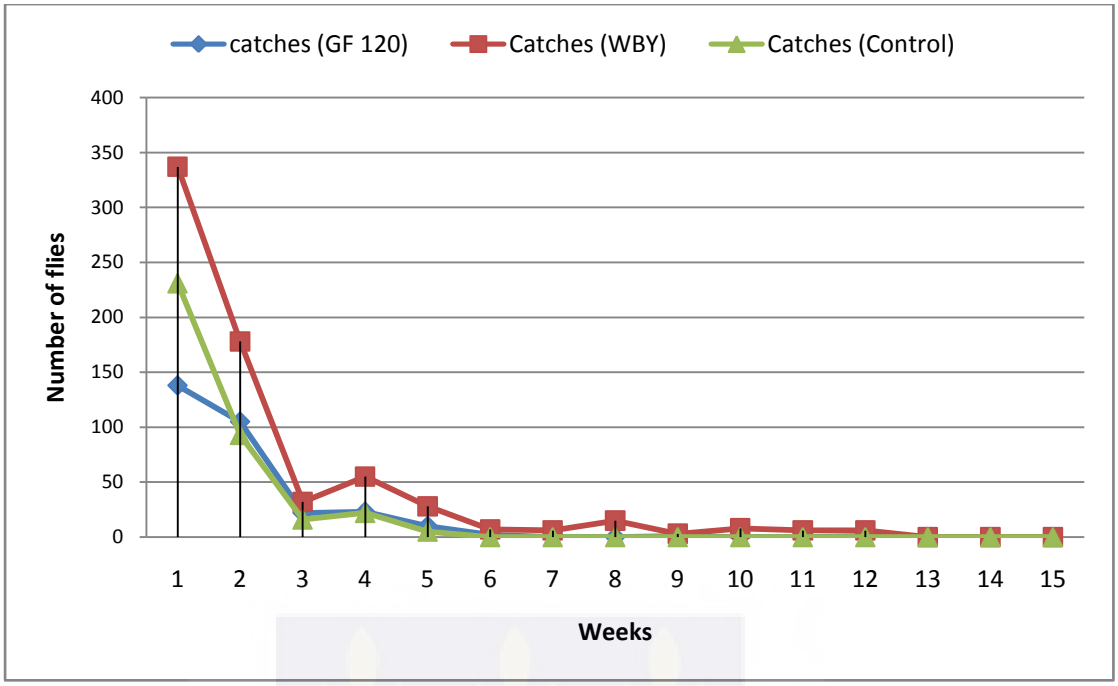

Fig. 4.5: Fly catches with TML baited traps

WBY plots during the pre-treatment period recorded the highest trap catches (337) in week 1 while the least was in week 3, (32). This reduced further in the treatment period till no catches were recorded during the last three (3) weeks of the study period. Ayenya 1 recorded the highest trap catches (511) while the least (58) was recorded at Akorley 2 (Fig. 4.5). In all, a total of 670 flies were caught during the study period in the WBY treated plots.

Control plot obtained its highest weekly trap catches (231) on week 1 but this declined in week 2 and week 3 recorded the least (16) during the pre-treatment period. The trap catches increased to 22 in week 1 during the treatment period however, this decreased or declined to 5 in week 2 and recorded no catches thereafter till week 12. Ayenya 1 again recorded the highest trap catches (330) and Akorley 2 had 21 catches which was the least.

A total of 950 flies were captured at Ayenya 1 and this was the highest catches recorded with TML. The least captures of 123 flies were recorded at Akorley 2 (Fig. 4.5)

4.1.5 Terpinyl acetate trap catches

The traps catches during season one (SO) for GF-120 plots recorded the least (6) during weeks 2 and 3 for the pre-treatment as week 1 recorded the highest (27). Week 1 in the treatment period had 2 catches which increased to 4 in week 2 and later to 7 in week 3. This was the highest trap catches recorded during the period. Week 4, 5 and 6 recorded one fly catch which came to zero for two subsequent weeks in week 8 and 9, then 2 catches and later zero till the end of the study period.

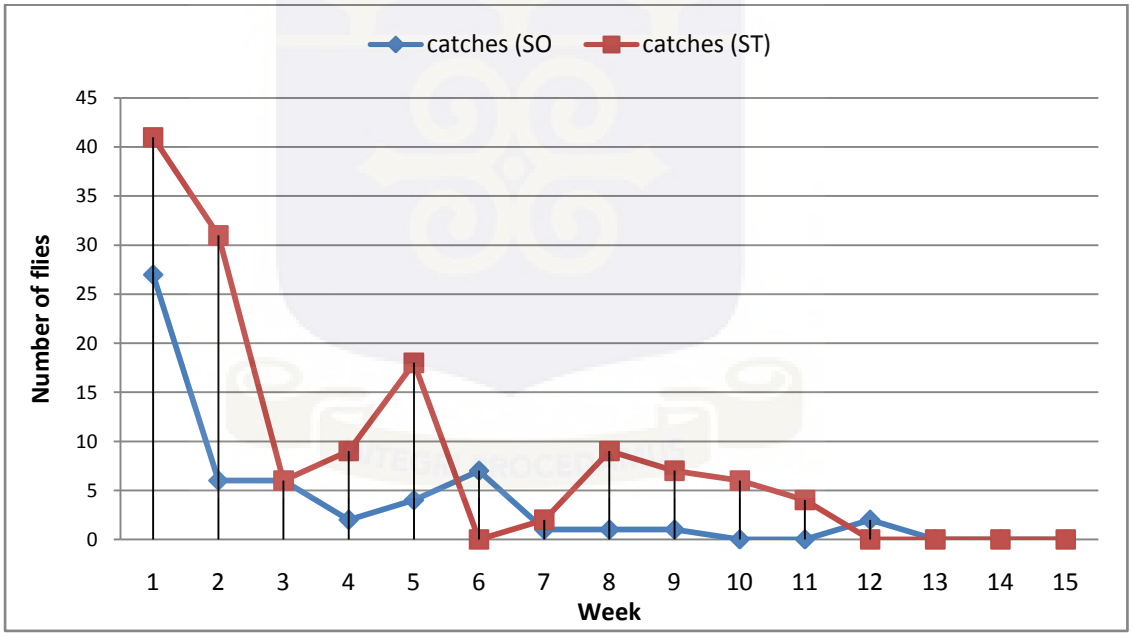

Fig. 4.6: Fly catches with Terpinyl acetate for GF-120 Plot

In ST, 41 and 6 fly catches were recorded in week 1 and 3 as the highest and the least respectively during the pre-treatment (Fig. 4.6). Pre-treatment periods for SO and ST recorded 39 and 78 total fly catches respectively. Treatment period in ST started with 9 trap catches in week 1 and increased to 18 the following week. In week 3, no flies

were caught but respectively increased to 2, 9, 7, 6 and 4 in the subsequent weeks. No catches were recorded during the last four weeks. A total of 56 fly catches were recorded in SO while 132 in ST for the GF-120 treated plots (Fig. 4.6). Ayenya 1 traps caught the least flies in the two seasons, 2 and 6 respectively while Akorley 2 recorded the highest (28 and 87).

WBY treated plots recorded relatively the lowest trap catches during the pre-treatment period. In SO, 26 catches were recorded in week 1 followed by 13 each in weeks 2 and 3. In the treatment period, 9, 5, 4 were the fly catches recorded in weeks 1, 2 and 3 respectively. However, the traps caught no flies for weeks 4, 5 and 6. Weeks 9 and 10 recorded 2 and 1 catches respectively followed by zero catches for two weeks. A total of 52 trap catches were recorded in the pre-treatment which reduced to 22 in the treatment period in SO. Ayenya 1 again recorded the least (3) catches in SO and ST (5) respectively during the two seasons. However, the highest (82 and 55) were trapped at Akorley 2 in the two seasons respectively.

The ST started with 32 trap catches in week 1 while week 3 recorded 4 fly catches in the pre-treatment. Week 2 of the treatment period recorded 13 fly catches and this reduced to 2, 1 and 2 in the respective weeks before catches increased to 7 then reduced to 6 and 1. The last four weeks recorded zero catches. There were 61 trap catches in the pre-treatment period however, a total of 37 fly catches were cumulatively recorded in the 12 weeks of application of treatment. There was one *B. invadens* each recorded in TA baited traps in SO and ST for WBY plot at Ayenya 1.

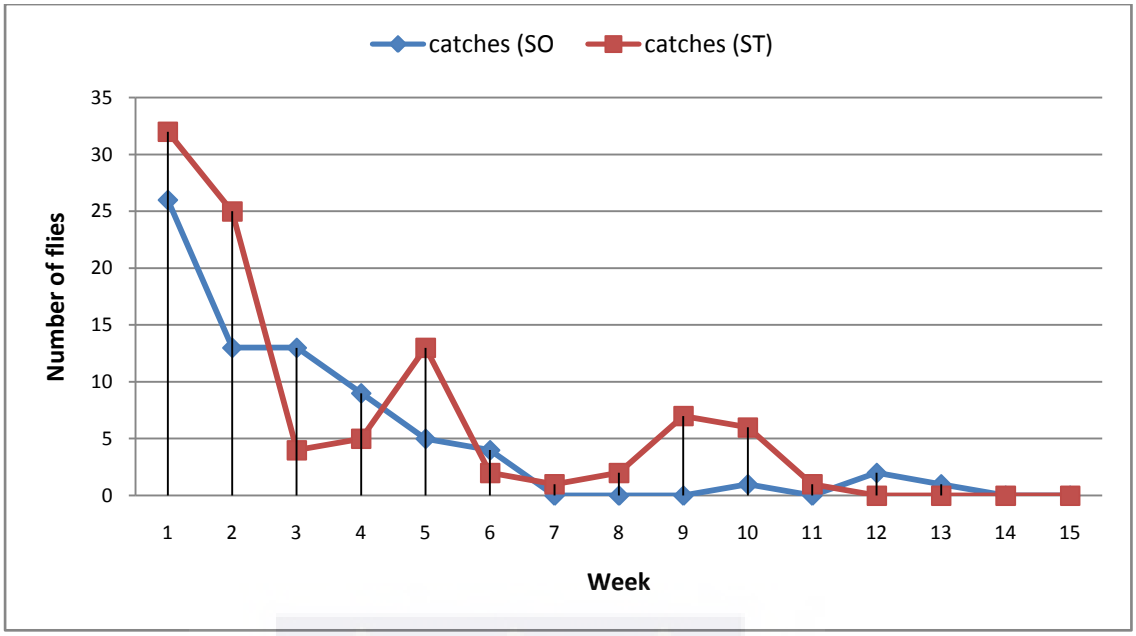

Fig. 4.7: Fly catches with Terpinyl acetate for WBY Plot

The Control plots recorded a total of 32 trap catches with week 3 being the highest (17) and week 2 (7) the least during the pre-treatment in SO (Fig. 4.8). For the treatment period, 17 fly catches were recorded in twelve (12) weeks. The highest (5) were caught in week 2 thereafter; it recorded 0, 1 and 2 till the last two weeks saw zero catches. The ST also recorded a total of 72 fly catches for the three (3) weeks of pre-treatment with week 1 recording the highest of 37 flies while week 2 had 2 flies (Fig. 4.8). Fifteen (15) trap catches were recorded in week 1 which was the highest followed by 10, 2 and 0 in the respective and subsequent weeks. These were also followed by 6, 4, 5, 5 and 1 trap catches; however, the last week recorded zero catches. A total of 48 fly catches were recorded in the period of treatment (Fig. 4.8). Ayenya 1 recorded the least catches of 6 and 2 in SO and ST in the control plots while Akorley 2 however, had the highest catches (36 and 75) in the respective seasons (Fig. 4.8).

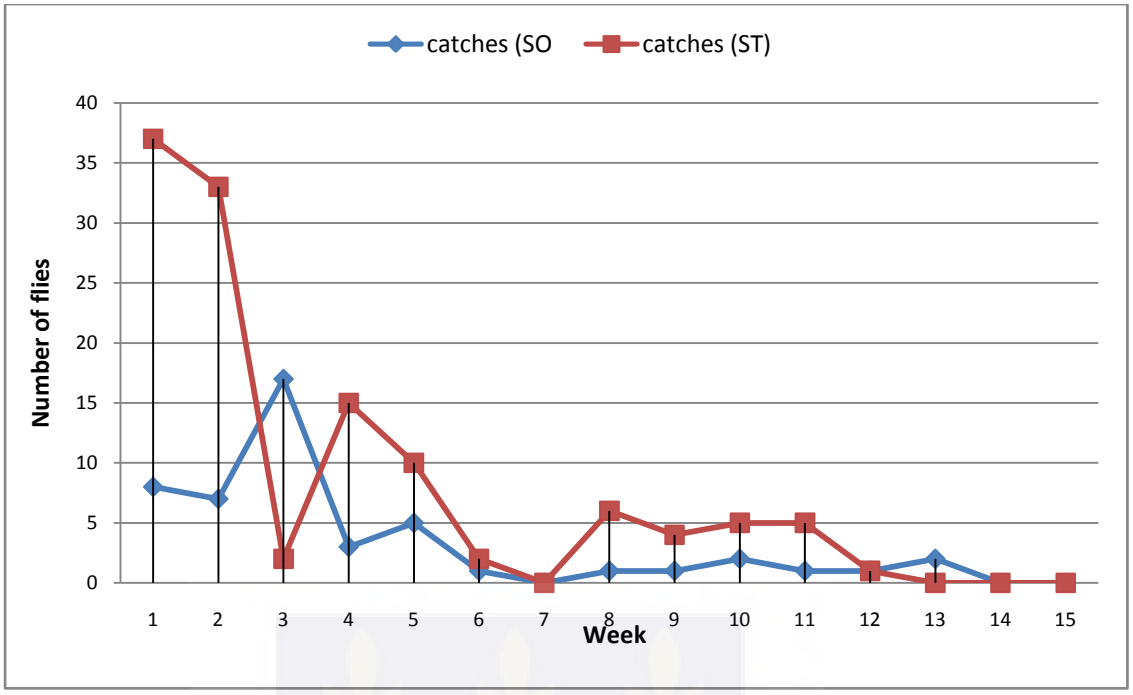

Fig. 4.8: Fly catches with Terpinyl acetate for Control Plot

The dominant species of fruit fly recorded from the Terpinyl acetate (TA) traps were *C. cosyra* followed by *C. capitata.* However, one *B. invadens* was captured in a Control plot for TA trap at Ayenya 1 in ST. *B. invadens* is not known to be attracted to TA lure; this indicates the high numbers of this species in the area. The number of flies from these traps was generally very low at Ayenya 1 throughout SO and ST. It was at Akorley 2 that a relatively high numbers of flies were caught followed by Akorley 1.

4.1.5.1 Total fruit fly trap catches

Captures of fruit flies for treatments over the study period were not significantly different from the others. Pre-treatment over 3 weeks recorded very high captures relative to the treatment period. WBY treated plot recorded the highest mean of 147.50 ± 73.98 in SO at Akorley 1.

Overall, the numbers of fruit flies captured at Akorley 1 ME traps were consistently higher than in traps baited with TA and TML. During the pre-treatment period, catches were not significantly different from TA and TML (Table 4.5). During the treatment period, ME traps significantly outperformed the other lures, with a mean number of 303.50 ± 18.37, $p < 0.0001$). Numbers from the other traps (lures) however, did not differ significantly from each other (Table 4.5).

Trap catches for the pre-treatment period were significantly different from the treatment at Ayenya 1 in SO. ME treated plots recorded the highest mean of 155.67 ± 15.99 while TA recorded the least (0.83 ± 0.40) during the period. TA plot catches were significantly different from TML and ME (Table 4.5).

During the treatment period, ME traps performed significantly different from the other two lures (TA and TML). It recorded a mean number of 1130 ± 110.63, P 0.0001). However, catches from TA and TML were not significantly different ($p = 0.005$).

In all, the flies trapped at Ayenya 1 was relatively high with ME performing significantly (1285.67 ± 118.41) (Table 4.5) different from the others.

Captures of fruit flies for the various treatments over the period at Ayenya 1 in SO, were not significantly different from the other. WBY recorded the highest mean (563.50 ± 277.91) while Control had the least mean value (419.17 ± 215.05).

Fruit flies captured for the treatment period at Akorley 2 SO were not significantly different from the rest. The pre-treatment period recorded relatively low catches in TA and TML (Table 4.5) for the three treatments. However, WBY had mean of 45.00 ± 16.48 as the highest with Control recording the least mean value of 16.33 ± 3.49. Total catches for the treatments were highest again in the Control plots with mean of 179.67 ± 107.99.

Trap or lure catches during the study period were significantly different (P=0.005). ME baited traps were highly significantly different 457.50 ± 34.36, (P <.0001) from both TML and TA traps. However, TA and TML were not significantly different from each other (Table 4.2).

From the results, more flies were relatively trapped at Ayenya 1 (Table 4.2) in SO than the other two sites. This was followed by Akorley 2 and Akorley 1 (Table 4.2). However, ME traps recorded the highest catches.

Table 4.2 Performance of different lures in terms of fly catches in three localities in season I

Lures	Statistical Parameters	Trap Catches		
		Pre-Treatment Period	Treatment Period	Total Catches (Pre-Trt + Trt)
Akorley 1				
TML		30.83 ± 10.90 a*	12.83 ± 8.05 b	43.67 ± 13.61 b
ME		22.00 ± 2.22 a	303.50 ± 18.37 a	325.50±18.76 a
TA		6.83 ± 2.74 a	3.50 ± 0.85 b	10.33 ± 3.12 b
	F	3.37	216.63	164.43
	Df	2, 15	2, 15	2, 15
	P	< 0.0620	< 0.0001	< 0.0001
Ayenya 1				
TML		143.17± 37.43a*	17.33 ± 6.14b	160.50 ± 42.34b
ME		155.67 ± 15.99a	1130.00 ± 110.63a	1285.67 ± 118.41a
TA		0.83± 0.40b	1.00 ± 0.37b	1.88 ± 0.65b
	F	13.39	102.35	92.94
	Df	2,15	2,15	2,15
	P	< 0.0005	< 0.0001	< 0.0001
Akorley 2				
TML		18.00 ± 3.47b	2.83 ± 0.70b*	20.83 ± 4.04b
ME		72.17 ± 16.67a	385.33 ± 42.75a	457.50 ± 34.36a
TA		12.83 ± 1.87b	5.00 ± 0.89b*	17.83 ± 2.07b
	F	11.84	79.55	159.81
	Df	2,15	2,15	2,15
	P	< 0.0008	< 0.0001	< 0.0001

*Means in the same column followed by different letters are significantly different (at p = 0.05), using Student Newman Keuls (SNK) test. ANOVA performed using arcsine transformed proportion values.

During the treatment period in ST, flies captured were not significantly different from others at Ayenya 1. However, very high mean numbers were recorded from the pre-treatment in all the treated plots. WBY plots recorded the highest mean value of 454.25 ± 262.43 (F= 0.27, df = 2, 10, P= 0.7701) while Control had the least (244.75 ± 141.25) at the same period.

There was a relatively decline in the fly captures in the treatment period as GF-120 plots had the highest mean value of 173.75 ± 99.80 which was not significantly different from the other treatments. Control recorded the least mean value of 94.75 ± 55.52, (F= 0.24, df= 2, 9, P= 0.7905).

Table 4.3 Performance of different lures in terms of fly catches in three localities in season II

Lures	Statistical Parameters	Trap Catches		
		Pre-Treatment Period	Treatment Period	Total Catches (Pre-trt + Trt)
	Ayenya 1			
TML		0	0	0
ME		758.50 ± 87.07a	284.17 ± 35.75a	1042.67 ± 120.73a
TA		1.17 ± 0.31b	1.17 ± 0.65b	2.33 ± 0.76b
	F	75.65	62.65	74.25
	Df	1,10	1,10	1,10
	P	< 0.0001	< 0.0001	< 0.0001
	Akorley 1			
TML		0	0	0
ME		62.33 ± 13.43a	45.83 ± 8.67a	108.17 ± 21.10a
TA		13.83 ± 1.33b	6.00 ± 0.63b	19.83 ± 0.87b
	F	17.65	24.64	22.32
	Df	1,10	1,10	1,10
	P	< 0.0001	< 0.0001	< 0.0001
	Akorley 2			
TML		0	0	0
ME		118.33 ± 41.65a	74.33 ± 22.47a	192.67 ± 60.41a
TA		20.33 ± 1.80b	16.17 ±3.07b	36.50 ± 4.62b
	F	6.91	8.92	8.56
	Df	2,10	2,10	2,10
	P	< 0.0075	< 0.0028	< 0.0033

*Means in the same column followed by different letters are significantly different (at p = 0.05), using Student Newman Keuls (SNK) test. ANOVA performed using arcsine transformed proportion values.

In all, GF-120 plots recorded the highest catches with mean value of 614.25 ± 353.33. It was however, not significantly different from other treatments.

Trap catches were significantly different for the two lures (ME and TA) during ST. ME traps recorded significantly high catches throughout the period with pre-treatment mean of 758.50 ± 87.07 and a treatment mean (284.17 ± 35.75). TA traps had mean, 1.17 ± 0.31 for pre-treatment and 1.17 ± 0.65 as treatment mean value (Table 4.3)

Flies captured for treatments in ST at Akorley 1 were not significantly different from each other. Catches over the period were relatively low for both pre-treatment especially for the treatment. GF-120 plots recorded the highest mean value for the periods (29.17 ± 16.39 and 21.83 ± 13.08) while WBY plots had the least value (18.67 ± 8.23 and 10.00 ± 4.48).

The number of fruit flies captured at Akorley 1 in ST was relatively lower in traps with TA, it is however, significantly different from ME trap catches during pre-treatment period (Table 4.3). During the treatment period, ME traps again performed better than TA with the mean value of 45.83 ± 8.67 ($F= .64$, $df=1, 10$, $p< .0001$). Performance of ME is however, significantly different from TA traps (Table 4. 3)

Fly catches for pre-treatment and treatment at Akorley 2 in ST were not significantly different from each other. GF-120 plots for the two periods recorded the highest mean values which totaled 120.17 ± 17 ($F = 0.68$, $df = 2, 15$, $P= 0.5226$). The WBY had the least mean of 40.67 ± 18.17. There was a marginal decline from the pre-treatment mean value to the value of the treatment.

Trap catches however, were significantly different from the lures (ME and TA). Throughout the period, ME traps recorded significantly high catches of 192.67 ± 60.41, $p = 0.0033$ as compared to TA mean catches of 36.50 ± 4.62. (Table 4.3).

During the ST, there was a decline in the numbers of fly catches in all the three localities. However, Ayenya 1 again recorded relatively the highest mean value (Table 4.3) of the catches during the period. Akorley 2 and I recorded marginal

catches in that order as ME traps again outperformed than TA traps. It should however, be noted that during the ST no TML traps were used due to its unavailability.

4.1.6 Non- target insect captures

A total of 297 non-target organisms were collected throughout the study period. WBY treated plots recorded the highest numbers of non-target organisms followed by GF-120 and Control in that order. In SO, 220 (74.07%) non-targets were recorded while ST however, recorded 77 (25.93%). In all, WBY treated plots recorded 37.04% of the catches while GF120 and Control recorded 34.34% and 28.62% respectively (Table 4.4). Trap catches at Akorley 1 recorded the highest number of 119 (40.07%) non-target organisms followed by Ayenya 1 (111) (37.37%) and the least by Akorley 2 with 67 (22.56%). The highest insect order caught during the study period was from the Coleoptera (Table 4.4) with the least from the Orders, Blattodea and Homoptera. Other non-target Orders were Diptera, Araneae, Hymenoptera (which were basically Ants), Neuroptera etc.

Table 4.4: Number of non-target species by Order

Non-target species	GF-120						WBY						Control						Total
	Season One			Season Two			Season One			Season Two			Season One			Season Two			
	AY1	AK1	AK2	AY1	AK1	AK2	AY1	AK1	AK2	AY1	AK1	AK2	AY1	AK1	AK2	AY1	AK1	AK2	
Coleoptera	10	8	6	9	5	1	7	5	4	3	7	2	16	4	1	2	3	3	**96 (32.3%)**
Diptera	9	1	3	4	1	1	12	4	3	3	0	1	11	7	3	3	1	0	**67 (22.6%)**
Lepidoptera	1	0	1	1	0	1	0	0	0	0	0	1	0	1	0	0	1	0	**7 (2.4%)**
Araneae	3	7	9	1	2	2	0	6	4	2	7	0	4	9	2	1	0	3	**62 (20.9%)**
Neuroptera	0	2	0	1	1	0	0	1	1	0	0	0	0	0	1	0	0	1	**8 (2.7%)**
Hymenoptera	1	2	3	0	1	0	0	36	3	0	0	0	0	1	6	0	0	0	**53 (17.8%)**
Blattodea	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	**1 (0.3%)**
Odonata	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	**2 (0.7%)**
Homoptera	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	**1 (0.3%)**
TOTAL	**24**	**20**	**22**	**16**	**12**	**5**	**19**	**52**	**15**	**8**	**14**	**4**	**31**	**23**	**13**	**6**	**6**	**7**	**297**
	66			**33**			**86**			**26**			**67**			**19**			

LOCALITIES: AY1 = Ayenya1, AK1 = Akorley1, AK2 = Akorley2

In SO at Ayenya 1, GF-120 treated plot attracted 24 non-target organisms while ST had 16. WBY plot also caught 19 and 8 for the respective seasons however; Control plot had recorded 31 and 6 catches. At Akorley 1, 20 and 12 catches were recorded in the two seasons respectively under GF120 treated plot. WBY for the two (2) seasons also recorded 52 and 14 (Table 4.4). The high numbers recorded in the Season one however, were mainly ants (Hymenoptera) (Table 4.4). The Control had 21 and 8 for the respective seasons. Akorley 2 recorded 22 and 5 catches for GF120 plot; 15 and 4 for WBY and 13 and 7 on the Control plot for the two respective seasons (Table 4.4). The highest non-target organisms (Order) attracted to the treated plots during the study period were Hymenoptera (32.3%) of the total organisms. However, the rest were Diptera (22.6%), Araneae (20.9%), Hymenoptera (17.8%) and others (Table 4.4).

4.1.8 Flies from incubated fruits

A total of 310 fruit flies were reared from the sampled mango fruits during the two seasons. The study revealed that Akorley 2 recorded the highest number of fruit flies (40.97%) followed by Ayenya 1 (33.87%) and Akorley 1 had the least (25.16%) (Table 4.5). The highest number of flies was reared from Control plot which recorded (52.58%) and the least was from WBY treated plot (20.32%). The flies reared from fruits sampled from GF-120 treated plot was 27.10% (Table 4.6). The fruit fly species that emerged from the fruits at all the three localitys was *B. invadens*. However, the only non-tephritid species that emerged from the fruits were *Carpophilus bipustulatus* (Heer) (Table 4.5). This belongs to the family Nitidulidae and Order Coleoptera. *C. bipustulatus* was identified at ARPPIS by Mr. H. Davies. This species is known to feed primarily on decaying plant materials, including damaged and fermenting fruit

and vegetables. Tables 4.5 and 4.6 summarise insect species reared from the harvested fruits during the study at the various localities and plots respectively.

Table 4.5 Fruit fly and non-tephritid species reared from sampled mango fruits at different localities

Locality	Tephritid species	No. of flies	Percentage (%)	Non-tephritid species	No
Ayenya 1	*B. invadens*	105	33.87	*Carpophilus bipustulatus*	14
Akorley 1	*B. invadens*	78	25.16	*Carpophilus bipustulatus*	9
Akorley 2	*B. invadens*	127	40.97	*Carpophilus bipustulatus*	12
TOTAL		310	100		35

Table 4.6 *B. invadens* and Non-tephritid spp reared

Treatment	No. Of Puparia	No. Of Flies	Non-tephritid spp.	No.
GF-120	131	84 (27.10 %)	*Carpophilus bipustulatus*	18
WBY	110	63 (20.32%)	*Carpophilus bipustulatus*	7
Control	196	163 (52.58%)	*Carpophilus bipustulatus*	10
Total	437	310 (100%)		35

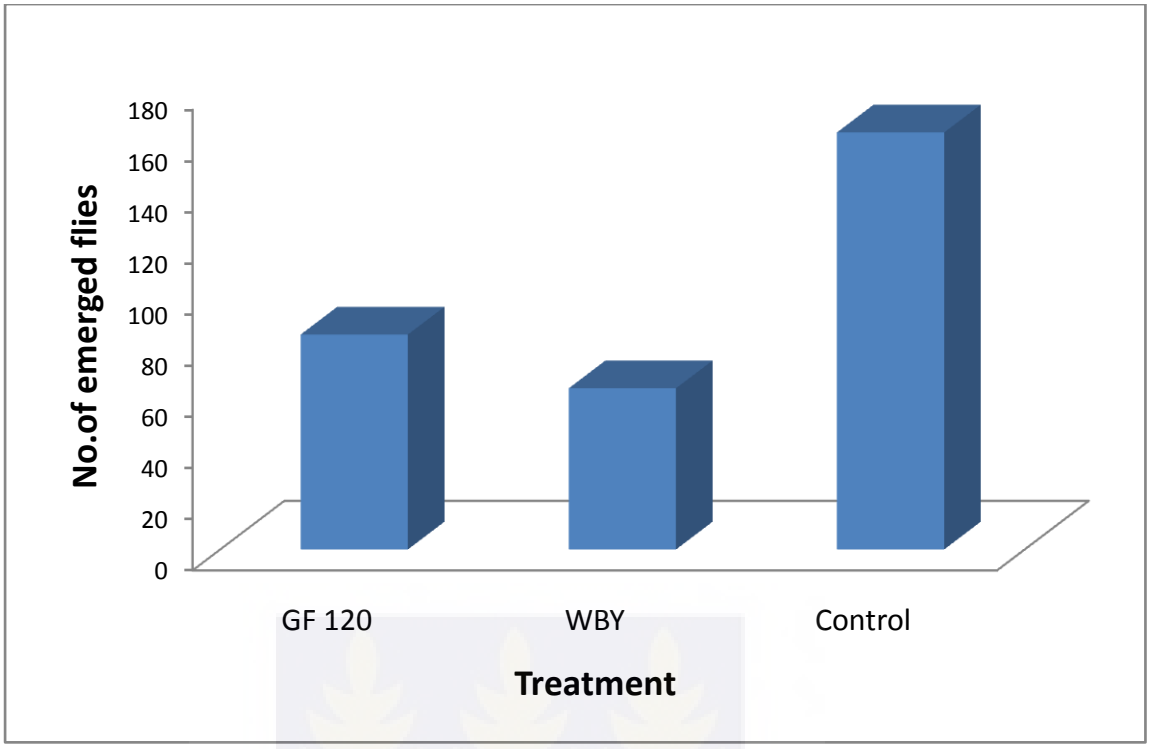

Fig. 4.9: Emerged flies by treatment

4.1.9 Infestation levels and percentage reduction of incubated mango fruits

The highest numbers of puparia were recorded in the Control plots (196) and WBY plots (110) had the least. The Control again recorded the highest (163) emerged flies and WBY had the least (63) (Fig. 4.5 and Table 4.5). The percentage reduction of fruits infestation by GF-120 was 33 % while that of WBY was 46 % (Table 4.7). Table 4.7 shows the infestation levels and the percentage reductions of the incubated mango fruits with the baits (treatments) during the study period.

Table 4.7 Infestation levels and percentage reduction of incubated mango fruits

Treatment	No. fruits	Wt. fruits (kg)	No. puparia	No. flies	% Emerge.	Infestation level (pup/kg)	Diff. (C-T)	% Reduction
GF-120 (T 1)	360	196.98	131	84	64.12	0.67	0.33	33.0
WBY (T 2)	360	200.56	110	63	57.27	0.55	0.46	46.0
CONTROL (C)	360	196.03	196	163	83.16	1.00	-	-

CHAPTER FIVE

DISCUSSION

5.1 Composition of fruit fly species at the study sites

Fruit fly species trapped or collected in the study areas showed four (4) species. These were *B. invadens, C. cosyra, C. capitata* and *C. ditissima.*

B. invadens recorded the highest (90.11%) number during the study period, followed by *C. cosyra* (5.94%), *C. capitata* (2.48%) and *C. ditissima* (1.47%). Relatively, the numbers of the two other species as per trapping results/data suggest that the introduction of *B. invadens* seems to be displacing the earlier known or indigenous fruit fly species in the orchards. Catches of the Africa Invader fly were greater than the other species across the three localities, suggesting a domination of the fly over the indigenous *Ceratitis* species (Lux *et al.,* 2003b; Ekesi *et al.,* 2006). Though *C. cosyra* and *C. capitata* were second and third in ranking respectively after *B. invadens,* the numbers of those flies were significantly lower across the three localities. The highest number of 974 flies collected was recorded at Ayenya 1, while Akorley 1 had 456 for the two seasons.

Trap catches of flies from the start of the study reduced steadily during the treatment application weeks. The numbers peaked up during the maturity stages of the fruits which indicated that the fruits were attractive for infestation. As the seasons drew to a close, the flies' number dropped drastically and this could be attributed to unavailability of suitable host for multiplication. In all the three (3) localities, the dominant fruit fly species was the *B. invadens.* The results of the study confirm the findings of Lux *et al*., (2003a, b), Ekesi *et al*., (2006), Mwatawala *et al*., (2009), Nboyine *et al.*, (2012) and Bulley (2012), which indicated that the mango ecosystem is dominated by *B. invadens.* Ayenya 1 recorded the highest number of *B. invadens* in

both seasons as indicated in Tables 4.1 and 4.2. The reason for the observed pattern and relative abundance of the flies was reported by Vayssieres *et al*, (2009b). They noted that climatic factors such as rainfall, humidity, temperature etc. are closely related with fruit fly population and its dynamics.

Ayenya 1 had a relatively higher humidity compared to the other localities. This could be attributed to the dense and large canopy covers of the trees in the orchard at Ayenya 1. The humid condition is suitable for *B. invadens* to develop and multiply hence its dominance in Ayenya 1. Aluja and Birke (1993) stressed the importance of microhabitat conditions on *Anastrepa oblique* Macquart presence and diurnal patterns of activity in a highly ephemeral and diversified environment. Nboyine *et al*., (2012) also attributed high numbers of *B. invadens* trapped to the fact that the Southern sector of the country enjoys what has been described as a 'double-maximum' or bi-modal regime of rainfall that occurs in the study areas. The high population could also be attributed to re-infestation from dropped fruits in nearby orchards. Management strategies, especially orchard sanitation put in place in the farm was very good as the farmer regularly picked and split of dropped fruits for local fowls to feed on the larvae. Other sites however, were relatively free from alternate hosts. This activity could contribute to the suppression of the fruit fly populations. At the onset of the study, population densities of flies were comparatively low as indicated by the trap catches. Season 1 in all the three localities generally recorded low trap catches in the pre-treatment period but when treatment started, catches relatively increased and declined as the fruit size enlarged towards mid-season. Yee (2007) observed that numerically fewer flies are expected in bait treatment sites. This finding could be due to the attraction of the baits applied in the orchards especially for *B. invadens*. Season

2 saw a reversal of this trend as the pre-treatment recorded very high catches for the first three weeks and subsequently dropped during the whole treatment period. This situation could be attributed to the emergence of adult flies from infested dropped fruits from the previous (Season 1) which led to the carryover of fruit flies in the three localities. This finding confirms the assertion by Mwatawala *et al.,* (2009) that there is a build-up of fly population with increase in number of fruits and its maturity.

Secondly, migration of flies from adjacent fields in search of protein based foods and other food items in the project sites could also account for the high numbers recorded. Mango production in the study area has two seasons in a year with few weeks of dry spell which normally promote flower initiation. This could substantially promote carryover of fruit flies in the production system especially in the mango production belt in the south.

There was no clear pattern of trap catches especially after the baseline survey or pre-treatment period in Season 1 as populations of the flies fluctuated on weekly bases till the second fruit sampling was carried out. On the other hand, there was distinct reduction in their numbers after the pre-treatment period in all the three localities culminating in low infestation in Season 2. This corroborated the work done by Pinero *et al.,* (2010), where the bait sprays used, suppressed populations of flies for the first 10 weeks of application.

The number of fly per trap per day was relatively significant in the GF-120 treated plots for *B. invadens* in all the three localities as high numbers were recorded but insignificant for *C. cosyra* and *C. capitata*. The high numbers of *B. invadens* were recorded probably due to the presence of the Methyl Eugenol lures and food baited sprays in the orchards. The flies caught in the traps were mainly males and according to Pinero *et al.,* (2010), Methyl Eugenol could be used as a way of suppressing the

male populations and not as a treatment factor. Together with others, Steiner *et al*. (1965); Steiner *et al*., (1970) and Koyama *et al*., (1984) further confirmed that combination of lure and bait with toxicant had been successfully used for eradication of *B. dorsalis* in Rota, Saipan and Okinawa respectively.

5.2 Efficacy of Waste Brewers' Yeast against fruit flies.

The WBY treated plots recorded a total of 7,247 *B. invadens* in ME baited traps (Fig 4.4). The highest catches (5,304) for the two seasons were recorded at Ayenya 1 (2,854 and 2,450) respectively. However, Akorley 1 had the least (900). For the others, TML and TA had relatively lower catches (Fig. 4.4 and 4.5). A total of 360 fruits sampled and incubated, gave 110 puparia for rearing of which 63 tephritid flies emerged constituting 57.3%. The number of puparia extracted from WBY treated fields was the least while Control plots had the highest (196) out of the three (3) treatments. The Control also had the highest puparia emergence (163) (83.2%) which subsequently resulted in very high infestation rate of 0.86. The results indicated that no indigenous fruit fly species were reared from the collected puparia. The reason for this could be due to complete displacement of the *Ceratitis* species during fruit maturity as indicated by the data and confirmed in Kenya (Ekesi *et al.*, 2009)

The general performance of WBY in the study was good as it recorded the lowest infestation rate of 0.61 as against the standard (GF120) which gave 0.74. On the other hand, the percentage reduction of fly infestation for the two treatments GF120 and WBY during the study are 13.95% and 29.07 % respectively. WBY was efficient as observed by Vijaysegaran, (1989) and Loke *et al.*, (1992) in their studies proved that WBY was an excellent attractant to fruit fly species and caused no phytotoxicity to the treated plants. In view of its performance in Australia, Lloyd and Drew, (1996)

mentioned that a formulation plant was established to convert crude yeast into autolysate which was used by the farmers to manage fruit flies.

For decades, management of pestiferous fruit flies in various areas of the world has relied heavily on the application of protein baits mixed with highly toxic insecticides (Steiner *et al.*, 1961; Roessler, 1989; Vargas *et.al*., 2005). More recently, improved behavioural approaches to pest management such as attract-and-kill systems that use reduced-risk insecticides have proven to be an excellent alternative (Shelton and Badenes-Perez, 2006; Cook *et al*., 2007). IAEA (2007) and Heath *et al*., (2009) recognised the need to develop improved lures and "attract-and-kill" devices for successful fruit fly control. In view of this development, WBY represents an alternate and subsequent improved source of cheaper protein bait for fruit flies management.

5.3 Comparing Waste Brewer Yeast (WBY) and GF-120 (SUCCESS APPAT®)

The use of protein bait sprays for control of tephritid fruit flies dates back many years (Roessler, 1989). However, with the greater concern about potential long-term harmful effects of organophosphate insecticides and the development of newer protein baits, the feeding responses of tephritids to these baits have recently received much attention. For these fly species, protein baits (those with hydrolysed proteins, which consist of amino acids or peptides) have some attractiveness, but the attractiveness of and feeding propensity on various baits differ (Moreno and Mangan, 1995; Fabre, *et al*., 2003; Vargas *et al*., 2003; Vargas and Prokopy, 2006).

GF-120 bait is a combination of attractant, feeding stimulant, and spinosad insecticide for control of fruit fly (Tephritidae) populations. The bait was formulated to attract multiple fruit fly species and to use the minimum concentration of an environmentally compatible toxicant for ultra-low volume (2–4 l/ha) application.

Waste Brewers' yeasts contain all the essential microbial growth factors for both fruit flies such as high level of amino nitrogen, peptides, vitamins and minerals and are economical and good alternatives used for many types of fermentations including cultures and bioremediation (Chang, 2009). The WBY is reported to be rich in proteins, amino acids, water-soluble vitamins (B-complex vitamins). These are the elements that most influence insect growth and fecundity. Research had indicated that combining bait with pesticide could reduce the fly infestation rate. Imidachloprid, an insecticide added to the WBY was effective in reducing the fruit fly infestation in orchards. During the study period (Season 1 and Season 2), the two baits with the three lures attracted a number of flies. There was no significant difference between GF-120 and WBY treatments ($p = 0.005$). However, GF-120 attracted more fruit flies than WBY but this was not significant.

The adult flies reared from the sampled fruits indicated that GF-120 treated plots recorded 84 as against 63 by the WBY which respectively constituted 27.1% and 20.32% of the number of puparia produced (Table 4.6). This clearly indicates that the level of protection given to the fruits by WBY + imidacloprid combination was significantly higher than the standard (GF-120) even in its crude status. More flies especially the female fruit flies were attracted to the treated areas for feeding and were killed before infesting fruits as indicated by Ekesi *et al*. (2010). This culminated into relatively lower infestation rate of fruits as GF-120 was 33 % while WBY was 46% (Table 4.7). The WBY again performed relatively better than the GF-120 in combination with the various lures which attracted and killed *B. invadens* except that of ME, which had 48.85% and 51.15% for WBY and GF-120, respectively. Control plot recorded the highest (1.00) infestation rate of *B. invadens* followed by GF-120 plot (0.67) with WBY plot (0.54) recording the least. Under the control treatment, no

bait was applied only trapping was carried out to assess the population dynamics and their effects on fruits. The high catches recorded in these plots were due to the fact that flies had not fed or ingested any poisonous bait. Thus the high infestation rate (1.00) resulting in high numbers of the flies reared (52.58%) from harvested fruits from this plot (Table 4.7). The fruits on these plots were not protected (as were the case for the other treatments) especially from the female flies that were searching for suitable hosts for oviposition.

5.4 Non-target captures

A total of 297 non-target organisms were captured during the study period. In Season 1, 220 were captured, WBY treated plot attracted 86 as Control had 67 of these organisms. There was drastic reduction (77) of these captures in Season 2 as GF-120 plot had 33 and Control recorded 19. On treatment bases for the two seasons, WBY treated plots captured 112 (37.72%); GF-120 99 (33.33%) and Control 86 (28.95%) (Table 4.4). The non-target captures were from nine (9) different insect orders (Table 4.4). Coleoptera (32.3%) being the highest captured Order followed by Diptera (22.6%), Araneae (20.9%), Hymenoptera (17.8%). Minor captures were Lepidoptera, Neuroptera, Blattodea, Odonata and Homoptera. These captures corroborated Bulley (2012) where seven (7) of the above Orders were captured in citrus orchards at Kade. Most of these insects were attracted to the traps probably due to the trapped flies which might be their prey and were knocked down by the killing agent (DDVP). Most of them were predators/ parasitoids (Araneae, Hymenoptera, Neuroptera, Blattodea and Odonata) which corroborated the findings of Nboyine *et al.*, (2012). Most of the Dipterans and some Coleopterans were carrion or decay related species which might be attracted due to the decaying flies. No honey bees or suspected adult parasitoids of fruit fly were captured. The non-target captures during the study were only 1.31% of

the total organisms captured which indicated that their attraction could not be as a result of direct attraction to the attractants used. Ekesi *et al*. (2010) encouraged the use of food baits as safe and relatively cheap means to suppress fruit flies but advised that they should not be used as a stand-alone method in the management of fruit flies.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The fruit fly species collected from the traps in the study areas were *B. invadens, C. cosyra* and *C. capitata*. *Bactrocera invadens* were dominant over the other species, followed by *C. cosyra* and *C. capitata.* One *C. ditissima* was however, recorded at Akorley 2. In all the three localities, Ayenya 1 recorded the highest catches of *B. invadens* followed by Akorley 2 and Akorley 1. Trap catches of *C. cosyra* was also higher than that of *C. capitata* in all the three study areas. The highest fly density was recorded with GF-120 treated plot throughout the three areas for the two seasons, while WBY and Control treatments followed in that order. Ayenya 1 recorded the highest fly density and the least was at Akorley 1 for the two seasons. Fly density from pre-treatment to treatment periods in Season One (SO) stood at 66.34 and 13.29 respectively. For Season Two (ST), 45.40 and 4.07 were respectively the relative fly density recorded in pre-treatment and treatment. The pre-treatment fly densities were significantly higher than the treatment densities for the two seasons. This reveals that the baits sprayed had impacted positively in reducing the fruit fly populations in the mango orchards.

Results from the study and observations made on the fields indicated that Waste Brewers' Yeast used as food bait relatively performed in reducing the infestation rate of the fruit flies. This reflected in the 46% reduction in infestation obtained after incubation of the sampled fruits. It implies that together with other management practices that would be employed in the fruit fly management can actually give total protection of fruits. WBY used as food bait can be said to have attracted the fruit fly species that were recorded in the mango ecosystem in the study areas as per data of

Nboyine *et al.*, (2012). The non-target catches under WBY treated plots are relatively not significant compared with the other treatments.

6.1.2 Performance of the two food bait sprays

Waste Brewers' Yeast was comparable to GF-120 (as the standard), as both baits were able to attract the same species of fruit flies. WBY in its crude form had performed relatively well and exhibited characteristics of food baits that are comparable to the GF-120 being imported.

6.2 Recommendations

The performances of the two baits are not significantly different; WBY which is locally developed bait can be used in place of the standard which is very expensive. The usage of the WBY, when embraced by the farmers will significantly reduce the cost of production; effectively manage the fruit flies in combination with other pest management strategies. This should increase the potential of fruits and vegetables to reach lucrative export markets. It is recommended that further research be conducted on the duration (hours or days) of soaking the milled WBY before applying. When this is carried out it will further improve upon its attractiveness and efficacy. It is also recommended that the use of WBY could be incorporated into an Integrated Pest Management (IPM) strategy for sustainable mango production in Ghana. This will compliment the current management practice that mainly targets the males of *B. invadens* with the use of Methyl Eugenol + insecticide in traps to reduce the fruit fly populations.

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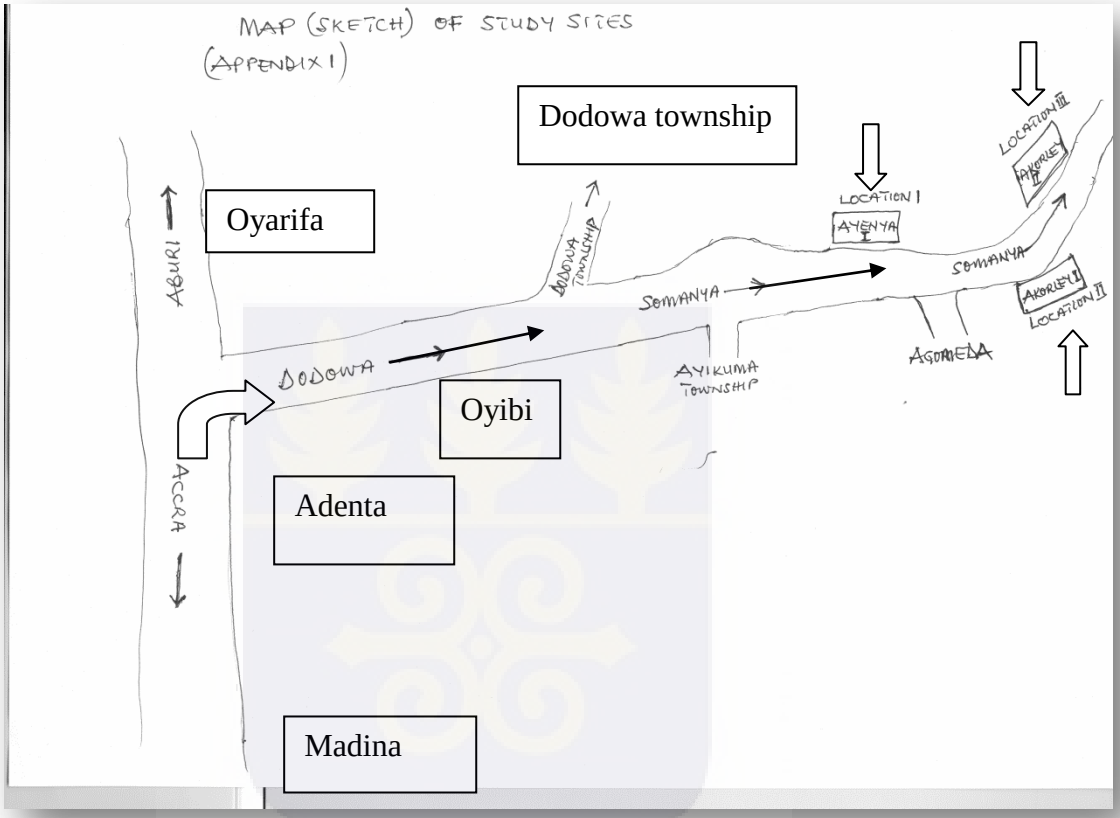
APPENDICES

Appendix 1: Map (Sketch) of study sites



Appendix 2: Plots Layout with Pheromone Traps within each plot

Locality I (Ayenya 1)

GF 1	**WB 1**	**C 1**
2 ME	2 ME	2 ME
2 TML	2 TML	2 TML
2 TA	2 TA	2 TA

Locality 2 (Akorley 1)

C 2	**GF 2**	**WB 2**
2 TML	2 TML	2 TML
2 TA	2 TA	2 TA
2 ME	2 ME	2 ME

Locality 3 (Akorley 2)

WB 3	**C 3**	**GF 3**
2 TA	2 TA	2 TA
2 ME	2 ME	2 ME
2 TML	2 TML	2 TML

Appendix 3: **Grinding of Waste Brewers' Yeast**

Appendix 4: Pictures of some tephritid flies captured by traps

Ceratitis capitata

Bactrocera invadens

Appendix 5: Fruit Fly Trapping Data Sheet

Date	Treatment	Trap No.	*Bactrocera* sp.			*Ceratitis* sp.			*Dacus* sp.			Non-target organisms										
			Total	*m*	*f*	*Total*	*m*	*f*	*Total*	*m*	*f*	Ants	Arachnida	Coleoptera	Diptera	Hymenoptera	Lepidoptera	Blattodea	Neuroptera	Orthoptera	Others	Remarks