KNOWLEDGE GAPS, TRAINING NEEDS AND BIO-ECOLOGICAL STUDIES ON FRUIT-INFESTING FLIES (DIPTERA: TEPHRITIDAE) IN NORTHERN GHANA

BY

BADII KONGYELI BENJAMIN

MASTER OF PHILOSOPHY IN ENTOMOLOGY

UNIVERSITY OF GHANA, LEGON, GHANA

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DECLARATION

I hereby declare that this thesis is the result of my own original research, and that it has neither in whole nor in part been presented for a degree elsewhere. Works of others which served as sources of information have been duly acknowledged by reference to the authors.

Candidate …………………………

Badii Kongyeli Benjamin

Principal Supervisor ………………….

Prof. Daniel Obeng-Ofori

Co-supervisor …………………..

Prof. Kwame Afreh-Nuamah

Co-supervisor ……………………

Dr. Maxwell Kevin Billah

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ABSTRACT

Tephritid fruit flies are a major threat to the horticultural industry in sub-Saharan Africa owing to the heavy losses they cause to fruit and vegetable crops, and the resultant quarantine restrictions. Addressing the fruit fly menace in Ghana requires effective stakeholder training along the fruit value chain, coupled with adequate research information on management strategies. Baseline studies were conducted in northern Ghana to determine the priority management training needs of fruit growers and Agricultural Extension Agents (AEAs), and to document the host range, species composition, seasonal phenology and parasitoid fauna of the pests. The studies involved the use of questionnaire for surveys coupled with a two-year collection and incubation of wild and cultivated fruits from selected sites in the Northern, Upper West and Upper East regions of the country.

Fruit growers in all the regions were generally aware that fruit flies were serious horticultural pests responsible for the high losses in their fruit and vegetable production. Fruit growers in the Northern Region were more familiar with the economically important fruit fly species (especially the African invasive fruit fly, *Bactrocera invadens*) and their damage impact, compared with those in the other regions. Even though basic control practices were adopted by some farmers, a significant proportion of the growers took no action to control the pests. Recommended fruit fly control strategies such as pheromone trapping, bait application, soil inoculation and biological control were virtually unknown to the growers, with the majority of them resorting to the application of unprescribed chemicals with potential environmental and health risks. AEAs demonstrated fair knowledge in majority of the competency aspects of the pests. The top 5 competency areas in need for further training of AEAs included; knowledge of the economically important species, their economic impact, life cycle, host plant associations and control strategies.

Out of 80 plant species studied, 65 (81.5%) of them were positive to 10 different fruit fly species. Eleven (11) plant species were reported for the first time as hosts to *B. invadens*, while two fruit fly species (*Dacus ciliatus* and *Trirhithrum nigerrimum*) were identified for the first time in the area. *Ceratitis cosyra* and *B. invadens* were the dominant fruit fly species recorded. Infestation by *B. invadens* was higher in commercial fruits while *C. cosyra* dominated in the wild hosts. Among the commercial fruits, infestation was highest in mango (*Mangefera indica* L), green pepper (*Capsicum anuum* L.) and water melon (*Citrulus lunatus* Thunb.), whereas sour sop (*Annona senegalensis* Pers.), tropical almond (*Terminalia catapa* L.), syncomore fig (*Ficus syncomosus* L.), African peach (*Sarcocepholus latifolium* Smith.), sheanut (*Vitellaria paradoxa* C.F. Gaertn.), persimmon (*Diospyros mespiliformis* A. DC.), icacina (*Icacina senegalensis* Juss.) and albarillo (*Ximenia americana* L.) dominated the wild host flora. The dynamics of emergence of *B. invadens* and *C. cosyra* fluctuated at various levels in response to the availability of host fruits and the influence of air temperature, relative humidity (RH) and precipitation, with precipitation showing the strongest influence. Four species of larva-pupal braconid parasitoids were reared from 14 fruit species that hosted *C. cosyra* and *B. invadens*. The parasitoids included *Fopius caudatus* (Szépligeti), *Psyttalia cosyrae* (Wilkinson), *P. concolor* (Szépligeti) and *Diachasmimorpha fullawayi* (Silvestri). The most abundant and diverse parasitoid was *F. caudatus* (61.0 %) while the least abundant was *D. fullawayi* (7.7 %). The overall mean parasitism level was 7.1 % with the highest record in sour sop, African peach and icacina. The peak occurrence of the parasitoids was on June and July, which coincided with the peak of the rains and maturity period of many of the surveyed crops.

It is important to train fruit growers on the basic expertise to help address the fruit fly menace in the area. Also, professional capacity development programmes for AEAs should look into how the 5 critical educational needs on fruit fly pests (namely knowledge of the economically important species, their economic impact, life cycle, host associations and control strategies) can be addressed in training workshops. The widespread availability of host plants and the diverse fruit fly species call for particular attention to their impact on commercial fruits, and development of management strategies against these economically important pests. An understanding of the occurrence periods of the different potential hosts and their influence on the population patterns of *B. invadens* and *C. cosyra* is also necessary for the development of sustainable IPM programmes. Finally, this study presents the first inventory of parasitoid fauna of major tephritid pests in the area, providing critical baseline data for future conservation or introduction of parasitoids for biological control efforts in the Ghana.

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CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Background

Over the last two decades, diversification into high value horticultural crops has been pushed as an economic development strategy of sub-Saharan Africa (Weinberger and Lumpkin, 2007). Diversification into horticulture has contributed to poverty alleviation by promoting food security while helping to restore equilibrium in the balance of payments by increasing total export earnings for African countries (World Bank, 2008). Fruit and vegetable crop production is one of the fastest growing sectors of the horticulture industry, providing food, income and employment as well as enhancing access to education and health care. The sector also provides women with economic opportunities especially in rural communities where the highest production of fruit and vegetable crops takes place (Norman, 2003). The changing dietary patterns leading to increased consumption of fruit and vegetables, may account for the fast growth of the sector. Additionally, the increasing liberal global trade arrangements have created new and lucrative production and market opportunities for fresh fruit and vegetable crops in the sub region, and thus, giving the industry more prospects for the future (Jaeger, 2008).

In Ghana, several fruit and vegetable crops are grown for both domestic and export markets. The major ones include mango, citrus, pineapple, papaya, banana, tomatoes, peppers, okra, garden eggs and the cucurbits. More than 90,000 tonnes of fruit and vegetables are exported annually from the country (GEPC, 2010). There are a number of public and private sector enterprises that ensure monitoring of compliance with quality standards, access to markets, improving national goodwill, enlisting government support and providing limited funding for research and development (Jaeger, 2008).

Several constraints, however, hinder the sector from realizing its full potential. Among them include insufficient investments, inadequate basic and adaptive research, limited knowledge of the incidence and management of major pests and diseases, poor extension of existing knowledge and method of dissemination, coupled with the porous borders and weak economic policies (Norman, 2003; Jaeger, 2008). The USAID-commissioned global horticulture assessment identified the following primary issues as of core importance to the development of the horticulture industry in producer countries: (1) market systems, (2) post harvest systems and food safety, (3) genetic resources conservation and development (4) sustainable production systems and natural resource management, (5) capacity building, (6) enabling environment, (7) gender equity and (8) nutrition and human health (World Bank, 2010). A critical look at the situation in Ghana shows a similar trend, and within the constraint of sustainable production systems, biotic stresses that include pests and diseases are considered crucial to development. Currently, infestation and damage by fruit flies has been the key biotic constraint to the increased and sustainable production, and marketing of fruit and vegetable crops in the country (PPRSD, 2010).

1.2 Problem Statement

Tephritid fruit flies are among the most economically important group of insects which pose serious threat to the horticultural industry worldwide (White and Elson-Harris, 1992; Ekesi, 2006). According to Thompson (1998), equatorial Africa is the aboriginal home of 915 fruit fly species from 148 genera with 299 species developing from either cultivated or wild host plants, or in both. Indigenous fruit flies in Sub-Saharan Africa belong to the genus *Ceratitis* MacLeay (e.g., *C. cosyra, C. capitata*, *C. ditissima*, *C. anonae*, *C. bremii*, *C. rosa* and *C. fasciventris*), and *Dacus* Fabricius (e.g., *D. bivitatus, D. ciliatus, D. punctatifrons. D. frontalis* and *D. vertebratus*) (Drew, 1992; Drew *et al*., 2005). In addition, four Asian invasive species of the genus *Bactrocera* Macquart, have invaded the continent. These are *B. invadens*, *B. cucurbitae*, *B. zonata* and *B. latifrons* (Ekesi, 2006). Fruit fly species of these three genera have established resident populations in tropical Africa, causing serious concern in mango, citrus and vegetable production. In Ghana, the earlier fruit flies observed to be of major concern were *C. capitata* (Wiedmann) which attacked citrus (Afreh-Nuamah, 1985; 1999; 2007) and *C. cosyra* (Walker) which attacked mango (Lux *et al*., 2003a, b). However, the arrival of the African invader fly, *B. invadens* (Billah *et al*., 2006) has jeopardized the situation in the fruit and vegetable production sector (PPRSD, 2010). Fruit fly pests are known to spread through and within the West African sub-region primarily by the movement of infested commodities due to the weakness of phytosanitary surveillance and control systems for the export of fruit and vegetable crops among member countries (Mwatawala *et al*., 2004). *Bactrocera invadens* in particular, was first detected in eastern Africa, Kenya in 2003 (Drew *et al*., 2005: Ekesi *et al*., 2006), and in Ghana in 2005 (Billah *et al*., 2006).

Fruit flies are polyphagous pests that cause extensive damage (both direct and indirect) to fruit and vegetable crops in sub-Saharan Africa (Ekesi, 2006; IITA-CIRAD, 2008). Direct fruit damage occurs when adult female fly punctures the fruit skin and lays eggs underneath it. Damage symptoms vary depending on the host fruit species. During oviposition, saprophagous bacteria from the intestinal flora of the fly are introduced into the fruit, causing rot of the fruit tissues surrounding the eggs. When eggs hatch, the rotten fruit tissues make it easier for the larvae to feed. The puncture and feeding galleries made by developing larvae also provide access for pathogens to develop, and increase the fruit decay, and thus, rendering it unmarketable. Generally, the fruit falls to the ground just before the larvae pupate (Ekesi, 2006; Afreh-Nuamah, 2007). Indirect fruit damage and losses result from quarantine restrictions that are imposed by importing countries to prevent entry and establishment of such unwanted pest species through the border lines (Ishida *et al*., 2005).

In Ghana, damage caused by fruit flies has been recognized as a quarantine problem for fruits destined for both international and local markets. Since the introduction of *B. invadens* into the country, the mango production sector has been particularly hit with heavy losses from producing communities (PPRSD, 2010). The damage to fleshy fruits is mainly caused by a limited number of highly polyphagous species, most of them likely belonging to the genera *Ceratitis* and *Bactrocera*. These losses can be very heavy or severe. For example, Lux *et al*. (1999) reports losses of up to 40% in mango in East Africa, while Vayssieres *et al.* (2005) mentioned loss averages ranging from 12 to 50% for the same host in Benin, depending on the season. *Bactrocera invadens* alone can cause production losses of up to 70% on mango, 40% on citrus and significant proportions on fruit and vegetable crops (White and Elson-Harris, 1992; USDA-APHIS, 2008). The presence of high populations of fruit fly species in fruit production areas can lead to severe economic losses for fruit growers, as well as a reduced source of essential dietary components especially vitamins and minerals to consumers. As a result of fruit flies, European and other international borders and airports have intercepted and destroyed large quantities of fruits from several African countries, and thus, causing major economic losses to affected nations. For example, the republic of South Africa, the Lebanon Republic and the United States have banned fruits exports from Ghana as a result of *Bactrocera* and *Ceratitis* species (STDF, 2009; PPRSD, 2010). The strict maximum residue level regulations in the European Union have further jeopardized the export market.

Fruit fly research and management in Ghana is yet to be fully optimized. Although some baseline studies have been conducted on the bionomics and management of the pests (Afreh-Nuamah, 1985; Billah *et al*., 2006; Utomi, 2006; Foba, 2009; Appiah *et al*., 2009; Abdullahi *et al*., 2011; Ambele *et al*., 2012; Foba *et al*., 2012; Nboyine et al., 2012; Wih and Billah, 2012). These studies are mostly specific to one crop or tephritid species, and/or generally targeted at the southern ecologies of Ghana. At present, there is still limited knowledge of fruit fly pests and their economic impact among stakeholders along the fruit value chain. Also, information on the bioecology of the pests and the sustainable strategies to manage them within the different agro-ecological zones of the country still remains fragmented or inadequate, and in many situations, unavailable. The northern sector of the country seems to be the most threatened with the fruit fly problem on mango which is the major host of fruit flies, is the most potentially exportable crop gaining commercial cultivation in the area.

1.3 Justification

The Economic Community of West African States (ECOWAS) has recognized the impact of fruit flies in the sub-region. At a regional validation workshop on “Study on damage inflicted by fruit flies in West African fruit production, and action plan for a regional response” held in Bamako, Mali in August, 2008, the issue of research and organizational problem, in relation to the management of fruit flies along the value chain, was identified as of major concern (STDF, 2009). In line with this, a resolution was passed directing all ECOWAS-member countries to establish national committees that would develop action plans to help address the fruit fly menace in the sub-region (COLEACP-CIRAD, 2009).

In Ghana, the Plant Protection Regulatory Services Directorate (PPRSD) of the Ministry of Food and Agriculture (MoFA), in collaboration with the universities, research institutions and other stakeholders, have initiated some fruit fly awareness campaigns and monitoring activities in some parts of the country. Moreover, in response to the resolution adopted at the ECOWAS workshop, the PPRSD of MoFA, in June, 2010, launched its Action Plan (AP) following the inauguration of the National Fruit Fly Management Committee (NFFMC) of Ghana (PPRSD, 2010). The committee seeks to set standards of public-private partnership for protecting the horticultural sector against fruit flies and other invasive pests in the country. Among the major components of the AP of the committee is to intensify stakeholder awareness, and develop and disseminate integrated management strategies for fruit fly pests in the country. This research project was designed in line with the AP of the NFFMC of Ghana to provide valuable information on fruit flies for the development of sustainable management interventions that would help address the fruit fly menace in the country.

1.4 Objectives

The study sought to determine some key educational and bio-ecological aspects, and their implications for the management of fruit-infesting flies in the northern savanna ecology of Ghana. The specific objectives were to determine the:

1. Knowledge gaps, perceptions and practices of fruit growers on fruit fly pests
2. In-service training needs of Agricultural Extension Agents (AEAs) on fruit fly pests
3. Species diversity and host range of fruit fly pests
4. Seasonal phenology of major fruit fly pests
5. Native parasitoids associated with fruit fly pests

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1.0 Phylogeny of fruit flies

2.1.1 The order Diptera

Diptera is the fourth insect order (after Coleoptera, Lepidoptera and Hymenoptera) in terms of number of known and described species (Rull, 2008). The order contains about 120,000 named species in approximately 130 families, with thousands of species of agricultural, medical and veterinary importance (Diniz and Morias, 2008). Diptera is considered to be the most ecologically diverse order of the Insecta class (Mendes, 2008). Dipterans diet encompasses all possible ranges from blood feeders, endo- and eco-parasites of vertebrates and predators to all forms of mycetophages, saprophages and phytophages (Rull, 2008). Members of the order can be found in every zoogeographic region of the globe, inhabiting a wide diversity of habitats (Grimaldi and Engel, 2005).

Dipterans are holometabolous endopterygote insects, undergoing complete metamorphosis, in which a pupal stage intervenes between the larval and adult instars. Immature stages are morphologically different from adult forms, and often have contrasting habitat and food requirements (Romoser and Stoffolano, 1994). Although some families, species, and sometimes members of one sex of flies are apterous (posses no wings), Diptera as a whole can be characterized for possessing only two functional front wings, and a pair of vestigial knob (named halters) behind the wings, that function as organs of equilibrium, helping the flies to remain stable during flight (Borror *et al.*, 1992). Two suborders can be recognized in Diptera; Nematocera and Brachycera. The Nematocerans include cane flies, midges, mosquitoes and gnats, which have thin multisegmented antennal flagella. Larval forms generally have conspicuous head, and pass through more than three instars before reaching the pupal stage (Mendes, 2008). The Brachycerans include higher flies, hover flies and dung flies, which possess shorter and thicker antennae with fewer flagellomer. These have robust bodies with legs shorter than the Nematocerans. Brachyceran larval forms have the posterior portion of the head capsule desclerotized and extended into the thorax (Rull, 2008). The phylogenic relationships between these two suborders are still controversial, although Nematocera is suspected to be paraphyletic (Mittelbach *et al*., 2007).

Within Brachycera, the infraorder Muscomorpha (=Cyclorrapha) is composed of species whose larval forms are commonly known as maggots, which are mostly saprophagous, and with the exception of their sclerotized mouth hooks, are soft bodied. Cyclorrapha are also characterized by the fact that pupation occurs within the tanned cuticle (the puparium) of the last larval instar (Rull, 2008). Within the Cyclorrapha, the division Schizophora comprised the largest tertiary radiation of insects, with approximately 50,000 species (Grimaldi and Engel, 2005). Schizophora is characterized by possessing a membranous sac that expands like a balloon to rupture the puparium during adult emergence. Such structure, called ptilinum, is then invaginated into the head, and as a consequence, adult schizophorans can be identified by having a ptilinal fissure bordering the face. Within the Schizophora the section Acalyptratatae includes species of flies that possess no calypteres on wings, which are lobes at the extreme base of the wing (Borror *et al*., 1992). Acalyptratatae includes families in the superfamily Tephritoidea.

2.1.2 The Superfamily Tephritoidea

The superfamily Tephritoidea includes eight known families of acalypterate flies: Lonchaeidae, Piophilidae, Pallopteridae, Richardiidae, Ulidiidae, Plastytomatidae, Pyrgotidae, and Tephritidae (Korneyev, 2000a). Lonchaeidae are commonly known as lance flies. There are about 500 described species in 9 genera. Lonchaeids are generally small, robustly built flies with blue-black or metallic bodies. Lonchaeid larvae are secondary invaders of diseased bodies or injured plant tissues, adults have the rare habit among acalypterate flies to form swarms for mating, and are found mostly in wooded areas (Rull, 2008).

The Piophilidae are mostly scavengers in fungi and animal products, with the family getting its common name, skipper flies, due to the fact that larvae tend to jump during their last instars before pupation. Pallopteridae or flutter-winged flies, is a little known small family, with larvae of some species feeding in flower buds, or occurring as predators of wood borer larvae under the bark of fallen trees. Over 50 species in 15 genera are found in the temperate region of the Northern and Southern hemispheres. The Richardiidae is a small family that consists of 30 genera and 175 species. It is a little known family whose adults can be captured in fruit-baited traps; the few larval feeding records of this family suggest that these flies feed on rotten vegetable matter. Most adults generally have conspicuously pictured wings, often with metallic-blue or greenish colours on bodies and legs, and a typical tephritoid ovipositor (Rull, 2008).

Ulidiidae and Plastytomatidae are both pictured-winged flies. The Plastytomatids are sometimes referred to as signal flies. Both families are abundant in the tropics, occurring in decaying tissues but also sometimes feeding on plants with a few species considered as pests. Most species share with the Tephritidae an unusual elongated posteroapical projection of the anal cell in the wing, but can be differentiated by the smooth-curving subcostal veins (Korneyev 2000a). Pyrgotidae are medium to large flies with considerable colouring of the wings. They are mostly nocturnal. Unlike other tephritoids, Pyrgotids are endoparasitoids; the females pursue scarab beetles in flight, laying their eggs on the back of the beetle, under the elytra, beyond host’s reach. Developing larvae enter the cavity of the beetle and eventually kill the host before pupation (Rull, 2008; Mendes, 2008). Phylogenetic relationships among tephritoid families have been reviewed by Korneyev (2000a).

2.1.3 The Family Tephritidae

Tephritidae is a very large family, which includes more than 4,000 described species. The family can be characterized by an elaborate wing patterns and the possession of a telescopic ovipositor by the female. Tephritidae is known as one of the most ecologically diverse families of Diptera, and due to its size, it has been difficult to synthesize phylogenetic relationships among higher groups of the family (Korneyev, 2000b). Phylogenetic relationships of important genera of the family have been provided by Norrbom and Thompson (2003). Despite the lack of a conclusive phylogeny, the study of Tephritidae can be approached by looking separately at five different subfamilies; Blepharoneurinae, Phytalmiinae, Trypetinae, Dacinae and Tephritinae, all of which are well represented in the tropics.

The subfamily Blepharoneurinae represents flies of the tropical group, and composed of five main genera; *Ceratodacus*, *Problepharoneura*, *Blepharoneura*, *Baryglossa*, and *Hexaptilona.* The first three genera consist of species of the neotropical and afrotropical regions, while the last two genera include species of the paleartic regions. Although this subfamily is composed of a reduced number of described species, recent scrutiny on flies in the genus *Blepharoneura* suggests that there may be more than 200 species. This subfamily is interesting as the group appears to be one of the oldest lineages in Tephritidae. All the genera for which biological data have been gathered feed on plants and parts of plants in the family Cucurbitaceae. There is suggestive evidence that these flies have undergone rapid processes of speciation, as much as more than one species can cohabit the same plant, exploiting different parts of it and exhibiting complex courtship behaviours (Condon and Norrbom, 1994).

Phytalmiinae is a subfamily comprising six genera; *Diplochorda, Ortaloptera, Phytalmia, Sessilinia, Tetrastiomyia,* and *Sophiria.* These are the flies with antenna-like head projections, sometimes referred to as antler flies or deer flies (not to be confused with Tabanidae). Decaying plant material is the larval food across this subfamily. All described species of antler flies occur between the island of Borneo and the Cape York Peninsula of Australia. The few behavioral studies on this group suggest that antler flies evolved in the context of male intrasexual competition. Resource defense mating systems for this group have been described by Dodson (1997), while Dodson (2000) provided a review on current knowledge on the Phytalmiinae.

Trypetinae is a large subfamily that includes 19 known genera; *Carpomya*, *Cryptodacus*, *Goniglossum, Haywardina, Myiopardalis, Rhagoletis, Rhagoletotrypeta*, *Zonosemata*, *Acidia, Euleia, Strauzia, Trypeta, Anastrepha, Toxotrypana*, *Epochra*, *Paraterellia, Chetostoma, Oedicarena*, and *Myoleja*. The genera *Rhagoletis*, *Anastrepha*, and *Toxotrypana* include several species of major economic importance. While members of *Rhagoletis* are both holartic and neotropical in distribution, *Anastrepha,* and *Toxotrypana* are restricted to the new world, the rest of Trypetinae is especially diverse in the old world tropics, which may be the center of origin (Foote *et al*., 1993). Within Trypetinae, the subtribe Trypetina contains all the known leaf-mining species of tephritids, along with others with different larval feeding habits. A comprehensive account of this group of flies is provided by Han (2000).

Tephritinae is considered the most specialized subfamily of Tephritidae. It is composed of six tribes with over 210 genera (Foote *et al*., 1993). Most species of Trypetini breed in flower heads, or form flower, stem, or root galls in plants of the family Asteraceae. Due to this habit, many of these tephritids have been used in biological control of weeds (White and Elson-Harris, 1992; Turner 1996). Sexual behavior and biology of some members of this subfamily have been reviewed by Headrick and Goeden (1998; 2000).

Dacinae is a subfamily that contains only three genera *Bactrocera, Dacus,* and *Ceratitis* all of which include many species of major economic importance. All members of this subfamily are native to the Old World, despite the fact that the Mediterranean fruit fly, *C. capitata* has been established in South and Central America since the beginning of the 20th century, and there have been recurrent introductions and eradication efforts of this pest along with the Olive fruit fly, *B. oleae,* the Oriental fruit fly, *B. dorsalis* and others in North America (Foote *et al*., 1993).

2.1.4 True Fruit Flies

The term “fruit fly” is sometimes used for two distantly related groups of flies, namely the families Drosophilidae and Tephritidae. The Drosophilidae includes “fruit flies” of the geneticists, which are in reality, micro-fungi feeders that have acquired this name because of their habit of feeding on decaying fruit (Aluja *et al*., 2003). The Tephritidae is generally described to include the “true fruit flies” because most species attack living plant material, and an estimated 40% of the over 5,000 described species attack intact and growing fruits. Females of fruit flies have an ovipositor, similar to the “sting” of a wasp, with which they puncture the skin of healthy fruits and lay their eggs therein. Larval development is completed within the fruit (which may become rotten as a result) and the fully grown larvae then drop into the soil and form a puparium (Aluja *et al*., 2003).

There are about 150 genera and 950 species of Tephritid fruit flies known in tropical Africa, most of which form a natural component of Africa's rich and varied biodiversity. About 70 species of fruit flies are considered important agricultural pests, and many others are minor or potential pests. Fruits and vegetables are the most important crops attacked, even though some seed crops are also affected (White and Elson-Harris, 1992).

2.2.0 Functional morphology of fruit flies

Morphology and anatomy of the different life stages of fruit flies, particularly characters useful for taxonomic purposes, have been described in detail by Drew (1982) and Munro (1984). Only those aspects relevant for an understanding of the group's developmental biology are considered here.

2.2.1 The adult

The adult body colouration of different fruit fly species varies from black through various shades of brown to orange or yellow. Yellow marks, particularly on the thorax, give many species a somewhat wasp-like appearance. This resemblance is particularly pronounced in certain *Bactrocera* subgenera and *Callantra* spp., which have petiolate abdomens, heavily fuscated costal stripes on the wings, and a jerky, wasp-like walk (Fletcher, 1987). The paired antennae each consist of three segments. Scanning electron microscope studies on *B. oleae* and *B. tryoni* indicate that the outer segment is covered with long cuticular spines interspersed with large numbers of chemosensilla of several distinct morphological types and functional significance (Drew *et al*., 1983; 1984; Giannakakis and Fletcher, 1985).

The general structure of dacine fruit flies is fairly typical of cyclorrhaphan Diptera. Male dacines, except those of some groups such as Gymnodacus, typically have a pair of combs (or pectins) comprised of stiff curved bristles on the lateral hind margins of the third abdominal tergite. These combs function as stridulatory organs during courtship (Drew *et al*., 1983). Both sexes have a pair of tergal glands (ceromae) that open onto the surface of the fifth tergite. These consist of dense groups of minute alveolae that secrete a waxy substance, which is spread onto the body and wings during preening (Munro, 1984). In female dacines, abdominal segments 7-9 form the ovipositor, which is usually smooth and pointed but is serrated in some species. The apical segment has a number of chemosensiIla; the most prominent are the preapical setae that arise from lateral grooves on either side of the segment (Hardy, 1969). These presumably play an important role in fruit discrimination (Fletcher, 1987).

2.2.2 The egg

The study of tephritid egg morphology has largely been confined to the description of surface features (Headrick and Goeden, 1993) mainly through transmission electron microscopy examination (Margaritis, 1985). Tephritid eggs are elongate ellipsoidal in shape and thus have only a single primary axis. At one end, the egg bears a pedicel. The pedicel bears the micropyle and the aeropyles. Typically, the micropyle is located on the apex of the pedicel and may have a single or multiple openings (Fletcher, 1987). The arrangement of the micropyle is similar among the nonfrugivorous species studied. The pedicel may be only a slight projection (Knio *et al*., 1996), but it may also occur as an elongated stalk nearly as long or longer than the body of the egg (Goeden and Teerink, 1996). The eggs of all tephritid species studied develop inside the ovariole with the pedicel oriented toward the ovary terminus. This orientation facilitates the functions of fertilization and oviposition. According to Headrick and Goeden (1994), fertilization takes place through the micropyle as the egg passes through the median oviduct. The basal end exits the gonopore first near the end of the aculeus that is inserted into plant tissues during oviposition. Embryogenesis proceeds after oviposition, and the head of the embryo develops and orients toward the pedicel. However, in many species, the embryo turns 180^{o} before eclosion and exits the egg through the basal end. This apparently serves to position the embryo so that the plant tissue is encountered immediately upon eclosion (Headrick and Goeden, 1991).

The surfaces of eggs have polygonal, typically hexagonal, reticulations or mass-relief-type ridges. These ridges represent the outline of the follicle cells responsible for laying down the chorion (Mouzaki and Margaritis, 1991). These reticulations may be prominent and bear additional structural ornamentation, as in *Tephritis baccharis* (Headrick and Goeden, 1991). The surface features of the egg are most strongly developed at the pedicel end, and diminish often to a smooth surface near the basal end, as reported in *Aciurina thoracica* (Headrick and Goeden, 1993). Goeden and Headrick (1991) hypothesized that because the pedicel end of the egg is left exposed to facilitate gas exchange, and the basal end is inserted into plant tissues, the pedicel would need greater structural support to protect the aeropyles and associated respiratory channels from distortion.

2.2.3 The larvae

Three free-living instars exist for tephritid fruit flies. The only known exceptions are *Urophora jaceana* and *Urophora cardui*, in which the first instar remains in the egg and exits as a second instar. The external anatomy of the larvae of frugivorous tephritids has been examined in detail, and at least partial descriptions based primarily on scanning electron micrographs for 25 species have been available (Knio *et al*., 1996). By comparison, White and Elson-Harris (1992) have developed an atlas of immature morphology based on the third instar of 34 economically important species. Several other structures including the median oral lobe, the lateral spiracles accompanied by a variable number of sensilla associated with the sensory organs of the gnathocephalon have been newly identified for various frugivorous species (Headrick and Goeden, 1993).

Tephritids have distinct anterior and posterior spiracles. With the aid of modern scanning electron microscopy, the lateral spiracles have been located on the meso- and metathoracic segments and the abdominal segments, excluding the caudal segment, which bears the posterior spiracles (Headrick and Goeden, 1990). Lateral spiracles are always located along the lateral mid-linenear the anterior portion of a segment, and they have a variable number of associated campaniform sensilla posterior of the spiracle. The number of sensilla ranges from one, in some *Aciurina* (Goeden and Teerink, 1996) and *Trupanea* (Knio *et al*., 1996) species to as many as four in *Stenopa affinis* (Goeden and Headrick, 1990). When more than one sensilla is present, they are typically arranged along a dorso-ventral axis adjacent to the spiracle.

2.2.4 The pupa

The puparium is the hardened, penultimate larval integument of the developing fly. It is remarkable in its external morphology in tephritid fruit flies. When the third instar larva is ready to pupate, it leaves the medium, and its anterior spiracles evert, its body shortens and ceases to move and it attaches to a firm substrate. The cuticle then transforms into a puparium, which is initially soft and white, but soon hardens, turning tan and eventually brown and bristle. Shortly after the puparium forms, metamorphosis then takes place. The prepupal integument is shed and adheres to the inner wall of the puparium. The pupa forms within the puparium after the prepupal molt. The pupa develops independently of the puparium and has bilobed thoracic spiracles for respiration (Headrick and Goeden, 1990). The larval tracheae adjacent to the anterior and posterior spiracular openings remain open, thus allowing for gas exchange for the developing pupa within the puparium (Fletcher, 1987).

Goeden and Headrick (1992) reported a pre-puparial stage in which the mouthparts are invaginated and the integument takes on a waxy appearance, but the processes of integument hardening and darkening are delayed. The latter processes may be triggered by changing environmental conditions by overwintering prepuparia of certain *Neaspilota* (Goeden and Headrick, 1992) and North American *Urophora* species, especially those found at higher altitudes (Goeden *et al.,* 1995).

Eclosion marks the end of pupation and the beginning of the adult life. The insect cracks open the puparium anteriorly and laterally at its seams and emerges from the pupal case. This almost invariably occurs around dawn, when leaves are still dump with dew, and the emerging fly can fold its new wings and harden its cuticle without the risk of desiccation. The timing of this is controlled by circadian rhythm (Fletcher, 1987).

2.3.0 General biology of fruit flies

Fruit fly biology is an extensive topic. The following account is largely based on information gathered from fruit infesting tephritids of economic importance and may not represent tephritid biology as whole.

2.3.1 Life cycle

Basic life cycles of tropical pestiferous fruit flies are roughly similar. A generalized developmental cycle of typical fruit fly is shown in Figure 2.1. Eggs can be deposited singly (as in *A. obliqua*), in strings (as in *T. curvicada*), or in clutches of various sizes (as in *A. ludens, C. capitata* and *B. cacuminata*) (Headrick and Goeden, 1994). Eggs are typically deposited under the epicarp or mesocarp of ripening fruit, although some species such as *A. sagittata*, or *T. curvicauda,* possess long ovipositors that they can employ to deposit eggs in or near seeds from which their offspring feed (Robinson and Hooper, 1989; Diaz-Fleischer *et al*., 2000). Egg hatch, like all other developmental stages of fruit flies, is dependent on environmental conditions. For example, eggs of *B. dorsalis, B. cucurbitae*, and *Ceratitis capitata* take from one to two days to hatch. *Ceratitis* *capitata* typically posseses 28 polytrophic ovarioles that can produce from 300 to 1000 eggs during the life of a female, and these are laid in clutches of 1 to 10 eggs (Mcpheron and Steck, 1996).

Prior to pupation, late instar larvae may leave host fruit while the early instar may still be attached to the tree, or more frequently pupate within the fruit once it has fallen to the ground. Within the fruit, pupation has been observed to be common among many tephritid larvae such as in the olive fruit fly, *Bactrocera oleae* and the Medterranean fruit fly, *C. capitata*. Moreover, larvae of some species like *C. capitata* jump by means of a spring mechanism that may serve to evade predators. Larvae of several species of *Anastrepha* and *Bactrocera* crawl out of the host fruit and seek adequate sites to bury into the ground, usually 2.5 cm and pupate therein (Bush 1966). Larvae seem to prefer sites with loose, moist, shaded soil for pupation. Larvae exiting the fruit in search of pupation sites are susceptible to dehydration and predation by ants and beetles (Aluja *et al.*, 2000).

After completion of metamorphosis, adults exit the puparium by rupturing one end with the aid of an appendage called *ptilinum*, which invaginates into the head soon after emergence. Newly emerged adults are desclerotized, and require some time for their cuticle to harden by exposure to the elements of nature. Tephritid adults are anautogenous, requiring to consume protein in order to reach sexual maturity. Sexual maturation with free access to protein sources can take from 5 to 20 days or more depending on the species. At sexual maturity, flies mate, oviposit and the cycle ends (Aluja *et al.*, 2000).

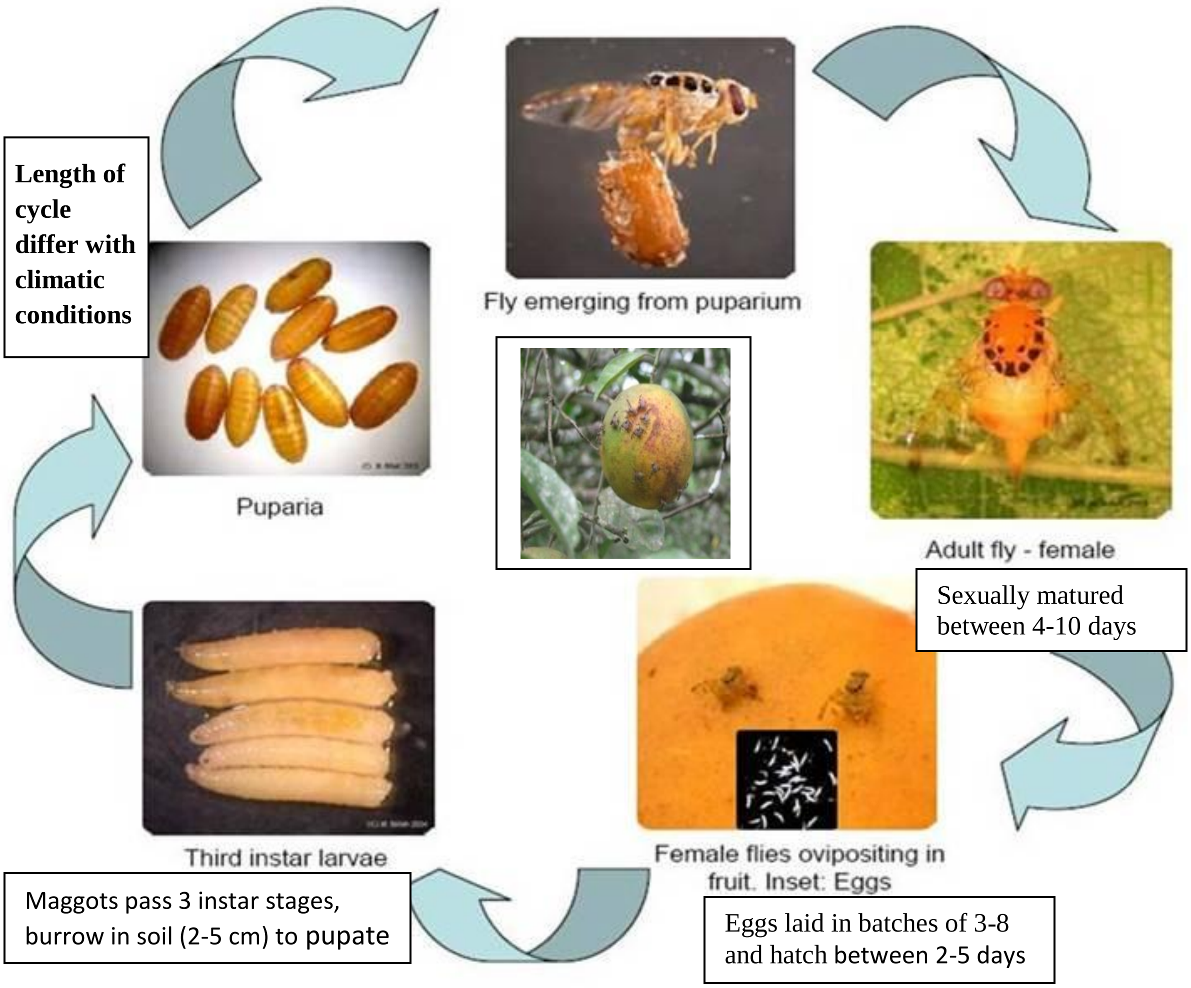

Figure 2.1: Generalized developmental cycle of fruit flies (Adapted from Ekesi, 2006)

Adult longevity is variable within and across species, and between both sexes. It has been suggested that some species of *Anastrepha* may enter aestivation as adults during periods of adverse climatic conditions and host unavailability. Some species of *Bactrocera* may reabsorb eggs into the body system during host scarcity (Vargas *et al*., 1997). At any rate, adult longevity appears to be the strategy of monophagous tropical tephritids to cope with fruit maturation periodicity (Aluja *et al*., 2000).

2.3.2 Nutrition

Essential nutrients for fruit flies (adults and larvae) are amino acids, vitamins, sugar, minerals and growth factors (Mazor *et al*., 1987). To meet the nutritional requirements, a large array of ingredients is used for artificial diets for larvae. Included among these are dried carrot, wheat products (germ, bran, floor), yeasts (brewer's yeast, torula yeast, yeast extracts), proteins (amino acids or enzymatic hydrolysate, autolysate), oils, sucrose, cholesterol, choline chloride, vitamins and salts. To provide texture, products such as tissue paper, cellulose, corn grits, bagasse and cassava, have been used. Antimicrobial agents such as nipagin, potassium sorbate, butoben, sodium benzoate and formalin, are used to keep artificial diets free from spoilage by micro-organisms, at least, until after the first instar. Egg production and hatchability are significantly reduced when vitamin E, biotin, choline chloride, inositol, nicotinic acid and riboflavin, are individually omitted from diet (Heath *et al.*, 1997; Lux *et al*., 2003a).

Adult flies require carbohydrate source, water and a protein substance in order to reach sexual maturity. In nature, although fruit flies have been observed feeding on a large range of products, such as decaying fruits, damaged fruits, plant sap, nectar, animal faeces, and honey, their major source of protein comes from bacteria belonging to the Enterobacteriaceae, commonly referred to as the fruit fly bacteria. A combination of sugar and enxymatic hydrolysed protein smeared on cards suspended from the tops of cages, and isolates of Enterobacteriaceae on agar plates placed on the tops of cages, provide adequate nutrients for a range of fruit fly species (Drew and Lloyd, 1987).

2.3.3 Host associations

Most species of Tephritidae studied are phytophagous. Host range varies considerably, often among closely related species (Norrbom and Kim, 1988). Many species are strictly monophagous. For example, *B. oleae* breeds only in olives, but some pest species are remarkably polyphagous. For example, *C. capitata* has been reported in more than 300 hosts (Liquido *et al*., 1991). Probably the majority of Tephritidae, however, are oligophagous, breeding in a few related or ecologically and chemically similar hosts. *Toxotrypana* species, for example, breeds in similar, latex-bearing, thick-skinned fruits of Caricaceae and Asclepiadaceae, two plant families that are not closely related (Norrbom and Kim, 1988). Even many of the polyphagous pest species, although able to breed in many hosts, have preferences for certain plant families or genera. Host races are known in *Rhagoletis* and possibly in *Eurosta* and *Tephritis* (Hernández-Ortiz and Aluja, 1994).

Although phytophagy is the predominant mode of feeding in the Tephritidae, the Tachiniscinae are all probably parasitoids (the only reared species is a moth parasitoid), and at least one adramine species (*Euphranta toxoneura*) is predaceous within galls. Saprophagy, which is predominant in the Platystomitidae and Otitidae, could be the primitive feeding habit for the Tephritidae. Some (probably most) Phytalmiini and Acanthonevrini are saprophagous, although many breed in damaged or recently dead tissues of limited ranges of plants. A few species have been reared from rotten fruits, decomposing tree trunks, or from under bark of live trees (Dodson and Daniels, 1988; Permkam and Hancock, 1995). Some species of *Acanthonevra* breed in decaying bamboo shoots (Hancock and Drew, 1995). *Termitorioxa termitoxena* has been reared from termite galleries in living trees as well as from under tree bark (Hancock, 2002).

Although tephritids are commonly known as fruit flies, a variety of host parts and tissues are attacked, including fruits (pulp and/or seeds), flowers, stems, buds, leaves, and roots. In phytophagous species, females deposit eggs in healthy plant tissues, where the larvae feed, and sometimes causing gall formation. Fruits and flowers (of diverse plant families) are the plant parts most commonly attacked, but many Trypetini are leaf or stem miners, and some Gastrozonina and

Acanthonevrini breed in bamboo shoots (Hardy, 1988, Hancock and Drew, 1995). The members of the subfamily Tephritinae have specialized in attacking Asteraceae and a few other families (Acanthaceae, Goodeniaceae, Lamiaceae, Verbenaceae). They breed in the flower heads or form galls, although the type and stage of flower tissue attacked varies (Headrick and Goeden, 1990), and galls of varying form and complexity may be produced on stems or roots, in flowers, or rarely on leaves (Freidberg, 1984). The larvae of species of *Rachiptera* and *Strobelia* secrete a liquid that forms a globular protective structure outside of its gall (Aljaro *et al*., 1984). Some species of *Tephritids* and *Campiglossa misella* have alternate gall-forming or stem-mining and flower-feeding generations, and *Trupanea conjuncta* is a faculative gall-former (Goeden, 1993).

There is no worldwide list of tephritid host plants other than that of White and Elson-Harris (1992). Liquido *et al*. (1998) listed and cataloged the reported hosts of *C. capitata*, and Copeland *et al*. (2002) reported numerous additional hosts. De Meyer *et al*. (2002) listed the hosts of all *Ceratitis* species recorded from the Afrotropics. Norrbom and Kim (1988) provided a list of the hosts of *Anastrepha*, and Norrbom (2004) provided a database of the hosts of *Anastrepha* and *Toxotrypana*. There are no comprehensive host lists for the other zoogeographic regions. For the Afrotropical Region, Munro (1984) includes numerous host data; host index for many Tephritinae, and the Dacini of the region. For the Australasian Region, the hosts of the Dacini were listed by Drew (1989), those of the Phytalmiinae, Ceratitidini, and most other non-dacine Trypetinae of Australia were listed by Permkam and Hancock (1995), and the most known hosts of the Tephritinae of Australia were included in Hardy and Drew (1996). For the Neotropical Region, host data for *Rhagoletis*, *Anastrepha* and *Toxotrypana* have been compiled (Norrbom and Kim 1988), and known host plants for the Brazilian and Chilean tephritid species were listed by Frías (1992). For the Oriental Region, Kapoor (1993) listed the hosts of the Indian species, and provided host indices for the species of Thailand and the Philippines.

In tropical Africa, host plants of fruit-infesting flies have received extensive evaluation in a number of ecologies. Detailed checklist of host plants of some major tephritid species in East and Central Africa is provided by De Meyer *et al.* (2002) and Ekesi and Billah (2006). Also, differences in host range among different polyphagous pests and the importance of certain plant families in the natural history of these pests have been studied in Kenya (Copeland *et al*., 2002, 2006), Benin (Vayssieres *et al.*, 2005), Tanzania (Mwatawala *et al.*, 2006a; 2009a), Mali (Vayssieres *et al.*, 2007). Other studies focussed on the fruit fly spectrum of one or few commercial hosts, such as mango and citrus (Vayssieres and Kalabane, 2000; Vayssieres *et al*., 2005). Other available records on this topic are scattered through the literature, many of which are locally- and/or species-specific and require further evaluation.

2.3.4 Symbiotic associations

Mutualistic relationships with microorganisms are extremely common among tephritid species. Possibly, the relatively low concentrations of proteins and other essential chemicals in vegetable tissues, make supplementary sources of certain nutrients mandatory. The vital importance of the symbiotes to their hosts is evidenced by the morphological adaptations evolved to ensure their survival and transmission from generation to generation (Bateman, 1972; Headrick and Gorden, 1998). The most elaborate adaptations so far reported for a tephritid are those of *Dacus* species (Rull, 2008). They multiply in the esophageal bulb and are released as compact masses, which pass down the gut and break down at the beginning of the hind gut. Electron microscopy has indicated that the bacteria subsequently collect and multiply in the diverticula that open into the rectum, and are transferred from there to the eggs during oviposition; some enter the micropyle and others remain on the egg surface (Mazzini and Vita, 1981). The bacteria enter the larvae at the time of hatching and multiply in the four mycetomes. Small numbers remain in the pupal stage and reinvade the esophageal bulb when it forms. This elaborate system is far from typical of the remainder of the Tephritidae. Fletcher (1987) reported evidence of increasing levels of development of the symbiotic organs, with the Trypetinae the most primitive, and the Dacinae the most highly developed.

The majority of the microorganisms which have so far been established as symbiotes of tephritids have proved to be rod-like, Gram-negative bacilli. Yeasts, fungi, and Gram-positive bacteria have been cultured from a number of species (Bateman, 1972) but have usually been shown to be simply associated organisms rather than symbiotes. It is probable that the most important function of the symbiotic bacteria is the production of specific nutrients which are absent or in low concentrations in the diets of the host insects. It is usually assumed that they supplement the larval diet primarily, even though the morphological adaptations which facilitate their survival are often far more elaborate in adults (Headrick and Goeden, 1998). Symbiotes may also be involved in the degradation of toxic substances ingested by the host insect. Fletcher (1987) suggested that use might be made of *D. oleae's* extreme dependence on its symbiotes to achieve suppression of field populations of this serious pest. The symbiotes are very rapidly killed by streptomycin, and of course, the resultant larvae die soon after hatching from the egg. The progeny of recombinant parents have a considerably reduced rate of survival.

2.3.5 Natural enemies

Many groups of organisms have been reported to attack tephritid fruit flies, but the records are widely scattered in literature and, except for some fruit fly species, there are few lists or review publications concerning tephritid natural enemies.

2.3.5.1 Predators

Common larval and pupal predators of tephritid fruit flies include Formicidae, predaceous wasps, Dermaptera, Staphylinidae, Carabidae, Coccinellidae, Chrysopidae, Pentatomidae, Coreidae, mites, crickets and myriapods (Sivinski, 1996). Immature stages of tropical fruit flies are known to be heavily preyed upon by ants (Van Mele and Cuc, 2000; Peng and Christian, 2005), especially during the vulnerable moment between leaving the fruit and securing a pupation site (Aluja *et al*., 2005). Van Mele *et al*. (2007) investigated the effect of the African weaver ant, *Oecophylla longinoda*, in controlling fruit flies in mango in Benin agrosystems and reported that conservation biological control with this predatory ant in high-value tree crops has great potential for African and Asian farmers. Staphylinid beetles can also prey on larvae in fallen fruits (Stibick, 2004). Mordellid beetles and birds attack the immatures of *Eurosta solidaginis* in their galls (Abrahamson *et al*., 1994). A cecidomyiid is an egg predator of *Bactrocera oleae* (Neuenschwander *et al*., 1983). Utomi (2006) conducted a preliminary survey on the natural enemies of *B. invadens* in four locations in the forest ecology of Southern Ghana. A range of predator insects of seven families belonging to five orders were recorded.

Spiders, wasps, birds, toads and gekkos have also been reported as predators of adult tephritids (Condon and Norrbom, 1994; Sivinski, 1996). Jumping spiders have been presumed to constitute a selective force on the evolution of wing patterns and wing displays of adult tephritids. Apparently, *R. pomonella* is able to deter spiders from pounding due to the fact that its wing patterns resemble a frontal view of a spider that conspecifics and avoid attack (Sivinski, 1996). Hendrichs and Hendrichs (1998) observed attack of vespid wasps on *C. capitata*, noting that calling males, females visiting leks, and ovipositing and mating couples were heavily predated upon. Drew (1987) reported that frugivorous rodents caused the highest mortality in two species of *Bactrocera*, and Thomas (1993) reported predation by rodents on immatures of *Blepharoneura* and *Anastrepha*.

2.3.5.2 Parasites

Over a 100 species of parasitic wasps in the family *Braconiadae* have been reared from fruit infesting tephritids. Parasitoids can utilize their tephritid host during the egg stage, as is the case with *Fopius arisanus* on eggs of *C. capitata*, or *Utetes canaliculatus* on eggs of *Rhagoletis pomonella*, which the parasitoids appear to find by following trails of marking pheromone of its host (Wharton, 1989). Other species parasitize tephritid larvae of different instars such as *Doryctobracon areolatus* and *D. crawfordi*, both of which attack larvae of different species of *Anastrepha* (Aguiar-Menexes and Menexes, (1997). *S*ome species also attack tephritid pupae such as *Pachycrepoideous vindemiae,* which has been found in the pupae of *C. capitata,* and *A. ludens* (Wharton *et al.*, 2000). Parasitoids attacking different developmental stages can specialize in single species. For instance, *Utetes canaliculatus*, specializes on tephritids in several genera. Also, *Diachasmimorpha longicaudata* has been reared from *Ceratitis, Bactrocera, Anastrepha* and *Rhagoletis*. It may parasitize dipteran insects in several families, as is the case with *Pachycrepoideous vindemiae* (Stibick, 2004).

Several species of parasitoids have been introduced or artificially reared and used in augmentative biological control programs against tephritids (Wharton, 1989). White and Elson-Harris (1992) provided references concerning the parasitoids (mostly Hymenoptera) of the 100 most economically important species of Tephritidae. Wharton (1989) listed parasite species used in biological control of fruit flies. A great deal of useful information on parasitic wasps attacking fruit flies worldwide is provided by Stibick (2004). In Africa, Wharton *et al*. (2000) reared ten hymenopteran parasitoids dominated by koinobiont assemblage from *C. capitata* and related tephritids from coffee plantations in Kenya. Billah *et al*. (2005) studied the effect of host larvae on three *Psyttalia* species, braconid parasitoids of fruit flies and reported that *Psyttalia* species are especially important in post-release sampling surveys to ascertain the establishment of the parasitoids in new environments where they may adapt to new fruit fly host species. The possibility of rearing some Opiine braconid parasitoids on four species of *Ceratitis* from Kenya was demonstrated by Copeland *et al*. (2006). In a preliminary survey in the southern ecology of Ghana, Utomi (2006) recorded range of parasitic wasps dominated by Braconidae, Opiinae and Ichneumonidae infesting fruit flies in mango and citrus plantations. The reproductive compatibility between four different species of *Psyttalia* from Kenya and individuals of the morphologically identical *Psyttalia concolor* from laboratory culture from Italy was assessed by Billah *et al*. (2008a) through cross-mating tests using single-pair and group mating methods. Vayssieres *et al.* (2011; 2012) provided update of inventory of parasitoids associated with fruit flies in cultivated and wild crops within the agrosystems of Benin and Senegal.

2.3.5.3 Pathogens

A number of pathogenic microorganisms have been known to attack tephritid fruit flies. For example, the fungus, *Stigmatomyces aciurae* (Ascomycetes) has been reported on *Anastrepha striata* adults collected in the field (Goeden and Benjamin (1985). Hedstrom (1994) reported records of *Stigmatomyces* fungus species known to attack Tephritidae, and *Laboulbeniales* species have been found on abdomens of various fruit fly species. A virus is known to attack *Bactrocera tryoni* (Sivinski 1996). Drew and Allwood (1985) described a species of Strepsiptera that parasitizes ten species of *Bactrocera*. Nematodes have also been used for the control of several tephritid species (Sivinski, 1996), but naturally occurring attacks have not been reported.

The use of microbial pesticides in control of fruit fly pests is generally considered as biotactical techniques. It should be remembered that nongenetic resistance may take place. This includes phenotypic changes in insect behavior or physiology and of host plant interference with pesticide action, including microbial pesticides such as entomopathogenic bacteria and viruses. These are particularly sensitive to plant chemistry because they infect through the gut. As a consequence, the composition of foliage ingested with the microbial pesticide can dramatically influence its effectiveness. (Appel and Schultz, 1994). Another factor to consider is rainfall. It has been suggested that a light rainfall may help in prolonging the period of activity of viral preparations by moving the virus downwards, towards the more shaded parts of a plant and away from light. This would help to prolong its effectiveness. No absolute proof of this hypothesis has yet been made. (D'Amico and Elkinton, 1995)

2.4.0 Ecology of fruit flies

A great deal of information on the ecology of tephritid fruit flies has accumulated over the years, but most of it is scattered and fragmentary. Investigations aimed at the systematic assembly of quantitative and qualitative information, leading to an understanding of the determinants of abundance of populations of species are presented here.

2.4.1 Life history strategies

The two most important parameters influencing the life history strategies of dacine fruit flies are (a) suitability of the environment for reproduction and survival and (b) host availability in time and space (Fletcher, 1987). The life history characteristics of the polyphagous species are best suited for exploiting resources that occur intermittently throughout most of the year, but are unpredictable in time and space. The adults have high mobility, relatively long life span (often more than three months), high potential fecundity (> 1000 eggs per female), scramble type competition in the larval stages, several generations per year, and the ability to pass unfavorable periods of the year in a facultative reproductive diapause when necessary (Vargas *et al*., 1983). The life history characteristics of the oligophagous species are similar in many respects to those of the polyphagous species. However, the majority of oligophagous species have a lower potential fecundity (400-600 eggs) (Fletcher, 1987) and their rate of egg production is more directly influenced by the availability of suitable hosts (Fitt, 1986).

The life history strategies of the monophagous and stenophagous species vary depending upon the fruiting characteristics of their hosts. In general, they have fewer ovarioles and lower potential fecundity than the other groups. The potential fecundity of *B. oleae* and *B. latifrons* is about 300 eggs per female (Vargas and Nishida, 1985). Females of *D. musae*, however, have about the same number of ovarioles as polyphagous females, and therefore possibly have the ability to lay a large number of eggs in a relatively short period when hosts are abundant. *Bactrocera opiliae* is univoltine and spends most of its life as an adult, although the actual reproductive period is quite short. Adults of *B. oleae* can survive several months when reproductively inactive, but during periods of intense oviposition, particularly in late summer, their longevity is markedly reduced (Kapatos and Fletcher, 1984). During much of the year, adults probably live a maximum of 1-2 months. Unlike most dacines, *B. oleae* lays only one egg per fruit and then marks the fruit with fruit juice. It is the only dacine known in which contest type competition normally prevents the development of more than one larva per fruit. A number of other monophagous species that infest small fruits, e.g. *D. cacuminatus* and *B. opiliae*, do not use marking compounds; overcrowding due to multiple ovipositions can result in high mortality of larvae (Fitt, 1981; Drew and Hooper, 1983), because the type of competition switches from scramble toward contest at relatively low larval densities per fruit.

The importance of dispersal also varies among monophagous species. Those that infest host plants that fruit erratically throughout the year, e.g. *D. cacuminatus*, appears to be highly mobile, and move around frequently in search of hosts. *Bactrocera opiliae*, which infests a host with a limited fruiting period, moves mainly from emergence site to dry season refuge, and then in search of fruiting host plants at the beginning of the subsequent wet season. In *B. oleae* the dispersive movements are determined largely by host availability in the areas where they emerge. The polyphagous dacines are the most strongly r-selected, and the monophagous species, such as *B. oleae*, are the least strongly r-selected, although they still fall nearer the r than the K end of the spectrum compared with most other tephritids (Fletcher, 1987).

2.4.2 Determinants of abundance

The family Tephritidae divides naturally into two major groupings on the basis of physiological and ecological characteristics: (i) the univoltine species, which usually have a winter diapause and inhabit the more temperate regions of the earth (e.g., *Rhagoletis* species); and (ii) the multivoltine species which have no obvious diapause and inhabit warmer regions (e.g., *Dacus* and *Anastrepha* species (White and Elson-Harris, 1992). The principal components of the life systems of tephritids are moisture, temperature, light, food, natural enemies, and symbiotes (Fletcher, 1987). The part which these factors play in the determination of numbers, and the aspects of behavior which are of particular relevance to survival and multiplication, would be examined here.

2.4.2.1 Effect of moisture

Environmental moisture is of special importance as a determinant of abundance for several tephritid species. The distribution of *B. cucurbitae* in India is largely determined by moisture. The population expands when rainfall is adequate and contracts during dry periods (Nishida, 1963). Moisture is of primary importance in the determination of abundance of the Queensland fruit fly, *B. tryoni*, at least toward the southern fringe of its permanent distribution. Over a period of several years, there was a highly significant correlation between the availability of moisture as measured by summer rainfall, and the peak numbers of this pest achieved each year. The effect is apparently mediated through a reduction in the fecundity of adult females during dry periods, by greatly reduced immigration from other areas, and by high mortality among newly emerged adults which struggle upward through dry soil into air with low relative humidity (Fletcher, 1987). In Nova Scotia, *R. pomonella* is also less common in hot dry summers than in cool wet ones due to desiccation of pupae in dry soil (Neilson, 1990). These effects have a direct bearing on the magnitude of adult populations of this species in dry years and in dry areas (Aluja *et al*., 2000). The longevity of adults of the walnut husk fly, *R. completa*, in field cages, is also considerably reduced at low relative humidities (Foote *et al*., 1993). Tephritids are rarely found in extremely dry parts of the world, perhaps because of limitations on the distributions of their host plants rather than on their capacity for physiological adaptation (Aluja *et al*., 2000).

A species which has become adapted for existence in a dry area is *R. slycopersella*, which is indigenous to the dry western plains of Peru. Exposure to the hottest and driest parts of the year is avoided by a pupal aestivation which delays adult emergence for as long as eight months. The pupae are resistant to desiccation, and rain induces a flush of emergence of adults (Boller and Prokopy, 1976; Pablo *et al*., 2008). The stages of the life cycle which appear to be most susceptible to desiccation are the mature larvae (in the interval between emergence from the fruit and pupation) and the newly emerged adults. Rain has been shown to influence the behavior of both of these forms. It stimulates the emergence of mature larvae from fruit in *A. ludens* and *B. tryoni* (Aluja, 1994), and induces an increased rate of adult emergence in *R. pomonella* (Boller and Prokopy, 1976; Boller, 1993).

2.4.2.2 Effect of temperature

The role of temperature as a determinant of abundance in tephritids, as in all poikilothermic animals, is mediated either directly or indirectly through its effects on rates of development, mortality, and fecundity. Rates of increase (or decrease) of individual populations are dependent upon the values of these parameters, and they in turn are determined by the multiple influences impinging upon the individuals from within the life system of the population (Drew and Yuval, 2000). Temperature is one of the most important of these influences. It has the dominant role in the determination of rates of development, and is therefore, largely responsible for the timing of the population processes, and their synchronization with changes in the environment. In most parts of the world, fruit flies are distinctly seasonal in abundance, with numbers high in summer and low in winter (Hallman *et al*., 2011).

In the univoltine (temperate) species, egg laying is usually restricted to a few weeks in summer (Bateman, 1972) but in the more tropical multivoltine forms, it may extend from early spring into late autumn, whenever suitable host fruits are available. The multivoltine species may produce up to six overlapping generations in a single season. Characteristically, their numbers buildup to a peak in late summer and early autumn, and then decline fairly rapidly (Xiaofei and Hui, 2009). Even in tropical areas such as Hawaii, where the difference between summer and winter is relatively small, there is a distinct seasonal pattern of abundance (Bateman, 1972). but this is probably more related to the availability of suitable hosts than directly to changes in temperature (Fletcher, 1989).

In general, development of the immature stages of tephritids is possible between 10°C and 30°C, although post-diapause pupae of some temperate species can develop at temperatures as low as 5ºC. Survival is possible over a much wider range. A few hours at 45ºC seems to be the upper limit, regardless of the stage of development, but the lower limit is indefinite; pupae of temperate species may be exposed in the field, to temperatures as low as -12°C, apparently without harm (Yuan *et al*., 2005). Fecundity is also dependent upon temperature, with maximum production of eggs within the range from 25°C to 30°C (Bateman, 1972). For oviposition, however, thresholds fall between 9°C and 16°C for various species. Upper limits are not clear, but in the field, egg-laying activity is often depressed during the hottest parts of the day (Hallman *et al*., 2011). More detailed information concerning the effects of temperature on survival and development has been outlined by White and Elson-Harris (1992) in their review of the bionomics of the group.

2.4.2.3 Effect of light

Light plays an extremely important role in the determination of fecundity in fruit flies, but has less direct effects on rates of development and mortality. It affects fecundity in two main ways: first, by influencing the general activity of adult females (especially feeding and ovipositional activity); and, second, by its important role in the synchronization of mating behavior (Bateman, 1972). *Bactrocera dorsalis* females reach sexual maturity earlier, mate sooner, and lay eggs earlier when kept in bright rather than dim light (Khalid and Mishkatallah, 2007). Similarly, females of *B. oleae* kept in bright light lay about six times as many eggs as those kept in the same room but in relatively dull light (Tzanakakis and Economopoulos, 1967). Fecundity in *D. tryoni* is considerably affected by illuminance. Changes in fecundity in this species associated with changes in both illuminance and photoperiod are directly correlated with feeding activity and rate of ovarian maturation although females kept at a low illuminance, approaching that which normally initiates sexual activity, also lay increased numbers of eggs (Bateman, 1972).

There are conflicting reports on the effect of increased illuminance on the age at which mating occurs. Light is one of the most important factors influencing oviposition in the temperate species. Direct radiation from the sun or from a strong artificial light source (4000 lux) directly stimulates oviposition (Boller, 1993). For many species of Tephritidae, falling illuminance at dusk acts as a stimulus for the initiation of sexual activity (Syed *et al.,* 1970; Fletcher, 1987). In *B. tryoni* the direct effect of light on the daily cycle of sexual activity is reinforced by a strong endogenous rhythm (Fletcher, 1987). In temperate species, the time of mating appears to be less rigidly defined. The host fruit is often used as a point of rendezvous for the sexes, and mating occurs either on the fruit or on foliage nearby (e.g., *R. pomonella*). In these circumstances, an elaborate mechanism to synchronize mating activity and restrict it to a certain time of the day is probably unnecessary. The fact that it is sometimes observed more commonly in the afternoon may be related to generalized daily activity in cooler areas rather than specific synchronization of mating behavior (Fletcher, 1987).

2.4.2.4 Food availability

The types of food required by the feeding stages (larvae and adults) of tephritids and available to them in nature, and in the extent to which the quantity available influences rates of development, fecundity, and mortality, is of much interest in this review. A great deal of research has been devoted to the development of larval media suitable for the maintenance of laboratory cultures of fruit flies and for the mass production of flies for use in biological control or sterile release programs. The majority of these media are based on those devised by Vargas *et al*. (1990) for *B. dorsalis*, *B. cucurbitae*, and *C. capitata* in Hawaii. Simple, efficient and relatively cheap media are now available for most of the pest species of Tephritidae (Ekesi *et al*., 2007). The history of the development of these media, their modifications for various species and the laboratory techniques devised for their efficient use, have been reviewed by Vargas *et al*. (1990).

No fruit fly larvae have yet been reared on a chemically defined medium, and consequently their precise nutritional requirements have not been precisely determined. The nutritional adequacy of fruit tissue itself, for most species, is still uncertain, although it has been established that the tissues of the olive are quite inadequate for the growth and survival of *Bactrocera* species in the absence of its symbiotic microorganisms, unless the fruit has been stored for some months after harvest. Where numbers of larvae infest a single fruit, it is assumed that they ingest and re-ingest tissues which have been exposed to the action of intestinal and extraintestinal microflora which may produce essential supplementary growth substances (Chang *et al*., 2004; 2006). Nutrition during the larval stage can influence the longevity and fecundity of the subsequent adults. Adults of *C*. *capitata* reared in peaches, persimmons, and cactus fruits live longer than those reared on figs or pears, or on artificial laboratory medium (Economopoulos, 1992). Larvae of *R*. *pomonella* reared on xenic or axenic laboratory media survive and develop as well as those reared in apples, but the adults produced from them show serious deficiencies in behavior and fecundity (Neilson, 1962).

More information is available about the nutritional requirements of adults. All species require a carbohydrate energy source and water in order to survive. In addition, most species require a variety of additional nutrients including proteinaceous substances, in order to achieve sexual maturity (Ekesi and Billah, 2006). Vargas *et al*. (1990) developed a chemically defined diet for adults of *B*. *dorsalis*, *B*. *cucurbitae*, and *C*. *capitata*, and showed a carbohydrate, amino acids, vitamins, and certain minerals, are essential for survival and ovarian development. Adults provided with mixtures of amino acids, vitamins, and minerals, plus sucrose and water live longer and lay more eggs than those fed on bulk nutrient substances (Calkins, 1989). Boush *et al.* (1972) produced a chemically defined medium for *R*. *pomonela* adults based on the chemical composition of the honeydew of the apple aphid, *Aphis pomi*. Aphid and coccid honeydew is generally regarded as the principal source of food for adult fruit flies in nature, but tryptophan, cystine, and cysteine are either absent or in low concentrations in honeydews from several homopterans and it may be that not all of these foods constitute complete diets for fruit flies (Fletcher, 1987). As Boush *et al*. (1972) pointed out, microorganisms may be involved in the production of supplementary nutrients. *Pseudomonas melophthora*, the intestinal symbiotes of *R. pomonella*, has been shown to be capable of amino acid synthesis, and it is likely that a wide variety of bacteria and fungi colonize most honeydew before it is ingested by fruit flies. Adult flies have been observed feeding on a considerable variety of other natural products, including the juices and tissues of damaged or decaying fruit, plant sap, nectar from flowers, and bird feces (Pinero *et al*., 2002). Liquido *et al*. (1991) has shown that *B. dorsalis* and *B. cucurbitae* feed on the secretions of extrafloral glands of several plants in Hawaii. In fruit flies, there is undoubtedly a general relationship between the amount of larval and adult food available to a local population and the rate of production of new individuals (Newell and Haramoto, 1968; Muthuthantri, 2008).

2.4.2.5 Overwintering

Most of the temperate species of fruit flies overwinter as diapausing pupae. Larvae enter the soil soon after they leave the fruit in late summer or autumn, pupate within a few days, and remain in diapauses until the following summer. A few individuals usually remain in diapause for an additional year, or perhaps for several years (Fletcher, 1987). This system is not completely inflexible, however; often a small proportion of individuals fail to enter diapause and emerge as adults in the same year in which they pupated (Aluja *et al*., 2000). Neilson (1962) has earlier found that pupae of *Rhagoletis pomonella* which were not allowed a lengthy exposure to low temperatures, but were held at the relatively high temperature of 21°C, did not enter prolonged diapause, but emerged after several weeks. Prokopy (1968) confirmed that diapause in *R. pomonella* is facultative. It can be prevented by rearing larvae at high temperatures and long photoperiods, and by holding the pupae at high temperatures. This procedure makes it possible to rear this species continuously in the laboratory, without delays caused by diapause (Aluja *et al*., 1997).

Another approach to continuous rearing is that of Averill and Prokopy, who selected a nondiapausing strain of *R. pomonella* from late summer second generation adults (Averill and Prokopy 1987). Overwintering in the more tropical species is normally accomplished by adults. They tend to congregate in locations which provide shelter and food. These overwintering groups often form fairly stable populations because birth rate is zero, death rate is low, and movements are inhibited by low temperatures (Chang *et al*., 2007). Aggregations consisting of as many as 800 individuals of mixed species have been described. They are usually restricted to patches of evergreen foliage such as citrus, banana, or other favorable plants. They may become active enough to feed during the warmer hours of the days, but tend to return to the same sheltered foliage when temperatures fall (Nishida, 1963; Chang *et al*., 2007).

2.4.2.6 Competition

There is some evidence that intraspecific competition may limit or depress population levels when a fruit fly species becomes abundant in relation to its resources. In dacines, the most obvious competitive interactions occur between females on fruit. Their aggression may reduce overall fecundity by restricting egg laying and possibly by encouraging females to disperse, so that more energy is diverted into metabolic activities than into oogenesis (Duyck *et al*., 2006a). Interactions among females, however, are relatively infrequent except at very high population levels. Competition among larvae in fruit appears to be more frequent and important. In most other dacines, scramble competition among larvae occurs to some extent, so that as larval density per fruit increases the resulting pupae and adults become smaller. Small females have fewer ovarioles, lower fecundity, and a reduced chance of survival, particularly in suboptimum conditions (Averill and Prokopy, 1987). In the polyphagous species that infest large fruits, scramble competition may operate over a wider range of larval densities than in the monophagous species that breed in small hosts (Duyck *et al.*, 2006a). Scramble competition only operates between larvae of a single age class; older larvae have a highly detrimental effect on younger larvae in the same fruit, owing to an interference of unknown mechanism (Duyck *et al*., 2006a).

The competitive successes of the Asian *Bactrocera* species over the native and introduced fruit flies in Africa have been well reported in Kenya (Ekesi *et al*., 2009; Rwomushana *et al*., 2009). In Egypt, because of the spread of *B. zonata*, the Mediterranean fruit fly, *C. capitata* has become more restricted to horticulture areas (Hashem *et al*. 2001; Safaan, 2006) and the mixed infestation in fruits of both fruit flies produced flies mostly of *B. zonata* irrespective of which insect infested the fruit first (Mohamed, 2004). Displacement can lead to shifts to hosts that were considered of minor importance before, or to climatic niche partitioning between the different pest species. Extensive work on these aspects has been carried out on the island of La Réunion where the native fruit fly species (*C. Capitata* and *C. Rosa*) are found and three exotic *Bactrocera* species have successively invaded the island (Duyck *et al*., 2006a). Presumably, the invasion of *B. zonata* (Saunders) in Mauritius in 1987 and La Re´union in 1991 may have compounded the displacement of the indigenous species (Duyck *et al*., 2004, 2006a, b, 2007).

Competition among fruit flies may be responsible for misleading impressions of host preferences. Intensive host surveys in littoral areas of Hawaii only rarely would have revealed *C. capitata* infestations in guava, mango, or other highly preferred hosts before the advent of *B. dorsalis* (Harris *et al*., 2002). This possibility that information on host preference may have been influenced by competition emphasizes the need for caution in the use of natural infestation data from different areas as a basis for designating biological races or strains. Furthermore, failure of a species of quarantine importance to cause natural infestation in a fruit or vegetable area where other fruit flies occur may not constitute reliable proof that the same fruit or vegetable could not serve as a host in other circumstances. Research on competition among fruit flies may eventually suggest introduction of a species representing a lesser economic hazard to replace amore serious pest (Duyck *et al*. 2007).

2.4.2.7 Overcrowding

Consideration of the biology of fruit flies suggests that there are three situations in which overcrowding may occur: (i) larvae may become overcrowded in fruit and suffer a shortage of either food or space; (ii) adults may become overcrowded in a local area and suffer a shortage of food or space; (iii) gravid females may suffer a shortage of either oviposition sites or undisturbed laying time, because of overcrowding on the surface of fruit (Fletcher, 1987). Maximum productivity of *B. dorsalis* in guava fruit, in terms of adults per larva, occurs at densities between 0.8 and 1.6 larvae per gram of fruit. At higher densities the productivity falls steadily until it reaches zero at about 6 larvae/g. In addition, pupae which develop from overcrowded larvae have a reduced probability of survival (Clarke *et al*., 2005). *Ceratitis capitata* larvae grow more slowly at higher densities and there is greater variability between individuals. Larval survival is decreased, and the subsequent adults have reduced longevity and fecundity (Duyck *et al*., 2004).

Overcrowding of larvae of *D. ciliatus* results in undersized adults, which have reduced tolerance to low temperatures. Winter survival may consequently be considerably affected (Deguine *at al*., 2012). Overcrowding of adults leading to shortage of food or space is probably a very rare occurrence in natural populations. However, Fletcher (1987) may have induced such a situation artificially when he released large numbers of sterile flies into small stable overwintering populations of *B. tryoni*. The numbers of wild flies in the areas declined sharply, shortly afterward, and were considered to have left because they began to meet other members of the same species too frequently. It has several times been observed that gravid females cease ovipositing in a dwindling crop of fruit well before the last of the fruit has fallen. Clarke *et al*. (2005) reported that gravid females of *B. dorsalis* lost interest in the fruit under these circumstances and spent their time in other activities, while in *B. tryoni*, Bateman (1972) showed that the gravid females actually left the orchard. Muthuthantri (2008) in investigating this phenomenon in *B. tryoni* found no evidence that females would not oviposit in fruit that was already infested, and proposed an alternative explanation based on the frequency of aggressive interactions among females on the surfaces of fruits. He records instances in which ovipositing females were frequently interrupted by intruders, even in populations at low density. At high densities, this behavior could seriously reduce the undisturbed laying time available to females, and so limit infestation rates in diminishing fruit. It may also act as a stimulus for gravid females to disperse.

2.4.3 Demography and population dynamics

Basic demographic parameters (e.g. pre-adult survival and development rates, adult survival, gross and net fecundity) have been determined for many tephritid species under laboratory conditions (Celedonio-Hurtado *et al*., 1988). Longevity and survivorship curves have been described for *A. sororcula* and *A. bistrigata* (Bressan and da Costa-Teles, 1991). Adult survivorship curves of several species studied so far are close to type III curves. Age at first reproduction is strongly influenced by temperature and ranges from 8 to 20 days depending on the species (Liedo *et al*., 1993). Food type, availability of water, fly size, and fly density influence life expectation and gross fecundity rates. For example, in large versus small (mean pupal weight of 24 versus 18 mg, respectively) mean gross fecundity for *A. ludens* was 1597 versus 1450, respectively (Liedo *et al*., 1993). Two points stand out from these studies: (a) gross fecundity rates and daily egg production under ideal laboratory conditions can be extremely high (e.g. 1000 eggs/female) and (b) adults can live for prolonged periods of time. For example, female and male *A. ludens* individuals can live as long as 11 and 16 months respectively, under laboratory conditions and 12 months under field conditions (Shaw *et al*., 1967).

Few studies in the vast tephritid literature examine the causes of mortality. Scattered efforts by early workers are incomplete and were carried out under laboratory conditions. Biotic mortality factors have been repeatedly identified, but the true impact on the population dynamics at the field level has rarely been determined. All immature stages (eggs, larvae, pupae) of Dacinae are attacked by a series of indigenous parasitoids (Aluja *et al*., 1990; Eskafi, 1990). As already reviewed in section 2.4.2, the most important abiotic mortality factors regulating population dynamics are water and temperature. Too much or too little water causes both immatures and adults to die. Pupal desiccation in dried soil appears to be a major mortality factor. The first days after puparium formation are critical in this respect. Excessively dry conditions may reduce female fecundity and affect survival rate of newly emerged adults. Fruits exposed to rain decay faster and cause first and second instar larvae to die. Excess water also hastens emergence from the fruit and concomitant puparium formation, and may reduce survivorship (Aluja, 1994).

Literature on the population dynamics of fruit flies in tropical Africa has been widely documented in several countries including Tanzania (Mwatawala *et al*., 2006a), Senagal (N'diaye *et al*., 2008), Ivory Coast (N'depo *et al*., 2009) and Egypt (Abdel-Galil *et al*., 2010). Studies based on adult population fluctuations in diverse ecologies indicate an emerging picture that adult populations in commercial orchards exhibit strong fluctuations from year to year and that these fluctuations are correlated with two factors: availability of host plants and climatic factors (especially rainfall) (Nguyen *et al*., 1992). In monocrop orchards, population numbers typically reach a peak shortly after host fruit has ripened and crash when no hosts are available. In mixed orchards, fluctuations are probably dampened by the presence of alternative host plants. Trapping studies in orchards clearly show that even though up to 15 *Anastrepha* species are commonly captured, one or two are dominant. The degree of species dominance is influenced by ecological background (i.e. host plant species richness and diversity) and by altitudinal gradients (Jiron and Hedstrom, 1991; Piedra and Zuniga, 1993).

2.5 Behaviour of fruit flies

2.5.1 Host finding behavior

Host finding behavior has been studied in great detail for the apple maggot fly *R. pomonella* and complemented with studies of different aspects of host finding for pest species in the genera *Anastrepha*, *Bactrocera* and *Ceratitis.* In some cucurbit-infesting species, feeding and mating take place almost exclusively on non-host plants (Steffens, 1983). Nevertheless, in the majority of species, host trees seem to be important sites for foraging for food and mates, as well as for oviposition. In general, fruit flies detect and orient to sources of host fruit volatiles from long distances to arrive to host trees. *Bactrocera* may respond to odour emitted by bacteria associated to fruit. Once on the fruit, females examine fruit by walking on its surface and probably identifying contact chemical substances with tarsal receptors. In general monophagous species are more specific in response to host volatiles while generalist species appear to respond to chemicals generally emitted by a wide variety of hosts (Fletcher, 1987).

Because they are highly mobile, the polyphagous species might be expected to have evolved efficient mechanisms for detecting hosts, but information on this is limited. All the dacines studied responded strongly to flat yellow squares or rectangles with peak reflectance close to that of green leaves (550 nm) and were less attracted to colored boards with peak reflective wavelengths above or below this value (Bateman, 1976; Hill and Hooper, 1984). In *B. tryoni*, response was increased with checkerboard patterns, which gave a contrast effect; yellow and green, and yellow and red induced the maximum response (Meats, 1989). Visual cues with the spectral wavelength of green leaves appear to act as supranormal foliage stimuli in tephritids and in numerous other herbivorous insects, and in combination with certain shapes act as token tree stimuli. However, *Dacus oleae* showed no specific response either to the undersurface of olive leaves or to yellow tints with the same spectral reflection (Prokopy, 1983). Available data suggest that host detection may be relatively short-range and may involve important olfactory as well as visual cues. Although adult dacines respond to a number of plant extracts, many are from nonhosts or are of general occurrence (Guerin *et al*., 1983), and there is no evidence at present that flies can locate host trees solely on the basis of visual or olfactory cues from the foliage. Once on the host plant, flies appear to locate individual fruit on the basis of vision responding to spherical objects of different colors that contrast against the background. There is an increasing amount of evidence that fruit volatiles are important in enabling flies not only to locate fruit, but also to discriminate between hosts and nonhosts and among fruits at different stages of ripeness (Fitt, 1981; 1986).

2.5.2 Feeding behavior

Fruit flies require a diet rich in amino acids, vitamins, minerals, carbohydrates, and water to survive and reproduce (Tsiropoulos, 1989). Newly emerged adults contain some reserves carried over from the larval stage, which enable them to survive for 1-2 days after emergence if other food is not available. *Bactrocera oleae* carries over enough protein to mature a few eggs (Fletcher and Kapatos, 1983; Manoukas, 1994). Feeding, however, is normally a daily activity that entails foraging for food on both host and nonhost trees. Peak feeding normally occurs in the morning, but some feeding may take place at other times (Drew *et al*., 1983). In some species of the *Bactrocera dorsalis* complex, males feeding on Methyl Eugenol and plants containing Methyl Eugenol enjoy greater reproductive success than other males; this compound has therefore been used as a potent male attractant for this group of flies. However, no Methyl Eugenol containing plants have been found in the tropical environments from which these flies originate, and therefore its role in nature remains a puzzle. Sources of food in nature for adult tephritids include fruit juices, extrafloral glandular exudates, nectar, pollen, aphid honeydew, bird faeces, yeast and bacteria. Fruit fly feeding behavior for all stages of fruit flies is reviewed by Drew and Yuval (2000).

Laboratory studies on *B. latifrons* maintained at 25°C and allowed to feed ad lib indicated that protein and sugar intake of males was generally lower but showed the same overall trends. In temperature regimes in which daily day-degrees were below the threshold for development, consumption of both protein and sugar fell to low levels (Vargas *et al*., 1993). Dacines have been observed both on host and nonhost trees feeding on honeydew, plant exudates, extrafloral nectaries, pollen, fruit juice, ripe fruits, microorganisms, and bird droppings (Drew *et al*., 1983; Katsoyannos, 1983). However, very little information is available about the quantitative aspects of adult nutrition in the field or about the factors that influence food-foraging behavior (Chang *et al*., 2004). Previous studies in Australia have shown that *B. tryoni* and some other species are attracted to and feed on cultures of the Enterobacteriaceae found on leaf and fruit surfaces. Feeding experiments indicated that females could mature eggs when fed on these bacteria. It has been suggested that the bacteria might be the major source of amino acids, vitamins, and other growth factors for adult fruit flies in tropical regions, where honeydew is scarce or absent (Drew *et al*., 1983; Drew and Lloyd, 1987).

2.5.3 Mating behavior

Tephritid mating behavior ranges from males that couple after little preliminary courtship to those that produce a repertoire of acoustic, pheromone, and visual displays, and from females that make few precopulatory mate choices to those that evaluate potential mates through various different channels. Similarly, female tephritids may mate multiple or only once or twice during their lifetime. Females that tend to be monogamous enter refractory periods that vary in length depending on the condition of their mate, with large, well fed males generally inducing longer refractory periods than males in poor condition (Fletcher, 1987). Mating behavior and mating system are important when considering the application of the sterile insect technique (Hendrichs *et al*. 2002). Male produced pheromone analogues have been used as attractants for monitoring purposes. Tropical fruit flies in the genera *Anastrepha,* and *Ceratitis* tend to form male aggregations called leks where males release sex pheromones that attract other males and females and where males engage in elaborate courtship displays that females appear to assess to select mating partners. *Bactrocera* species have been reported to mate on host plants where males release pheromones that attract females. By contrast, males of several species in the genus *Rhagoletis* patrol host fruit and defend such territories from invading males, forcing copulations on females seeking oviposition sites without courting (Sivinski *et al*. (2000).

The majority of dacine fruit flies, including most pest species, mate at dusk under low light intensity (less than 1000 lux), although some species (e.g. *B. oleae*), start mating in the late afternoon at a somewhat higher light intensity (Suzuki and Koyama, 1981; Lee *et al*., 1983). In contrast, there are a few species, including *Bactrocera* that mate during the day at high light intensities (Smith, 1989). Mating behavior has rarely been observed in the field. It seems, however, that mating occurs predominantly on the foliage of host plants. Even so, matings on nonhosts have been observed in *B. cucurbitae* (Rahman *et al*., 2003), and many of the cucurbit-infesting species mate exclusively on nonhosts (Matanmi, 1975). Field cage studies indicate that males, of *B. tryoni* (Tychsen and Bateman, 1978) and *B. cucurbitae* (Rahman *et al*., 2003) engage in lekking behavior. As light intensity drops near dusk, they aggregate on specific parts of a tree and take up individual territories on leaves, which they aggressively defend from incursions by other males.

Sexually active males of *B. tryoni*, *B. dorsalis*, and *B. cucurbitae* stridulate (produce a high-pitched buzzing sound) by rapidly drawing their wings across their stridulatory organs, and simultaneously release pheromone from their rectal pheromone glands (Kuba and Koyama, 1985). A number of compounds have been identified in the rectal pheromone gland secretions and cold-trapped volatiles from tephritids. Females of *B. oleae* release an airborne sex pheromone that is a blend of four compounds, 1,7-dioxaspiro (5.5) undecane, a-pinene, nonanol, and ethyldodecanoate (Mazomenos and Haniotakis, 1985); this attracts males from a distance. The major component, both in quantity and in biological activity, is the spiroketal, which alone can attract males to traps in the field. E-6-Nonen-l -ol and p-cymene have also been identified in the cold-trapped effluent of sexually active females (Gariboldi *et al.,* 1982), but the role of these compounds as pheromone components remains uncertain (Jackson and Long, 1997). Wild males of *B. oleae* produce the same spiroketal as females, plus diethyl-5-oxononadioate, in their rectal glands (Mazomenos and Pomonis, 1983). Studies indicate that the spiroketal is released as a racemate. Males respond only to the R -(-)-enantiomer, which functions as a long-range sex attractant, and females respond only to the S -(+) - enantiomer, which function as a short-range arrestant and aphrodisiac (Haniotakis *et al*., 1986).

When adult *B. invadens* were released on field cages containing fruiting mango trees, mating behavior started and continued 1-2 hr period immediately preceding sunset. Prior to 17 00 h, males formed aggregation of 1-2 flies per observational count. At 1800 h, the number of males increased to 5-9 and leking was exclusively on leaves. Calling which consisted of males fanning their wings rapidly and rubbing their abdomen with their legs started at 1800 h and 48% (24/51) of fanning took place at 1830 h and later increased to 64% (41/64) at 1900 h as compared to only 21% (6/28) of males observed after 1900 h (Ekesi *et al*., 2009). Calling among groups of 7-9 flies created a buzzing sound with small white clouds (possibly dispersing pheromones). Calling males frequently changed perches on leaves than non-calling males. A male under observation called for up to 3.9 min during which females landed at 2-3 cm in the front of the male. Thereafter, the male stops wing-fanning and mount on the female and copulation occurred. At 1830 h, 30% of total mating was observed and at 1900, 54% of the total mating was recorded. Pairing mates remained on the leaves for 5.1 min and then flew away. No wing-fanning occurred during mating and no obvious courtship behaviors were observed (Ekesi *et al.*, 2009).

2.5.4 Oviposition behavior

Adults of many tephritid species oviposit into the flesh of developing host fruit, which usually has limited carrying capacity for larval progeny (Fitt, 1989). After fruit examination females probe the fruit with their ovipositor to assess suitability for larval development. Fruit fly females have receptors in the tip of their acculeus that allow them to assess sugar content and perhaps other chemical substances. Females may probe fruit several times before acceptance. Females of *C. capitata, Bactrocera dorsalis, and Bactrocera tryoni* can in some cases reuse oviposition holes perhaps to avoid ovipositor ware in hard fruit or to create larval aggregations large enough to overcome chemical plant defenses (Fletcher, 1987). Flies, in the tropical genera *Anastrepha*, and *Ceratitis* mark fruit after successful ovipositon by dragging their extended acculeus on the surface of fruit and depositing a host marking pheromone. Such pheromones generally deter other females from ovipositing in occupied fruit minimizing in such way larval competition. Host marking pheromone of some species may be recognized by other species. Although flies in the genus *Bactrocera* do not mark fruit, females appear to be capable of recognizing and avoiding oviposition in occupied fruit perhaps through perception of bacterial activity associated with feeding larvae. Oviposition behavior of fruit flies is reviewed in detail in Diaz-Fleisher *et al*. (2000)

Studies on *B. cucurbitae* using artificial fruit models containing pieces of fruit indicated that attraction to the fruit, exploratory behavior after arrival, piercing of the fruit, and egg-laying are all influenced by olfactory stimuli, although color and shape also have a role (Rahman *et al*., 2003). In laboratory studies monophagous species were able to discriminate between host and nonhost fruits even before landing on them. Females of *B. oleae* can recognize olive fruits purely by vision, on the basis of shape, size and color (Fitt, 1983). Once a potentially suitable fruit has been located, the female explores it before attempting to oviposit. Many species oviposit in recent oviposition stings of other females or in breaks in the skin caused by other agents (Fitt, 1983). Fletcher (1987) observed that females of *B. tryoni* and *D. ciliatus* choose shaded rather than sunny positions on fruit for oviposition.

Clutch size may vary considerably depending on host fruit quality (size and ripeness), host abudance, frequency of host occurrence and the physiological state of the female (age and egg load) (Diaz-Fleischer *et al.*, 2000). Awmack and Leather (2002) noted that when reaching clutch size decisions, female flies use physical or chemical proximate cues such as host state (eg., flowering stage), age, size, leaf pubescence, smoothness, shape, colour and nitrogen and water content to determine host quality. The time spent on oviposition varies, but *B. tryoni* takes about 1-3 min per oviposition and *D. jarvisi*, which lays more eggs per clutch, takes about 4-6 mins. If other females land on the fruit, ovipositing females will interrupt their activity and attempt to drive them off. There is no evidence that any tephritid deposits an epideictic oviposition deterring pheromone on the fruit after egg-laying as many other tephritids do (Rahman *et al*., 2003). However, after oviposition female *B. oleae* suck up the olive juice that exudes from the oviposition puncture and spread it on the surface of the fruit to deter other females from ovipositing (Fitts, 1984). A number of compounds in olive juice, including dihydroxyphenyl ethanol (Vijaysegaran, 1985), pyrocatechol, benzaldehyde and acetophenone, have been found to have deterrent properties.

Presence of larvae in fruit has a deterrent effect on ovipositing females of many *Bactrocera* species (Prokopy and Koyama, 1982). Fitt (1984) found that the effect was detectable as soon as the larvae hatched and started feeding, and that in *B. tryoni* the effect was interspecific. The stimulus was shown to be present in partly worked fruit tissue from which larvae had been removed. In *B. oleae*, a deterrent effect was noted in fruit containing second- and third-stage larvae, and it has been suggested that this was due to lipo soluble volatile substances released from olive tissues attacked by the feeding larvae (Girolami *et al.*, 1983).

2.5.5 Movements

Two types of adult movements are discernible in natural populations of fruit flies; non-dispersive movements and dispersive movements.

2.5.5.1 Non-dispersive movements

These are characteristic of individuals that inhabit an area where ample host fruits are available for oviposition. Adults tend to remain in such areas, and their movements are associated with the normal activities of feeding, ovipositing, and mating. These movements are clearly non-dispersive. They often have a daily periodicity and they rarely take the individuals far from their host plants. Adults of *B. dorsalis* associated with melon fields in Brazil have a distinct pattern of movements which are repeated daily. No flies were present in the fields in the very early morning. Throughout the day, and particularly in the afternoon, they move in from nearby wild vegetation, reaching a peak in the fields at about 5 pm. From then onward their numbers dwindle until by dark all have moved out of the fields and back to the surrounding vegetation. The movements into the fields appeared to be solely for the purpose of oviposition, since the flies are predominately gravid females; the males and juveniles remain outside the fields, where the wild vegetation provides food and shelter (Aluja *et al*., 1993).

Similar behavior has been observed in *B. zonata* in West Pakistan. The adults remain in the vicinity of host orchards but visit them for oviposition only. They move out to surrounding trees and crops to rest and feed (El-Aw *et al*., 2003). According to Chang *et al*. (2006), adults of *B. dorsalis* are not found in large numbers on fruiting guava trees except during the daily peak of oviposition activity. They move to other plants nearby for food and shelter. But in West Pakistan, *B. dorsalis* adults remain in the orchards when there are few fruits on the trees. They are not seen on surrounding vegetation, or on the trees of adjacent orchards where there are no fruits (Thoyias and Loera-Gallard, 1998). The tendency of mature *B. tryoni* adults to remain in parts of an orchard where ample fruit is available has been demonstrated by Muthuthantri (2008). Marked adults were recaptured again and again in blocks of trees where fruit was available. Their numbers dwindled rapidly when the supply of fruit declined but the same adults could then be recaptured in another block where fruit was beginning to ripen.

Similar non-dispersive movements have been observed in many of the temperate species of Tephritidae. Extremely restricted movements of adults of *R. completa* released in walnut orchards have been reported by Aluja (1994). The farthest distance travelled by marked adults of *Urophora jaceana* in a patch of its knapweed host, was only 22 yards in 14 days. *Rhagoletis cerasi* adults rarely leave an area where host fruits are available, even though they are physiologically capable of flights of up to 5 miles per day according to studies with flight mills (Bateman, 1972; Aluja, 1994).

2.5.5.2 Dispersive movements

This type of movement is characteristic of individuals that have either not located an area where suitable hosts are available or have left such an area when the supply of host fruit declined. Such adults tend to move frequently; their direction of movement may be oriented in relation to the wind, and they may travel considerable distances in a relatively short time. The movements of juveniles in the interval between emergence from the soil and the development of reproductive maturity are probably of the dispersive type, at least in some species. It is presumed that dispersing individuals that locate an area which satisfies their current physiological requirements will tend to change to a nondispersive movement pattern and remain in that area (Bateman, 1972).

For the tropical species at least, there appear to be three distinct stimuli, which may prompt adults to leave an area and embark on a phase of dispersive activity. The first, and probably the most important, is the disappearance of fruit, which the population has been utilizing for oviposition. The second is associated with the commencement of warm weather in spring, which initiates movements away from overwintering areas. The third relates to the movements of juvenile adults which often show a strong tendency to disperse during the period between their emergence from the soil and the onset of sexual maturity (Bateman, 1972; Chang *et al.*, 2006). Fletcher (1987) studied dispersive movements of *B. tryoni* by maintaining large numbers of traps in areas of dry sclerophyl bushland, a type of vegetation which contains no known hosts of this species. Some of the areas are remote from any human habitation or any concentration of hosts, and the flies which appear in these traps must have travelled many miles from their emergence sites. Flights of this order must be regarded as dispersive. He has found a remarkably constant pattern of such dispersive activity each year. *Anastrepha ludens* apparently indulges in extremely extensive dispersive movements as it infests successive crops in different parts of Mexico (Shaw *et al.*, 1967; El-Aw *et al.*, 2003).

The environmental changes which initiate these movements are often obscure, but disappearance of fruit from an area is sometimes clearly implicated (Aluja *et al.*, 1997). Among many insects, juvenile adults constitute the principal dispersive phase (Chang *et al.*, 2006). Observations confirming this tendency in fruit flies have been earlier reported for *R. cerasi* by Boller *et al.* (1976) who considered the first few days after emergence as of some importance for dispersal, and for *B.*

cucurbitae by Rahman *et al.* (2003), who showed that young adults move out of the melon fields soon after their emergence. In *B. tryoni* also, most juvenile adults leave their breeding area within a day or two of emergence and some have been recaptured as far as 15 miles away (Muthuthantri, 2008). Moreover, studies on flight mills have shown that juveniles of this species have a much greater capacity for sustained flight than mature adults (Aluja *et al.*, 1993).

2.5.6 Rhythms of activity and resource utilization patterns

In general, dacine fruit flies are diurnal insects and at night rest on the undersides of leaves of host plants or other trees. Their daytime activities can be divided into five main functional categories: feeding, mating, ovipositing, dispersing, and resting or sheltering. The time spent in each type of activity depends upon many factors including age, sex, availability of mates and hosts, and short- and long-term climatic conditions (Muthuthantri, 2008). Certain activities are restricted to fairly specific times of day owing to the interaction of internal circadian rhythms and external factors such as temperature and light intensity (Smith, 1985). In certain species mature males and mature virgin females show peaks of locomotory activity and other sexually associated behaviors, including male stridulation, pheromone release, and response to sex pheromones, at dusk (Aluja, 1993). Studies on *B. tryoni* indicate that the synchronization of the various components of sexual behavior with dusk involves the effect of decreasing light intensity on an underlying rhythm of readiness to mate, which has a genetic basis (Smith, 1985). This rhythm is under circadian control; it persisted for at least four days, with a periodicity of 28 hr, under a constant low light intensity of 10 lux (Muthuthantri, 2008).

Some species only call (emit series of courtship sounds through wing fanning and release of a sexual pheromone) in the early morning, such as *A. robusta* (Arakaki *et al*., 1984), and others, such as *A. ludens*, *A. grandis*, and *A. pseudoparallela*, restrict their calling activities to the late afternoon.

Other species such as *A. obliqua* call both during the morning and afternoon. In the case of behaviors such as feeding, resting and oviposition, flies exhibit plasticity and can adapt to local microhabitat conditions (Aluja, 1993).

2.5.7 Response to lures

Some of the most important advances made in recent research on tephritids have been in the field of attractants. Solutions of hydrolyzed proteins are attractive to males and females of most species of fruit flies, and are currently used for control purposes in most parts of the world. Extremely efficient synthetic male lures are also now available for some of the more serious pest species, mainly as a result of development work by Jang and his associates (Jang *et al.*, 2007). The biological significance of these chemicals is still speculative, although methyl eugenol, the powerful attractant for males of *Bactrocera* species, has long been found in the blossom of *Cassia fistula*, a plant which that species frequently visits (Kawano *et al*., 1968). Feron (1962) has suggested that siglure (sec-butyl-6-methyl-3-cydohexene-l-carboxylate), an attractant for males of *Ceratitis,* is effective because it activates a nervous mechanism which controls sexual activity, in much the same way as does the natural pheromone of that species. Similarly, Muthuthantri (2008) suspected a relationship between the natural sex pheromone of *B. tryoni* and the male attractant for that species, cue-lure (4-(p-acetoxyphenyl)-2-butanone). Many uses have been found for male lures inducing the eradication of certain isolated populations control on an area basis, the estimation of numbers in natural populations, and surveys and detection related to quarantine (Ishida *et al*., 2008).

Available studies in Africa have shown that parapheromones and food baits are highly attractive chemicals to tephritid pests. Rwomushana (2008) evaluated the efficacy of Nulure, Torula yeast, Corn steepwater and a local yeast-based attractant in Multilure, Easy and Lynfield traps in attracting *B. invadens* on mango in Kenya. Multilure trap baited with torula yeast and Nulure were the most attractive bait and trap combinations with total captures of 18-30 *B. invadens*/trap/day and 11- 23 flies/trap/day, respectively. Ekesi *et al*. (2007) in a field trial on mango orchards to compare catches of *B. invadens* in Multilure trap baited with female selective food-based attractants observed that Nulure/borax solution, putrescine (PT)/trimethylamine (TMA)/ammonium acetate (AA) were highly effective in attracting the fly.

Other field trials conducted in Kenya compared 6 commercial food attractants (Biolure, Torula yeast, Mazoferm, Nulure, Hymlure) and 2 locally developed attractants from waste brewer's yeast (Kenya and Ugandan Yeast). Mazoferm, torula yeast and the food lures based on local waste brewer's yeast captured significantly more female flies than Biolure, GF-120, Nulure and Hymlure (Ekesi, 2010). In Benin, Torula yeast, Nulure and Biolure were tested for attraction to *B. invadens*. Catches were 3-4 fold-higher in torula yeast than in Nulure. Using the Modified McPhail traps baited with different types of lures (Trimedlure, Methyl eugenol, Cue Lure, protein bait and single matrix BioLure containing putrescine, ammonium acetate and trimethylamine) to document the diversity of fruit flies in four main agroecological zones in the Morogoro region of Tanzania, Mwatawala *et al*. (2006b) caught the following number of *B. invadens* in the different attractant types: methyl eugenol (180269 flies), protein baits (4944 flies), BioLure (324 flies), Trimed lure (62 flies), Cue Lure (15 flies). Studies by Kimbokota (2010) provide important baseline information to identification of volatiles from host fruits that could be utilized for detection, monitoring and management of *B. invadens.* The author trapped volatiles from ripe fruits of the 3 major host plants above and GC-EAD analysis detected a total of eight active compounds from the host fruits. Moreover, assessment of the relationship between sexual maturation rate and response to methyl eugenol in field cages revealed that males of both laboratory and wild populations of *B. invadens* responded strongly to methyl eugenol prior to sexual maturity and this probably contributes to the success of male annihilation in management of *B. invadens* (Manrakhan, 2006).

2.5.8 Larval behavior

Fruit tissues are low in protein and it is generally thought that larval forms of fruit flies have to rely on bacteria to provide certain essential amino acids and other growth factors. The chemical and nutritional components of olive fruit and the major biochemical groups (i.e. lipids, proteins, amino acids, and peptide acids) for immature larvae and newly emerged adults of *B. oleae* have been determined by (Manoukas, 1989). Synthetic diets have been developed for the major pest species, but many aspects of larval nutrition are yet to be investigated. Larvae of many of the specialist species are able to develop in commercial fruit that they do not utilize as hosts in the field, and development in nonhost wild fruits is often inhibited. This suggests that monophagous and stenophagous species have evolved specialized mechanisms that enable them to exploit their particular hosts, and that host selection is maintained largely by female oviposition preferences (Fitt, 1986).

During development the larvae tunnel in the fruit, macerate the tissues, and ingest the broken-down tissues and associated bacteria. In larger fruit they move toward the center, which may offer some protection from parasites and certain predators. When mature, larvae of most species leave the fruit and burrow several centimeters into the soil, where they pupate (Fitt, 1981; Neuenschwander, 1984). Mature larvae of all species studied have the ability to hop, which appears to be a defense against ground-dwelling insect predators, particularly ants. *D*acus *oleae* pupates in fruit during summer and early autumn and in the ground in the winter and spring (Kapatos and Fletcher, 1984). Prior to pupation in the fruit, the mature larva tunnels to the fruit surface and eats away all but the thin outer membrane of the pericarp so that the emerging adult can escape from the fruit. The two most pronounced rhythmical behaviors during development are larval exit from the fruit prior to pupation and adult eclosion. These behaviours have their peak around dawn and are controlled by light and temperature cycles (Laudeho *et al*., 1979; Smith, 1987).

2.6.0 Economic importance of fruit flies

2.6.1 Beneficial fruit flies

Although fruit flies are commonly considered as pests, some species are valuable agents for biological control of weeds (Harris, 1989; White and Elson-Harris 1992, Turner 1996). Most species that have been used or tested for biological control belong to the subfamily Tephritinae and attack plants of the family Asteraceae (e.g., Mediterranean fruit fly, *C. capitata*). The lantana gall fly, *Eutreta xanthochaeta* together with other agents has achieved partial to substantial control of *Lantana camara* L. in Hawaii. It also was released in Australia and South Africa but did not establish there. *Procecidochares alani* has controlled *Ageratina riparia* (Regel) in some areas of Hawaii. *Procecidochares utilis* was also introduced in Hawaii for the control of *Ageratina adenophora* (Sprengel). It has been ineffective in wet areas, but has controlled the weed in dry zones. It also was released in Australia, New Zealand, South Africa and Madeira, and has been established in India, Nepal and China, although it has not successfully controlled its host there (White and Elson-Harris, 1992).

In western North America, *Urophora stylata* has reduced seed production in *Cirsium vulgare* (Savi) Tenore, and *U. affinis* and *U. quadrifasciata* have reduced seed production in *Centaurea diffusa* Lam. and *C. maculosa* Lamarck. In the Pacific Northwest, *U. affinis* and *U. quadrifasciata* are close to the threshold needed to achieve economic control of spotted knapweed, reducing seed production from 50-90%. Six other species of Tephritidae have been established in North America as weed biocontrol agents, but in most cases it seems too early to evaluate their effect on the target weeds. In Australia *Urophora solstitialis* has contributed to the control of nodding thistle (*Carduus nutans*). White and Elson-Harris (1992) and Turner (1996) provided the most comprehensive lists of species released or considered as biocontrol agents.

Other tephritids are key subjects for the study of basic biology, and some are important models for testing evolutionary or ecological theories. For example, the apple maggot and related species of *Rhagoletis* is used for studying sympatric speciation (Bush, 1993), the Mediterranean fruit fly for demographic research (Carey, 1993), and various Tephritinae (e.g., *Erosta solidaginis* and species of *Urophora*) for resource partitioning and other eclogical studies (Abrahamson and Weis, 1997).

2.6.2 Pest species of fruit flies

Fruit fly pests of economic importance worldwide belong to the genera *Anastrepha*, *Rhagoletis*, *Ceratitis*, *Dacus* and *Bactrocera* (White and Goodger, 2009). *Anastrepha* and *Rhagoletis* include species from the Holarctic and Neotropic regions while *Bactrocera* includes species from the Asian Pacific regions (White and Elson-Harris (1992). According to De Meyer *et al*. (2012), Sub-Saharan Africa (SSA) is the aboriginal home to 915 fruit fly species from 148 genera, out of which 299 species develop in either wild or cultivated fruits. Most species which attack commercially grown fruit crops belong to just two genera; *Ceratitis* (95) and *Dacus* (195) (White and Goodger, 2009). A few species belong to other genera such as the coffee fruit flies (*Trirhithrum)* which are close relatives of *Ceratitis*, or the genus *Bactrocera*, which are close relatives of *Dacus.* De Meyer *et al*. (2012) classified pest species of fruit flies in Africa into indigenous and invasive species, which belong mainly to four genera: *Bactrocera, Ceratitis, Dacus,* and *Trirhithrum* (Table 2.1).

2.6.2.1 Indigenous fruit fly pests

Africa is the aboriginal home of several species of highly damaging fruit flies. For example, on mango, the results of several surveys across SSA show the crop is attacked by native fruit fly species such *C. cosyra*, *C. quinaria*, *C. fasciventris, C. rosa*, *C. anonae* and *C. capitata*. Traditionally, yield loss on this crop due to native fruit flies can range between 30–70% depending on the locality, season and variety (Lux *et al.*, 2003a). Other important native *Ceratitis* species in the region include *C. quinaria*, *C. rubivora*, *C. puntata*, *C. discussa*, *C. ditissima*, and *C. pedestris*, that attack a variety of important fruits and vegetables. On cucurbits, several native *Dacus* species (e.g. *D. bivittatus*, *D. lounsburyi*, *D. ciliatus*, *D. puntatifrons*, *D. frontalis*, *D. vertebratus* and others) also inflict considerable losses to crops especially the cucurbits (White and Elson-Harris, 1992; De Meyer *et al.*, 2002; Ekesi, 2006).

2.6.2.2 Exotic fruit fly pests

Although Africa is known to be the origin of several fruit fly introductions and establishments worldwide, (the most notorious species being the Mediterranean fruit fly, *C. capitata*) with the intensification of fruit trade, the continent has also become highly vulnerable to introduction of alien fruit fly species. In 1997, *B. zonata* was introduced into Egypt (cited by De Meyer *et al*., 2012). In 2003, *B. invadens* was detected for the first time in Africa (Drew *et al*., 2005). In 2006, the Solanum fruit fly *B. latifrons*, a primary pest of solanaceous crops was detected in Tanzania (Mwatawala *et al*., 2007). Although damage by *B. latifrons* is currently concentrated on local solanum species such as *Solanum aethiopicum* and *S. macrocarpon* (De Meyer *et al*., 2012); Mwatawala *et al*., 2009a); tomato seems to be most at risk. The melon fly *B. cucurbitae* has also been in Africa for years without a clear date of introduction (White and Elson-Harris, 1992). *Bactrocera cucurbitae* is possibly the world's most damaging fruit fly species on cucurbits. The invasion of alien species can cause extensive economic and ecological damage, with unpredictable negative effects on native populations. Alien species' impact on environment is believed to be second only to habitat destruction (Naeem *et al*., 1995; Lyon and Miller, 2000). Invasive species can alter successional patterns, mutualistic relationships, community dynamics, ecosystem functions and resource distributions. Invasive species that cause extinction of native species will ultimately reduce local and global species diversity (Vitousek *et al*., 1996).

Among all the native and exotic fruit fly species, one species, commonly referred to as the African invader fly, *B. invadens* is thought to be responsible for causing extensive economic losses to horticultural crops throughout Africa since its first report in 2003. The rapid spread and devastating impact of *B. invadens* in SSA has been a matter of serious concern to the horticulture industry. *Bactrocera invadens* is believed to be native to Sri Lanka and currently reported from 28 African countries including the Comoros Island and Cape Verde. It attacks over 40 host plants but mango is the preferred host plant, causing over 80% damage on the crop. It has rapidly displaced several of the indigenous fruit fly species and currently ranked as the most important fruit fly pest in the African continent. The Inter-African Phytosanitary Council (IAPC) of the African Union (AU) has described it as a devastating quarantine pest (French, 2005). It has a broad temperature range, has been trapped at high altitudes (>1600 m above sea level) and has the capability for invading other regions of the world.

Several countries in Africa continue to suffer significant loss in revenue due to lost export markets associated with the presence of the pest in the countries where it has been reported. A concerted effort is required by the fruit fly donor communities to provide technologies, build capacity and create awareness on the importance of this important pest for improve horticulture in Africa and beyond.

Table 2.1: Fruit fly species of economic importance in Sub-Saharan Africa

Genera	Species	Notes
Ceratitis	*C. cosyra* (Walker)	Commonly called the mango/marula fruit fly. Major mango pest across Africa, causing 20-90 crop loss (av. 30%). Present in central, Eastern and West Africa. Primary host plants include mango, marula, guava and custard apple, but attacks variety of other plants. A major quarantine pest.
	C. capitata (Wiedemann)	Commonly called the Mediterranean fruit fly. Most widespread of all fruit fly species in Africa. Attacks over 300 host plants. Very important quarantine pest, capable of withstanding low temperatures.
	C. rosa (Karsch)	Commonly called the natal fruit fly. Occurs in Eastern, Central and Southern Africa.Very competitive African species. Known distribution is mainly southern and eastern Africa. It has been introduced to the Mascarene Islands: Mauritius and Réunion. Has a broad host range attacking over 100 plant species. Very important pest of mango and papaya. species. It should be considered as a potential invasive species in other parts of Africa, outside its current range, and in other parts of the world. *A pest* of quarantine significance.
	C. fasciventris (Bezzi)	Formerly regarded as a variety of *C. rose*. Occurs in Central, East and West Africa. Major pest of mango and guava but also attacks a variety of other host plants. Capable of withstanding low temperatures.
	C. anonae (Graham)	Distributed across East, Central and West Africa. Attacks over 50 fruit species but principal pest of mango in West Africa. Females are extremely difficult to differentiate from those of *C. rosa* and *C. fasciventris*
	C. rubivora (Coquillet)	Commonly called the blackberry fruit fly. A rare species occurring in Eastern and southern Africa. Principal pest of berries such as rasp berry and black berry.
Dacus	*D. bivitattus* (Bigot)	Commonly called the pumpkin fruit fly. Occurs in eastern and West Africa. Mainly pest of cucurbits.
	D. ciliatus (Loew)	Commonly called the lesser pumpkin fly. Reported from East, West and Southern Africa. Primary pest of cucurbits recorded from nearly 20 commercial host plants.
	D. frontalis (Becker)	Occurs mainly in East and Southern Africa. Pest of cucurbits principally on cucumber, pumpkin and watermelon.
	D. vertebratus (Bezzi)	Commonly called the jointed pumpkin fly. Occurs in East, West and Southern Africa. Pest of cucurbits with special preference for watermelon.
	D. lounsburyii (Coquuilet)	Occurs in East and Southern Africa. Recorded mainly on sweet melons, watermelons and pumpkins.
Trirhithrum	*T. coffeae* (Bezzi)	Small black dark species. Occurs mostly in Central and West Africa. Mainly found in coffee growing areas and in members of the Rubiaceae family. Attacks variety of species including arabica coffee

Table 2.1 Cont.

	T. nigerrimum (Bezzi)	Small black dark species. Occurs mostly in Central and West Africa. Mainly found in coffee growing areas and in members of the Rubiaceae family. Attacks variety of species including arabica coffee
Bactrocera	*B. cucurbitae* (Coquillet)	Commonly called the melon fly. Reported from East and West Africa since 1930s. Primary pest of both cultivated and wild cucurbits.
	B. latifrons (Hendel)	First detected in Tanzania (2006) and in Kenya (2007). Restricted to Solanaceous plants. Does not respond to methyl eugenol, Only responds to Alpha-oinol+cade oil (Lati-Lure)
	B. zonata (Saunders)	Commonly called the peach fruit fly. Pest in Egypt, Libya and Indian Ocean Island of Mauritius. Have wide host range and an important pest of mango and citrus. Responds well to methyl eugenol. Constantly monitored across the frontiers of Sudan and other bordering countries.
	B. invadens (Drew, Tsuruta and White)	Commonly called the African invader fly. Originally detected in Kenya in 2003 and in Ghana in 2006. Now reported from 23 African countries. Over 39 host records in 21 plant families (and rising) but mango is most preferred. Major devastating quarantine pest.

Adapted from Ekesi and Billah (2006); De Meyer *et al*. (2012).

2.6.3 Damage caused by fruit flies

Because of their polyphagous habit, fruit fly pests inflict serious damage on fruits and vegetable crops. Direct damage begins when female fly punctures the fruit skin and oviposite underneath it. Fruit injury results from the ovipositional punctures on the skin which reduces the quality and market value of the fruit. Damage symptoms vary from fruit to fruit. During oviposition, fruit-rottening bacteria from the intestinal flora of the fly are introduced into the fruit. These bacteria multiply and cause the tissues surrounding the egg to rot (Vayssieres *et al*. 2009a).

When the eggs hatch, the rotten fruit tissues make it easier for the larvae to feed inside the fruit, resulting in a soft, mushy mess. The puncture and feeding galleries made by developing larvae also provide for pathogens to develop and increase the fruit decay. From a quantitative point of view, the damage is caused by larvae of second and especially third stages, by the removal of the significant proportion of the pulp which as a consequence results in reduction in the yield and quality of the harvestable fruits. Generally, the fruit falls to the ground as, or just before the maggots pupate and emerge as adult to continue the cycle (Ekesi, 2006).

Figure 2.2: Fruit fly damage symptoms on various types of fruit.

2.6.4 Economic impact of fruit flies

Fruit fly infestation has let to severe fruit damage and heavy fruit losses from many fruit producing communities in sub-Saharan Africa. This has taken a heavy toll on profitable fruit crop production in the subregion (Lux *et al*., 2003a). Annual damage caused by fruit flies is worth millions of dollars to fruit and vegetable crops (NRC, 1992). Prior to the invasion of Africa by *B. invadens*, the major fruit fly pests were the *Ceratitis* species, whose average damage range was estimated at about 20-30% on mango and citrus alone (Lux *et al*., 2003a). In South Africa, *C. rosa* ranked second in importance only to *C. capitata*, and in some situations, even more serious pest (CDFA, 2007). In many West African countries, including Ghana, *C. cosyra* featured prominently on mango (Afreh-Nuamah, 1999) but in recent times, this pest and other related species has continued to suffer competitive displacement by the invasive *Bactrocera* species (Ekesi *et al.*, 2009).

Currently, the African Invader Fly, *B. invadens* is found in almost all countries in sub-Saharan Africa. It is thought to be responsible for causing extensive economic losses to horticultural crops throughout Africa since its first report in 2003. It is an overabundant, highly polyphagous species attacking 40 host fruit and vegetable crops in 22 families. Damage may exceed 70% on mango and 40% on citrus (COLEACP-CIRAD, 2008). An assessment of damage of *B. invadens* on mango in Benin showed loss averages varying from 10-57% between the months of April and June (Vayssieres *et al*., 2005). In Senegal, fruit growers reported an average yield loss of about 40% all year round (Video Senegal (2007). Losses due to *B. invadens* in Ghana have been estimated to over 40% (PPRSD, 2010).

Indirect losses caused by fruit flies results from quarantine restrictions that are imposed by importing countries to prevent entry and establishment of unwanted fruit fly species (Ronald and Jayma, 2007). The effect of these pests has let to barriers to trade in fresh fruit commodities, costly surveys, control and eradication programmes throughout the world (Ishida *et al*., 2008) and thus, imposing limits on the export market (Raga *et al*., 2004, Ekesi and Billah, 2006). The introduction of uniform and strict maximum residue levels (MRL) across Europe compound the problem and further jeopardizes export.

Of greater concern is the fact that even in countries where fruit fly management methods are undertaken, rejection by European markets is on the increase largely because with global trade and passenger trafficking, they are easily translocated and the risk of majority of African fruit flies as key and potential quarantine pests is becoming increasingly realized (OleMoiYoi and Lux, 2004). Quarantine regulations imposed by an importing country can either deny a producing country a potential export market, or force the producer to carry out expensive disinfestations treatments against fruit flies (White and Elson-Harris, 1992). As presented in Table 2.2, the African continent has experienced several interceptions of fresh mangoes imported to the European Union (EU). Though the updated record is not available at present, the figures indicated here should not be promptly regarded as reduced infestation levels of fruit-infesting flies in the continent; it should be consistent with the limited means of fruit fly surveillance and control currently available in the fields. COLEACP-CIRAD (2009) noted that it would be more meaningful to link any improved record with an intensified selection work for noninfested fruits during and after harvest operations together with a reduction in the period of export. But the economic losses remain the same for African producers with less marketable fruit over a shorter period and more infested fruit whose disposal is becoming more and more difficult (COLEACP-CIRAD, 2009).

Table 2.2: EU interceptions of infested mangoes from Africa.

Importing country	2007		2008		2009		2010		2011		2012	
	No. interceptions	Entry point	No. Interceptions	Entry point	No. interceptions	Entry point	No. interceptions	Entry point	No. interceptions	Entry point	No. interceptions	Entry point
Burkina Faso	3	FRA	4	FRA	5	FRA	9		5	FRA	8	FRA
Cote d'Ivoire					2	FRA	1	FRA				
Gambia			1	GBR							1	GBR
Ghana	1	GER	2	NLD	2	NDL(1) GBR(1)	1	NDL	1	NDL		
Guinea			1	FRA								
Mali	14	FRA	5	FRA(3) NDL(1)	13	FRA	4	FRA	3	NDL	7	FRA(2) NDL(2)
Senegal	15	FRA	2	FRA(1) NDL(1)	4	FRA(2) GBR(2)	1	NDL			1	FRA
Cameroon	17	FRA	5	FRA	9	FRA	2	FRA	2	FRA	4	FRA
Cent. Afric. Rep.	1	FRA							2	FRA		
Kenya	2	FRA	3	FRA(1) GBR(2)	1	FRA	1	GBR	4	FRA	1	FRA
Egypt	1	FRA			1	FRA			2	FRA		
TOTAL	**54**		**26**		**37**		**22**		**19**		**22**	

Adapted from COLEACP-CIRAD (2009); EUNSPH (2012)

The rapid spread and devastating impact of *B. invadens* in SSA has been a matter of serious concern to the horticulture industry. For example, export of potential host crops such as mango, avocado and cucurbits from Kenya, Tanzania and Uganda are already banned in Seychelles, Mauritius and South Africa. Trade of several horticultural produce between Africa and the US has been severely hampered by recently issued Federal Order by US banning importation of several cultivated fruits and vegetables from African countries where *B. invadens* has been reported (USDA-APHIS, 2008). In the case of avocado, Kenya lost US$ 1.9 million in 2008 due to *B. invadens* quarantine restriction imposed by South Africa. The current export volume for banana in Mozambique is estimated at 35,000 tons per year with a foreign exchange value of US$ 17.5 million. South Africa, its major trading partner has closed its markets to fresh fruits including bananas and mangoes from the northern part of the country due to the presence of *B. invadens*. At Vanduzi Company in the Central province of Manica about US$ 1.5 million had been lost due to the presence of *B. invadens* and quarantine restrictions on the export of various fresh fruit and vegetable crops (Cugala *et al*., 2009).

These restrictions seriously threaten the income, food security and livelihood of millions of families that produce and sell fresh fruit and vegetable crops across Africa. With increasing emphasis on quality of fruit and vegetable produce, and the possibility of expansion of trade in horticultural commodities, importing and exporting countries are giving increasing attention to fruit fly management at pre-harvest and post-harvest levels (Drew, 1992).

2.7.0 Management strategies for fruit flies

Fruit fly management generally involves two basic approaches; the eradication approach and the IPM approach (Lux *et al*., 2003a).

2.7.1 The eradication approach

This approach usually involves an area-wide action to eliminate the target fruit fly population so as to create a fruit fly-free area/zone. Such a pest-free zone may however,be liable to future re-infestation (Myers *et al*., 1998). Eradication is costly and is justified only when a highly productive industry is threatened, or when the pest has just arrived in the area (Wilson, 2006). Follet and Neven (2006) observed that eradication of a pest from an agricultural region is theoretically challenging and depending on the method used, can be socially and environmentally unacceptable. For instance, eradication in an urban area using aerial and ground application of pesticides can evoke public opposition.

The major means by which eradication can be achieved is through a “birth control” method based on genetic manipulation, known as the Sterile Insect Technique (SIT) (IAEA, 2003). This control method makes use of artificially sterilized populations of the male fruit fly pest to mate with unsterilized female in the wild, and thereby interfere with the normal reproductive efforts of the target species (Van der Vloedt and Klassen, 2006). Irradiation is presently the most practical way to sterilize insects. Reproductive sterility is induced by exposure of the flies to X-rays, electron beams, and most commonly gamma rays from a Cobalt-60 or Caesium-137 source (Robinson, 2005). It is among the most nondestructive pest control methods and unlike biologically based methods, it is species-specific and does not release toxic agents into the environment (Hendrich *et al*., 2002). The method is effective especially if the sexually mature males are aggressive and effectively compete with wild males in searching for and mating with indigenous females. It also has the advantage of being compatible with other control methods and has increased efficiency with decreased target population density (IAEA, 2003).

Many attempts have been made in controlling fruit-infesting flies using SIT. For instance, SIT was successfully applied against the Mediteranean fruit fly, *C. capitata* from areas it had already infested in Southern Mexico (Hendrich and Hendrichs, 1998). This fused initially on the concept of eradication, following the successful example of the screwworm which was eradicated from the United States, Mexico and Panama (Wyss, 2000). Since then, a sterile fly barrier had been maintained in that region. The successful application of SIT in Chile to eradicate *C. capitata* in 1995 opened trade opportunities estimated over five years at a benefit to Chilean fruit industry of $500 million (SAG, 1996). Also, SIT was successfully used to eradicate *B. dorsalis* (Hendel) from Okinawa and neighbouring islands in the Ryukyu Archipelago, Japan (FFEPO, 1987). A more recent study conducted by Ogaugwu (2007) indicated the possiblity to produce sterile, viable and competitive males of *B. dorsalis* in Ghana.

However, because of the polyandrous and long distant migratory abilities of the flies outside the release area, or the release ratio being too small to overcome the high population densities throughout the year (Wong *et al*., 1984; Sheo *et al*., 1990; Follet and Naven, 2006), SIT does not seem suitable for continental areas. Also, Gould and Schliekelman (2004) pointed out that if the pest populations consist of sub-populations and some populations are not accessible to released insects, migration among sub-populations may prevent eradication. SIT may also be ineffective in cases where the insect pests targeted do not reproduce sexually, or the released males are not relatively competitive in searching for and mating with the wild females (Van der Vloedt and Klassen, 2006). In Africa where there is a multiple of species coexisting, the use of SIT may end up eradicating one and creating a new ‘champion’ pests. The small scale nature and fragmented orchards in Africa will also make it difficult to use SIT (Manrakhan, 2006).

2.7.2 The IPM approach

In situations where eradication methods are not available or justifiable, the Integrated Pest Management (IPM) strategy is used. This strategy combines as many compatible methods as possible to reduce yield losses and allow fruit production (Klungness *et al*., 2005). Previous experience with exotic and native fruit fly species in Africa and with other species in similar agroecologies in Latin America and the South Pacific has shown that management of fruit fly species in general is unlikely to be successful if based on a single management technique (Aluja *et al.,* 1996; Allwood and Drew, 1997; Lux *et al*., 2003a). An IPM strategy offers the best method to improve the economics of the production system by reducing yield losses and enabling growers to comply with stringent quality standard of the export market (Aluja *et al.*, 1996; Allwood and Drew, 1997; Lux *et al.*, 2003a). The approach that is being promoted across Africa by the *icipe*-led African Fruit Fly Program (AFFP) is to use a combination of management techniques that is based on at least 2 or all the components listed in this review. The major components of integrated fruit fly management are discussed below.

2.7.2.1 Monitoring with attractants

Monitoring is a techniques used to understand insect activity so as to help make pest management decisions. Information on the seasonal population fluctuation and peak period of pest activity is an important component of any pest management strategy because a warning of the timing and extent of pest outbreak can improve efficiency of control measures (Ekesi *et al*., 2006). The estimate of pest abundance or a change in numbers provides an essential measure by which control decisions can be made (Dent, 1992). Fruit fly monitoring helps to i) determine fruit fly pests in an area, ii) determine distribution of pest species, iii) determine local hot spots with high populations of the pest, iv) track changes in population levels, v) determine the efficacy of control measures, and vi) facilitate early detection of new fruit fly pests in a particular area (Manrakhan, 2006). Tools used in monitoring fruit flies consist of attractants, traps and insecticides (used in traps as killing agents to retain captured flies). The two main types of attractants used in fruit fly monitoring include parapheromones (male lures) and food baits (Cunningham, 1989; Heath *et al*., 1997; Lux *et al*., 2003a).

Use of parapheromones

Parapheromones are lures that attract only male fruit flies. They are highly species-specific and are known to have a high efficacy in attracting fruit flies from long distances (White and Elson-Harris, 1992; Economopoulos and Haniotakis, 1994). The use of parapheromones in fruit fly control is a technique commonly referred to as the Male Anihilation Technique (MAT). MAT aims at reducing male fruit fly populations to levels that mating does not occur or occurs at very low levels. Parapheromones are available in both liquid form and polymeric plugs (in the form of a controlled-release formulation). Male lures in liquid form last between 2-4 weeks (Ekesi and Billah, 2006).

The major types of attractants include; Methyl eugenol (ME) (benzene, 1,2-dmethoxy-4-2-propenyl); Cuelure (CUE) (4-(p-hydroxyphenyl-2-butanone acetate); Trimedlure (TML) (tert-butyl-4-5-chloro-2-methylcyclohexane-1-carboxylate); Terpinyl acetate (TA) (alpha, alpha,4-trimethyl-3-cyclohexene-1-methanol); and Vertlure (VL) (methyl-4-hydroxybenzoate). ME and CUE attract several species of *Bactrocera*, TML and TA attract several species of *Ceratitis*, while VL attract some species of *Dacus* (IAEA, 2003; Manrakhan, 2006). These attractants are currently being used in fruit fly management in many countries in Africa including Ghana (Ekesi and Billah, 2006; Billah *et al*., 2006; IITA-CIRAD, 2008).

The traps and trapping procedures for monitoring fruit flies are dependent on the attractant and the nature of the area (IAEA, 2003). In commercial orchards with continuous blocks, traps are arranged in grid system while in scattered orchards with dispersersed settlements and backyard host plants, or in areas with wild and commercial hosts, traps are arranged in a system that follows a road network, allowing acess to the host areas. There is no specified layout for early detection except that traps have to be placed at points of entry and points of fruit trade (Manrakhan, 2006). The selection of a proper trapping site is critical in ant trapping survey. It is important to develop a list of fruit fly host trees for the fruit fly species that need to be monitored and be familiar with these host trees. Traps must be placed on or close to host trees. Whenever possible, a fruiting host should be chosen for setting traps. In areas with no host, traps should be placed on trees that can offer shelter, protection and food to adult fruit flies. The traps should be placed about 2-4 m above ground within the canopy layer in a shaded spot. The references of the trap location should include visible landmarks, ribbons or full address of the property.

The application of Geographical Positioning Systems (GPS) can be a very effective tool in both trap location as well as analysis of trap captures (IAEA, 2003). Trapping density will depend on the lure/attractant efficiency, trap efficiency, altitude, location, presence of hosts, climate, topography and fruit fly species (Ekesi and Billah, 2006). Trap servicing and rebaiting interval also depends on the objectives of the trapping survey and the type and formulation of attractant that is being used. The outcome of trapping activity should be reported as the population index representing the average number of flies captured in one trap in one day that the trap is exposed to in the field (IAEA, 2003).

Use of Foodbaits

Fruit fly suppression is mainly based on the use of food baits (hydrolyzed proteins or their ammonium mimics) mixed with a killing agent and this method has been tested for the management of *Bactrocera* and other species. These are lures that attract both male and female fruit flies. They are not species-specific and are known to have a low efficiency compared to male lures (White and Elson-Harris, 1992). The use of food baits for fruit fly control is a technique commonly referred to as the Bait Application Technique (BAT). These baits can also attract a number of non-target insects, including beneficial ones. They are available in both liquid and dry synthetic forms. Ammonia is the principal attractant emanating from food baits there are variety of commercially available food baits. These include liquid proten hydrolysates, yeast products, ammonium salts, and the three-component lure (consisting of putrescine, ammonium acetate and trimethylamine) (Mazor *et al.*,1987; Heath *et al*., 1997; Lux *et al*., 2003a; IAEA, 2003; Ekesi and Billah, 2006). A number of commercial baits are now available in the market; such products as Nulure, Buminal and SolBait that can be mixed with insecticides such as spinosad for direct application. Another commercial product is GF-120 (Success Apart) which is already premixed with spinosad and can be applied using the on label information on the pakaging container.

In Africa, Ekesi *et al*. (2007) assessed the efficacy of Nulure bait mixed with spinosad in suppressing the population of *B. invadens* and other native fruit fly pests on mango in Malindi, Kenya. Effectiveness of GF-120 spinosad fruit fly bait in suppressing *B. invadens* and other mango infesting fruit flies was assessed by comparing treated orchards with untreated mango orchards in Benin (Vayssieres *et al.*, 2009b). GF-120 provided an 81% reduction in the number of pupae/kg of mango fruit after weekly applications for 7 weeks and an 89% reduction after 10 wk of weekly applications (Vayssieres *et al*., 2009b). Field trials conducted for 2 seasons on mango orchards at Nthagaiya, Kenya, showed that application of GF-120 led to a significant reduction in fruit damage by *B. invadens* and indigenous *Ceratitis* species compared to the control (Ekesi., 2010).

The bait system is therefore an integral component of IPM in horticultural crops because it reduces pesticide usage with minimum effect on predators, parasitiods and pollinators. Protein bait application is less time consuming and less demanding of labour (Smith and Nannan, 1988). However, a major problem in the use of baits in Africa is that they have to be imported, thus making them expensive and inacessible to a large number of fruit and vegetable growers. Research at the International Centre of Insect Physiology and Ecology (ICIPE) has shown that a protein bait from brewer's yeast (obtained as an industrial by-product), when applied in low volumes as spot spray to 1 square metre of mango canopy or to the mango trunk, provided good control of mango-infesting fruit flies. Research is however, continuing in ICIPE at formulating the bait to enhance its attractiveness to fruit flies, and such bait, once fully developed should be available in the near future as a cost-effective alternative to the imported products. Work on brewers' yeast has also been done in Ghana on mango and citrus (Bulley, 2011).

2.7.2.2 Soil inoculation

An important component of fruit fly control is soil treatment with fungal pathogens to kill the mature maggots and puparia. This is a new method of fruit fly control, targeting the immature stages of the fruit flies (maggots and puparia). The active ingredient is the fungus *Metarhizium* *anisoplie,* a naturally occuring fungus isolated from the soil that is being used worldwide as a biological pesticide for controlling different kinds of insect pests. The fungus is formulated as granules and can be dispersed by hand and then raked into the soil where it can persist for over a year (Ouna, 2010).

In recent studies, several potent isolates have been identified against *B. invadens* both for soil inoculation targeting pupariating larvae and adult using autodissemination devices (Ekesi *et al.*, 2007; Ouna, 2010). The ultimate goal is to reduce oviposition by gravid female fruit flies and the overall effect of fungal infection on adult fecundity and fertility has been shown to be very high. Ouna (2010) demonstrated over 70% reduction in *B. invadens* egg fertility due to fungal infection. In field suppression trials, Ekesi *et al.* (2007) applied granular formulations of *M. anisopliae* at the rate of 60 kg/ha (one gram of spore consisted of 3 x 108 conidia) once at the onset of mango fruiting to assess the impact of the treatment on the population of *B. invadens* and mango fruit infestation. Results showed that application of the fungus reduced fruit fly population by 64% relative to the control. Mean fruit infestation was 46% in the fungus treatment and 73% in untreated control plots. Granular formulation of fungal biopesticides as used in this study has the advantage of increasing the concentration of inoculum in the soil through sporulation in and/or on the granular substrate, and microcyclic conidiation. While soil inoculation with *M. anisopliae* cannot be considered as a stand-alone strategy, the fungus has a significant role to play when combined with other IPM component for *B. invadens* suppression.

Removal of excess leaf litter before application enhances activity of the fungus. The fungal granules are compatible with most commonly available pesticides, fungicides and fertilizer meant for soil application, as they may delay activity of the fungus. This technique of fruit fly control is expected to be environmentally friendly and easily adoptable by peasant farmers, and can be used as a supportive measure to the bait sprays. Further research on formulation of the fungus is on-going and the product would be available for use in the near future. Soil can also be inoculated with neem cake and other botanical formulations to kill pupating larvae (Ekesi and Billah, 2006).

2.7.2.3 Post-harvest fruit treatment

Without post-harvest treatment to provide quarantine security, exports of fruit and vegetable crops to lucrative markets abroad is limited due to quarantine restrictions. Therefore, effective post-harvest quarantine treatments that are not harmful to either the product or people coming in contact with or consuming the fruits, must be applied to the export commodities. The available quarantine treatment technologies (as alternatives to toxic fumigation) include: i) heat treatment to increase temperature of host fruits above thermal limits of the fruit fly, ii) cold treatment to decrease temperature of host fruits below the thermal limits of the fruit fly, and iii) irradiation with gamma rays from a Cobalt-60 or Caesium-137 source to kill the developing flies (Robinson, 2005). In Africa, the parameters for treating fruits against fruit flies have not yet been established, but once developed, these treatments should increase the export potential of tropical fruit and vegetable crops from Africa (Ekesi and Billah, 2006). Currently there is no known published research on the use of post-harvest fruit treatment methods against tephritid pests on the continent. Cold (citrus and avocado) and heat (mango) treatments have commenced at ICIPE in close collaboration with the Citrus Research International (CRI), South Africa and South African Avocado Growers Association (SAAGA) to develop post harvest treatment parameters for *B. invadens*. Once completed and implemented, this should increase export potential for these fruits from Africa (Ekesi and Billah, 2006).

2.7.2.4 Cultural Control

Cultural control includes practices that may be regarded as part of the normal production system and do not involve the application of insecticides. Poorly managed or abandoned fruit crop farms and a variety of wild hosts can result in high population build up of fruit flies. Cultural control method relies on farm sanitation and crop hygiene targeted at breaking the reproductive cycle of the pests. It is based on an understanding of the biology of the flies, which ensures that larvae in the dropped fruits do not mature in the soil. It entails the collection and destruction of all infested fruits found on the trees and all falling fruits containing fruit fly maggots and puparia on the ground (Ekesi, 2010). Fruit destruction is achieved by crushing the infested fruit in a grinding machine. Infested fruits may also be burried deep (at least >50 cm) under the soil surface with an addition of sufficient lime to kill the developing larvae. This can contribute significantly to reduction in fruit fly populations in the farm. Rwomushana (2008) was able to demonstrate that the density of *B. invadens* was significantly higher in fallen mango on the ground compared with that sampled from the tree signifying the important role of orchard sanitation in the management of the insects. The collection and deposition of fallen, damaged and unwanted fruits in an Augmentorium (Klungness *et al*., 2005) is being strongly advocated among fruit and vegetable growers across Africa. Removal of infested fruits can contribute significantly to reduction of fruit fly population (Rwomushana, 2008).

Cultural control for fruit flies is a laborious exercise but can be quite effective if the fruits are regularly collected and destroyed twice a week for the entire season. Collection and destruction of fallen, damaged, over-ripe and friuits is strongly recommended to reduce resisdent populations of fruit flies in orchards. The collected fruits should be destroyed by either burning or burying. One effective means of achieving cultural control against fruit flies is collection of infested fruits, tying them in black plastic bags and exposing them to the heat of the sun for a few days untill the fruits are rotten and all the maggots in the bags are dead (Mau and Kessing, 1992). The fruits should be buried at least, 50 cm (about 2 feet) deep to present the emerging adult flies from reaching the soil surface (Ekesi and Billah, 2006). The control of *B. zonata* using killing bags has been successfully reported in Egypt (Mohamed and El-Wakkad, 2003).

To eliminate or reduce resident population reserviors, crop sanitation has been an essential component of fruit fly management programmes in the Integrated Tamale Fruitts Company (ITFC) in the Northern Region on Ghana. The adoption of sound crop sanitation practices has helped to release pressure on other components of control systems, particularly protein bait sprays whose effectiveness are threatened under high fruit fly population pressure. Under quality assurance schemes being adopted for production of export commodities, sound crop sanitation has become a prerequisite for any farm that is global-gap certified for export production (Ekesi, 2010).

2.7.2.5 Mechanical fruit protection

Notwithstanding the presence of fruit flies in the farm, wrapping or bagging of individual fruits with newspaper or paper bags to prevent adult female flies from laying eggs on the fruits is also a practice of producing fruits that are free from fruit fly attack. To be effective, the fruits must be wrapped or bagged well before fruit fly attack, ie at least, one month before harvest. Although laborious, it is an effective method for high value fruit produced for export or fruits produced in backyard gardens for family use (Ekesi and Billah, 2006). At present, there is no known published research on the use of mechanical fruit protection methods against tephritid pests in the continent.

2.7.2.6 Early Harvesting

Avoidance of fruit fly infestation is possible by hrvesting fruits at the stage of maturity when fruits or vegetables are not very susceptible to attack fruit fly development does not occur in certain fruit such as papaya, banana and sapodilla when they are 100% green. Only the ripe fruits are good host. Bananas, for example, have been exported around the world because they are not susceptible to fruit flies at the matures green stage. Thus, early harvesting to evade fruit fly infestation is an important techinique in the production of these fruits. Although early harvesting is practiced for mango, it is effective as some fruit fly species like *B. invadens* and *C. cosyra* are capable of infesting even immature or mature green mangoes (Ekesi *et al.,* 2006).

2.7.2.7 Biological Control

Biological control is the use of parasitiods, predators or pathogens to control pest populations. Fruit fly parasitoids are insects that develop by laying their eggs in fruit fly eggs or larvae. The host is killed when the parasitoid larval development is completed. Parasitoid wasps are introduced into fruit farms for fruit fly control. They are fairly specific to certain fruit fly species or genera. Natural enemies must be conserved so that they can contribute to the control of all stage of the fruit files. A major hazard to natural enemies is the blanket spray of pesticides that also kill them. Limited application of blanket sprays and use of localized spot treatment will assist in the conservation of important natural enemies for use in biological control programs (Wilson, 2006).

Biological control practices are advantageous in that the natural enemies are naturally programmed to search for the target pests (Gilmore, 1989). It is also relatively safe, permanent and economical (Ekesi and Billah, 2006). Amongst other species, the Opiinae which are koinobionts, are the most abundant group of tephritid parasitoids and are more frequently collected and used in IPM and biological control (CABI, 1999). They parasitize the young larvae that are developing under the skin of fruits. *Terastichus* spp (Eulophids) are larvae-pupal parasitoids and they can complement the activity of the Opines (CABI, 1999). *Fobius* (*Opius*) *longicaudatus* var. *maliaensis* Fullaway, *F*. *vandendoschi* Fullaway, and *Fopius ariasanus* Fullaway, have become established in Hawaii and are primarily effective against the oriental and the Mediterranean fruit flies in cultivated crops (Mau and Kessing, 1992). Clausen (1978) reviewed the numerous releases that have taken place in Hawaii and noted that all the benefits are almost entirely due to *F*. *arisanus* (*Opius oophilus*). He observed a decreased infestation of about 80% in guava as a result of reduction in *B. dorsalis* populations through the effects of parasitism.

A recent study conducted in Benin on the use of ants to manage fruit flies revealed that *O. longinoda* significantly reduced the number of fruits damaged by deterring fruit flies from attacking the fruits. Although predation on adults of fruit flies took place, deterrence and disturbance by ants during fruit fly oviposition seemed to be the most important causes of reducing fruit fly damage (Van Mele and Coc, 2000: Van Mele *et al*., 2007). Also, birds and rodents have been reported to cause a high level of larval mortality by consuming infested fruit (Drew, 1989). Similar groups of predators are likely to play a role in restricting fruit fly populations throughout Africa, and their conservation may be of practical importance. However, a thorough assessment of their impact on fruit fly population in various regions in Africa, and in various production systems needs to be validated.

Use of parasitic hymenoptera to control tephritid fly populations date to the beginning of the 20th century when natural enemies where sought in Africa to control *C. capitata* in Hawaii (Wharton 1989). Following successful establishment of some species in the Island, *Diachasmimorpha* *longicaudata* has been introduced and established in many parts of the world. Extensive work has followed leading to the development of mass rearing systems for some species (Wong and Ramadan 1992), and incorporation of augmentative releases in conjunction with the sterile insect technique to eradicate Medfly *Ceratitis capitata*, Melon fly *Bactrocera cucurbitae*, Mexican Fruit fly *Anastrepha ludens*, West Indian Fruit fly *A, obliqua,* and Caribbean fruit fly *Anastrepha suspensa.* Details of the available parasites and predators that have been tested against Tephritid fruit fly pests in sub-Saharan Africa are shown in Table 2.3.

Other biological control agents that have been used against Tephritids include Nematodes, protozoan bacteria and fungi. *Anastrepha* larvae are susceptible to the entomopathogenic nematode, *Neoaplectana* spp (Rhabditida, Steinematidea) and *Heterorhabditis* spp. Pathogens like protozoa, *Bacillus thuringensis* (Bt) and fungi have also been used. Fuji and Tamashiro (1972) made the first observations of pathogens attacking fruit flies in Hawaii. They reported infection of *B. dorsalis* and *C. capitata* by the protozoa *Nosema tephritidae*. The microbial agents commonly tested against tephritid fruit flies in Africa are presented in Table 2.4. Although successes have been generally limited, the use of natural enemies (pathogens, parasitoids and predators) for the suppression of fruit flies has always had a wide appeal because it is relatively safe, permanent and economical. Several species of parasitoids and predators abound in fruit and vegetable agroecosystems, which can contribute to the suppression of fruit flies (Stibick, 2004). Efforts to conserve these natural enemies through efficient mangement based on the fruit fly IPM components described above may contribute to the overall suppression of fruit flies. The search for and research on biological control of fruit flies, especially the invasive species, in Africa should also remain an integral part of the fruit fly suppression campaign.

Table 2.3: Parasites and predators used against African tephritid pests.

Fruit fly Species	**Parasites/Predators**	**Notes**
B. cucurbitae	*Psytallia fletcheri*	Common Indian egg-larval Braconid parasite from Hawaii. Prefers wild hosts for parasitization
	Opius watersi	Egg-larval Braconid parasite from North India and Ceylon
	Biosteres angaleti	A Braconid larval-pupal parasite from the Indo-Australian Region
	Diachasmimorpha longicaudatus	An Indo-Australian Braconid larval parasite, now in Hawaii, Fiji, Australia, America, Carribean, Florida.
	Diachasma fullawayi	A Braconid parasite from Hawaii
	Galeus silvestrii	A Diapriid parasite from Hawaii
	Pachycrepoideus Dubius	A Pteromalid parasite from Hawaii
	Tetrastichus Giffardianus	A Eulophid parasite from Hawaii
	Dirhinus anthracia	A Chalcid parasite from S. India. From Africa to Middle East and SE Asia.
	Spalangia nigra	A Pteromalid, pro larval-pupal parasite from Europe, N. America.
	Pachyneuron Vindemmiae	A Pteromalid pupal parasite from Morocco, Introduced to Reunion
	Fopius vandenboschi	A Braconid parasite from SE Asia, Thailand
	Syntomosphyrum Indicum	An Eulophid parasite from SE Asia
	Opius compensans	A Braconid parasite from India with 10-12% parasitism
B. invadens	*Diachasmimorpha Longicaudata*	An Indo-Australian Braconid 2-3rd stage larval parasite from Carribean, Florida.
	Opius formosanus	An egg-larval Braconid parasite from Formosa in Hawaii
	Psyttalia fletcheri	A Braconid parasite fromThailand
	Opius kraussi	An egg-larval Braconid parasite from Australia
	Fopius arisanus	A Braconid egg/pupal parasite from Malaya in Hawaii.
	Tetrastichus dacicida	An Eulophid pupal parasite ex. *Dacus*, *Pardalaspis* and *Pterandrus* spp. from Kenya
	Biosteres skinneri	A Braconid parasite from Malaysia, Philippines which more readily attacks Tephritids in cucurbits.
	Opius fijiensis	A Braconid egg-larval parasite from Australia, S. Pacific
	Spalangia gemina	A Pteromalid pupal parasite with a wide host range from Asia through S. America
	Thyreocephalus Albertisi	A Staphylinid predator from the Philippines
	Anisolabis eteronoma	An earwig (Carcinophiridae) predator which feeds on larvae in fruit and soil
	Dirhinus auratus	A Chalcid parasite from India

Table 2.3 Cont.

	Aceratoneuromyia Indica	An Eulophid parasite from Malaysia
	Coptera silvestrii	A Psiline parasite from Africa (Benin, Ghana, Niger, Nigeria, Senegal, Kenya, Monzambique, Zululand).
B. latifrons	*Biosteres arisanus*	A Braconid egg parasite from the Indo-Australian Region
	D. longicaudatus	An Indo-Australian Braconid larval parasite
	Biosteres persulcatus	A Braconid parasite from India
	Fopius vandenboschi	A Braconid 1st stage larval parasite from SE Asia, tested in Hawaii
	Fopius arisanus	A Braconid larval-pupal parasite from India, Thailand
	Dirhinus luzonensis	A Chalcid parasite from the Philippines
	Pachycrepoideus Dubius	A Pteromalid parasite from South China
	Psyttalia fletcheri	A Braconid parasite from Thailand
	Psyttalia sp. nr *makii*	A Braconid parasite from Thailand
	Dichasmimorpha Kraussi	An Opiine larval parasite from Australia, introduced to Hawaii for control
	Utetes bianchii	A Braconid parasite from Thailand
B. zonata	*D. longicaudatus*	An Indo-Australian Braconid larval parasite, now in Hawaii, Fiji,America, Carribean, Florida.
	Fopius persulcatus	A Braconid parasite from India
	Fopius vandenboschi	A Braconid parasite from Thailand
	Austroopius sp.	A Braconid parasite from India
	Opius sp.	A Braconid parasite from India
	Psyttalia makii	A Braconid parasite from Thailand
	Psyttalia fletcheri	A Braconid parasite from Thailand
	Trybliographia daci	A Cynipid larval-pupal parasite from Pakistan.
C. anonae	*Biosteres caudatus*	A Braconid larval parasite from Nigeria, French Cameroons, Sierra Leone
	Galesus silvestrii	A Diapriid pupal parasite in small numbers from Nigeria. Also found on *Dirhinus giffardii*
	Dirhinus giffardii	A Braconid pupal parasite from Nigeria
	Spalangia afra	A Pteromalid pupal parasite from Nigeria
	Biosteres desideratus	A Braconid parasite from Africa
	Biosteres fullawayi	A Braconid parasite from Africa and widely spread to Hawaii, Spain, Puerto Rico, Australia
	Coptera silvestrii	A Psiline parasite from Africa (Benin, Ghana, Niger, Nigeria, Senegal, Kenya, Monzambique, Zululand).
C. capitata	*Diachasmimorpha (=Opius) tryoni*	An Australian Braconid egg-larval parasite from Queensland fruit fly, dominant on Medfly in Hawaii
	Diachasmimorpha Kraussii	An Australian Braconid larval parasite.
	Opius fullawayi	A West African Braconid egg-larval parasite
	Opius humilis	A Braconid larval parasite, effective on Medfly in Hawaii.
	Dirhinus giffardii	A West African Chalcid pupal parasite from Hawaii and Egypt

Table 2.3 Cont.

	Tetrastichus Giffardianus	A West African Eulophid pupal parasite, almost negligible, except in certain fruits.
	Galesus silvestrii	A Diapriid pupal parasite from Nigeria
	Trichopria capensis	A Diapriid pupal parasite from South Africa
	Syntomosphyrum indicum	An Eulophid late instar larval parasite from India
	Opius kraussii	A Braconid larval parasite from Australia with decided preference for Medfly
	Fopius arisanus	A Braconid egg/pupal parasite which outcompetes other parasites
	Bracon celer	A Braconid larval parasite from Kenya
	Doryctobracon Areolatus	A Braconid larval-pupal parasite of late instars from N. and S. America.
	Coptera haywardi	A Diapriid pupal endoparasitoid from Latin America, but unable to develop on irradiated hosts
	Coptera silvestrii	A Psiline parasite from Africa (Benin, Ghana, Niger, Nigeria, Senegal, Kenya, Monzambique, Zululand), introduced to Hawaii
	Aganaspis pelleranoi	An Eucoilid parasite from Costa Rica, Argentina. Seeks out late instar larvae through fruit holes
	Biosteres desideratus	A Braconid parasite from Africa reared in lab.
	Odontosema Anastrephae	A non-specific larval-pupal parasite from Costa Rica
C. cosyra	*Opius cosyrae*	A Braconid parasite from northern Africa.
	Opius perproximus	A Braconid larval parasite from West Africa
	Biosteres fullawayi	A Braconid parasite from the Cameroons
	Coptera silvestrii	A Psiline parasite from Africa (Benin, Ghana, Niger, Nigeria, Senegal, Kenya), introduced to Hawaii
C. ditissima	*Biosteres caudatus*	A Braconid larval parasite from Africa
	Biosteres giffardii	A Braconid parasite from Africa
C. rosa	*Fopius ceratitivorus*	A larval-pupal Braconid parasite from Africa
	Opius africanus	A Braconid larval parasite from South Africa
	Pachyneuron Vindemmiae	A Pteromalid pupal parasite from Morocco.Intro. Reunion
	Dirhinus giffardii	A West African Chalcid pupal parasite, only occasionally found in Hawaii, also in Egypt & Brazil
	Isurgus sp.	An Ichneumonid parasite from Africa
	Coptera silvestrii	A Psiline parasite from Africa (Benin, Ghana, Niger, Nigeria, Senegal, Kenya), introduced to Hawaii
D. bivittatus	*Diachasma fullawayi* var. *Robustum*	A pupal parasite from French Guinea
	Biosteres caudatus	A widely diffused Braconid larval parasite from Nigeria
	Coptera silvestrii	A Psiline parasite from Africa (Benin, Ghana, Niger, Nigeria, Senegal, Kenya, Monzambique, Zululand).

Table 2.3 Cont.

	Tetrastichus Giffardii	A widely diffused Braconid egg-larval parasite from Victoria
	Tetrastichus dacicida	A Eulophid parasite from the Cameroons
	Spalangia afra	A Pteromalid pupal parasite from Africa
	Dirhinus sp.	A Chalcid parasite from Africa
	Biosteres desideratus	A Braconid parasite from the Cameroons
	Opius perproximus	A Braconid parasite from the Cameroons
D. ciliatus	*Opius perproximus*	A Braconid larval parasite from West Africa
	Biosteres caudatus	A widely diffused Braconid larval parasite from Dahomey
	Opius fletcheri	Common Indian Braconid egg-larval parasite, in Hawaii restricted to Melon Fly.
	Opius phaeostigma	A Braconid parasite from South Africa
	Sarcophaga flagellata	A Sarcophagid parasite (Diptera) from the Italian Somaliland
	Diachasma brevistyli	A Braconid parasite from the Italian Somaliland
	Spalangia afra	A Chalcid (pupal) parasite from Africa
	Dirhinus luzonensis	The most abundant Chalcid parasite from India
D. frontalis	*Biosteres Longicaudatus*	A Braconid parasite from the Cape Verde Islands
	Opius concolor	A Braconid parasite from the Cape Verde Islands
	Dirhinus ?giffardii	A Chalcid parasite from the Cape Verde Islands
D. Punctatifrons	*Tetrastichus Giffardianus*	An Eulophid parasite
Trirhithrum Coffeae	*Fopius ceratitivorus*	A Braconid parasite from Africa and widely spread to Hawaii, Spain, Puerto Rico, Australia
	Biosteres caudatus	A larval-pupal Braconid parasite from Africa
	Biosteres fullawayi	A Braconid larval parasite from Africa
	Opius sp. nr. *Desideratus*	A Braconid larval-pupal parasite from Uganda, in 7 to 23% of larvae
	Opius cosyrae	A Braconid larval pupal parasite from Uganda, in 2-7% of larvae
	Tetrastichus giffardii	A Eulophid multiple pupal parasite with up to 12 parasites per pupa, from Uganda
	Syntomosphyrum sp.	An Eulophid pupal parasite from Uganda
T. nigerrimum	*Opius perproximus* var. *Modestior*	A Braconid parasite from Nigeria
	Biosteres caudatus	A Braconid larval parasite from Victoria
	Galesus silvestrii	A Diapriid pupal parasite from Nigeria
	Opius perproximus	A Braconid larval parasite from West Africa
	Microbracon celer	A Braconid parasite from Kenya

Adapted from Stibick (2004); Vayssieres *et al*. (20011a, 2012)

Table 2.4: Microorganisms and microbial toxins used against African tephritid pests.

Species	Biological Mode	Product	Specifics
B. cucurbitae	Through adult contact	Agent: Avermectin B_1 (MK-936) a powerful toxin derived from Streptomyces *avermitilis* fermentation.	In Lab, applied to thorax, at 0.042 ug/g LD50 15 days With sublethal doses, fecundity, and fertility reduced by up to 79%
	Through larval Contact	An entomogenous nematode Agent: *Steinernema carpocapsae*	Augmentation to eradication is 500 nematode per cm^2 applied to soils. Causes 89% mortality
	Through adult Contact	An Endosymbiotic bacteria of the genus *Wolbachia*, inducing cytoplasmic incompatibility, thelytokous parthenogenesis, male-killing or feminization.	In field collected adults from Thailand
B. dorsalis	*Opius oophilus*, a parasite	unspecified bacteria and fungi Agent: *Leucothix mucor*	Females serve as carriers of bacteria and fungi that destroy a considerable portion of the host eggs. In Lab, applied to thorax, at 0.021 ug/g LD50 15 days
	Through adult contact.	Agent: Avermectin B_1 (MK-936) a powerful toxin derived from *Streptomyces avermitilis* fermentation.	With sublethal doses, fecundity, and fertility
	Through rotting fruit by contact with larvae and pupae	A bacterial pathogen	Identified as a major cause of mortality.
	Through larval contact.	Agent: *Steinernema carpocapsae*, an entomogenous nematode	Augmentation to eradication is 500 nematode per cm^2 applied to soils. Causes 94% mortality
	Through adult Consumption	Agent: 3.6% Phloxine B + 7.1% methyl eugenol	In lab trials, males were killed in less than 2 hours

Table 2.4 Cont.

	Through adult Contact	An endosymbiotic bacteria of the genus *Wolbachia*, inducing cytoplasmic incompatibility, thelytokous parthenogenesis, male-killing or feminization.	In field collected adults from Thailand
C. capitata	Through adult Contact	Agent: Avermectin B1 (MK-936), a powerful toxin derived from Streptomyces *avermitilis* fermentation (EPA, 1989)	In Lab, applied to thorax, at 0.29 ug/g LD50 10 days. With sublethal doses, fecundity, and fertility reduced by up to 29%
	Through adult consumption	Agent: Phloxine B - Mazoferm 802 formulation for field application Mazoferm 802 - corn condensate hydrolyzed by a *Lactobacillus* sp.	In field trials, aerial application reduced the population of medfly by 75% against the control catch
	Saccharopolyspoa spinosa, a soil bacterium, through ingestion.	Spinosad Agent: Spinosyn A Spinosyn D+SolBait	Test plots sprayed through aerial applications at the rate of 1.8 liters/hectare resulted in 96% reduction in Medfly populations.
	Entomophthora muscae, an entomogenous fungus	Kills the adult through growth and sporulation.	Field collection of adults only
	Entomophthora schizophorae	Kills the adult through growth and sporulation.	Field collection of adults only
	Through adsorbtion into the peel of the fruit	A hormone from the fungus *Gibberella fujikuroi*, gibberellic acid (GA_3) + a surfactant (L-77) Commercial formulations available	Reduces host susceptibility/ attractiveness to fruit flies by preventing aging of the peel (yellowing) 10 ppm GA_3/L-77 sprayed to run-off on fruit
	Through larval/ pupal contact.	An entomogenous nematode Agent: *Steinernema feltiae*	Optimal 500 nematode per cm^2 as a soil drench. Causes 87.1% mortality.
	Through larval/ prepupal contact.	An entomogenous nematode Agent: *Steinernema carpocapsae*	Augmentation to eradication is 500 nematode per cm^2 applied to soils. Causes 97% mortality
	Through larval/ prepupal/pupal contact.	An entomogenous nematode Agent: *Steinernema riobrave*	Optimal 100 nematode per cm^2 applied to soils. Causes 82% mortality
	Through larval contact.	A predator nemetode Agent: *Diplogaster* sp.	Test shows nematodes will devour larva by paralysis and digestion of contents.

Table 2.2 Cont.

	Through contact with the adult.	An exotoxin product Agent: *Bacillus thuringiensis*	Also lethal to mammals if injected and not registered for use in many countries, including the U.S.
	Through contact with the pupa	A fungal Agent: *Metarhizium anisopliae* var. *anisopliae*	At applications of 8.25, 7.8 and 28 x 10^6 conidia/ml, deaths were about 6-33.7% in the first week to 24.1-66.3% in the second week and 100% by the 6th week.
	Through egg Contact	A bacterial Agent: *Serratoa marcescems* strain (EC 3.1.21 to EC 3.1.31)	Prevented eggs from hatching under lab conditions
	Through contact with the pupa	A microsporidian Agent: *Nosema tephritidae*	Virulent, Dosage?
	Through contact with adult	A bacterial Agent: *Beauveria bassiana*	A facultative pathogen attacking adults. Through soil inoculation
	In the adult	A Picornavirus Agent: *Ceratitis* Picornavirus V	In lab, a natural virus found in the species. Pathogeny questionable
	In the adult	A Reovirus Agent: Ceratitis Reovirus I	In lab, a natural virus found in the species. Pathogeny questionable
	In the adult	A Rhabdovirus Agent: Rhabdovirus signa	In lab, pathogenic when injected into adult.
	In the adult	A Picornavirus Agent: Picornavirus C (DCV)	In lab, pathogenic when injected into adult.
C. cosyra	Through contact with 3rd instar larvae and pupae	A bacterial Agent: *Beauveria bassiana*	A facultative pathogen attacking larvae, pupae and deferred mortality of emerging adults through soil inoculation
	Through contact with the pupa	A fungal Agent: *Metarhizium anisopliae* var. *anisopliae*	A fungal agent attacking larvae, pupae and deferred mortality of emerging adults from soil
C. rosa,	Through contact with 3rd instar larvae and pupae	A bacterial Agent: *Beauveria bassiana*	A facultative pathogen attacking larvae, pupae and deferred mortality of emerging adults through soil inoculation
C. fasciventris	Through contact with the pupa	A fungal Agent: *Metarhizium anisopliae* var. *anisopliae*	A fungal agent attacking larvae, pupae and deferred mortality of emerging adults through soil inoculation

Adapted from Ekesi *et al.* (2006); Ekesi (2010)

2.7.2.8 Chemical control

Tephritid fruit flies have been controlled since the beginning of the 20^{th} by combining a bait with different insecticides. Hydrolyzed proteins and partially hydrolyzed yeast at a 4:1 ratio with organophosphates (malathion) have been applied aerially at ultra low volume in a number of eradication efforts around the world. Bait spray is generally applied on bands or spots reducing thus the area of coverage by exploiting the attractive properties of the bait and adult fly mobility. Current research focuses in replacing malathion with more specific and environmentally friendly products such as Spinosad, or Phototoxic dyes. Detailed review on this subject has been given by Moreno and Mangan (2000).

For flies in the genus *Bactrocera* male annihilation programs have been successfully implemented in several parts of the world (Koyama *et al*., 2004; Ekesi and Billah, 2006; Mwatawala *et al*., 2007; IITA-CIRAD, 2008). This technique consists of spreading wooden blocks impregnated with Methyl Eugenol and malathion that massively attract male *Bactrocera* that are killed when feeding on the bait. The attractive effect of Methyl Eugenol is so potent that males can be annihilated, severely affecting the reproductive capacity of the pest population. Releases of sterile insects can follow male suppression to guarantee eradication. A recent example of the use of this technique is the eradication of *Bactrocera papayae* from Queensland (Hancock *et al.* 2000).

CHAPTER THREE

3.0 GENERAL MATERIALS AND METHODS

3.1.0 Study area

3.1.1 Location and size

The geographical focus of the study is Northern Ghana. Ghana lies on the West African Gulf of Guinea at latitude 4° 44'N and longitude 1° 12' E of the equator, occupying a land area of 239, 020 km² for the economic zone (MLF, 1994). Northern Ghana represents the northern belt of the country which, in this study, comprises the Northern, Upper West and Upper East administrative regions of Ghana (Figure 3.1). It has a land area of about 98,000 km², which is about 41% of the total land area of Ghana (Blench, 2007). The Northern Region is located on the North Southern part of the country, lying on latitude 9° 30' N and longitude 1° 00' W of the equator. It is known as the largest region in Ghana, occupying a land area of about 70, 383 km², representing about 29.0% of the total land area of Ghana. The region shares boundaries with the Upper West and Upper East regions to the north, the Brong-Ahafo and Volta regions to the south, the Republic of Togo to the east and the Republic of Cote d'Ivoire to the west (Blench, 1999).

The Upper West Region is located on the north western corner of the country between latitude 9° 30' N and longitude 1° 25' west of the equator. It occupies a land area of about 18,478 km², representing about 7.7% of the total land area of Ghana. The region is bordered on the north by the Republic of Burkina Faso, on the west by the Republic of Cote d'Ivoire, on the east by the Upper East Region and on the south by the Northern Region (Songsore, 1994). The Upper East Region is located on the north eastern corner of the country between latitude 100° 30' N and longitude 00° 10' west of the equator. It occupies a land area of about 8,842 km², representing about 3.7% of the total land area of Ghana. It shares boundaries with the Republic of Burkina Faso to the north, the Republic of Togo to the east, the Upper West Region to the west and Northern Region to the south (Kranjac-Berisavljevic, 1999).

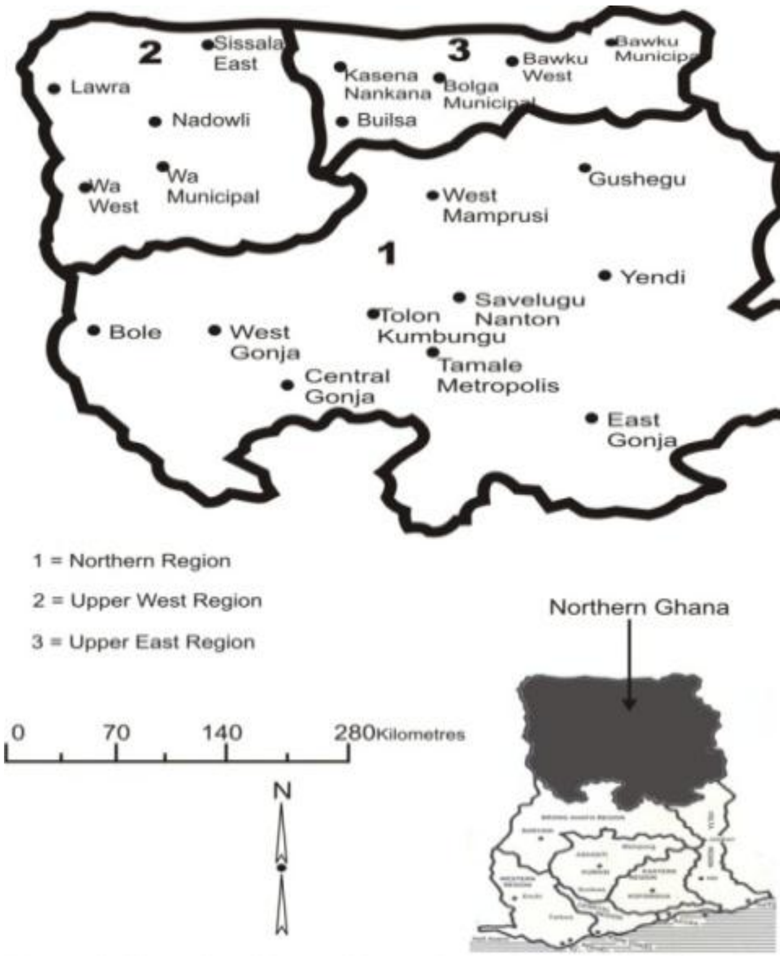

Figure 3.1: Map of northern Ghana showing the study regions and districts.

3.1.2 Agro-ecological conditions

The climatic classification of the north of Ghana can be described as semi-arid tropical and mild sub-arid wooded savanna. There are three sub-agroecological zones in the area namely the Guinea savanna, Sudan savanna and Sahel savanna zones. The Guinea savanna zone predominantly covers the Northern Region, and parts of the Upper East and Upper West regions, which are predominantly Sudan savanna. The north-eastern portion of the Upper East region, extending through Bawku West and Bawku East Districts, dominates the Sahel savanna zone (MoFA-GTZ, 1992).

Two regimes of wet and dry seasons exist in the savanna ecology of Ghana. The wet season lasts from April/May to October while the rest of the year is dry. Rainfall intensity varies from 100-200 mm/h with an annual mean of 900-1000 mm, with its peak in September. According to EPA (2002), the main feature of the rainfall in northern Ghana is its character and variability. The seasonal northward movement of the Inter-tropical Convergence Zone (ITCZ) accounts for the seasonal patterns and north-south banding of the vegetation and thus, dictating the moisture situation in the ecology. There exists a single rainy season where the monthly totals increase slowly from March/April till a peak is reached in August/September (Gyasi *et al*., 2006). The rainy season is the most important aspect of the weather in this part of the country since most food crops are cultivated during this period. Temperatures are relatively higher in the north compared to the rest of Ghana. Maximum temperatures (nearly 40ºC) are recorded in March while the lowest minimum (about 18ºC) are in December and January during the harmattan period (EPA, 2002).

The vegetation of the Guinea savanna zone consists typically of ground cover of grasses and shrubs of varying heights interspersed with fire-resistant deciduous broad leaved trees at the forest margins. This grades into more open grassland with widely spaced short trees towards the Sudan savanna. The Sudan savanna consists of shorter drought- and fire-resistant widely sparse trees interspersed with open savanna grassland. Grass cover in the Sahel savanna is very sparse and in most areas, the land is bare and severely eroded (Adu, 1972; 1986; Gyasi *et al*., 2006). The savanna ecosystem of Ghana is generally rich in various species of fauna and flora which are of ecological and agricultural significance to the livelihoods of the people. Agriculture is predominantly on smallholder basis though there exist many large scale arable farms and tree crop plantations, particularly for mango, water melon, cashew and others.

3.2 Survey studies

This aspect of the study was a preliminary survey using questionnaire to obtain baseline information on the knowledge, perceptions and practices (KPP) of fruit growers and the in-service training needs of Agricultural Extension Agents (AEAs) on tephritid pests and their management in northern Ghana. Farmers' KPP was assessed based on procedures for analyzing agricultural problems and assessing the knowledge base of farmers, their individual perceptions and adaptive pest management practices. The procedure based on the assessment of farmer's KPP documented by Werner (1993) and Mumford and Norton (1993) was adapted. The survey questionnaires were administered among fruit growers in selected districts in the regions using stratified random sampling procedures. Semi-structured questionnaire designed in a closed- and open-ended fashion were administered through face-to-face interviews combined with field observations. Statistical analysis was performed using the Statistical Package for Social Scientists (SPSS).

The in-service training needs of Agricultural Extension Agents (AEAs) on fruit flies were determined using the Borich needs assessment procedure (Borich, 1980). A survey using questionnaire was conducted among crop-based AEAs in selected districts within the 3 regions. Fifteen competency aspects of fruit fly pests were developed, combined in a rating scale and used to measure AEAs perceived level of knowledge and competence about fruit flies and their management. The mean weighted discrepancy score was calculated for each of the competencies, and used to rank the in-service training needs of AEAs. Data were collected with the assistance of the District Directors of Agriculture and Plant Protection Service Officials of the various regions and districts. The statistical package mentioned above was used to analyze the data.

3.3 Bio-ecological studies

This aspect of the study sought to determine the species spectrum, host plant range, seasonal phenology and parasitoid fauna of fruit flies in northern Ghana. The study involved collection and incubation of wild and cultivated fruits from selected sites over a two year period. Fruit samples were collected at regular field trips to the sampling sites within the three Northern, Upper West and Upper East regions. Collection interval was set to ensure that all collection sites were visited in all months throughout the study period. A total of 20 sampling localities consisting of 10 from the Northern Region, and 5 each from the Upper West and Upper East Regions were covered. The major areas surveyed, their agroecological conditions and approximate geo-referenced positions are presented in Figure 3.1 and Table 6.1.

Fruit samples were transported in plastic containers to the laboratory for the incubation studies. Batches of fruit samples were maintained in incubation chambers for an average of 5 weeks under ambient conditions, and the setups were regularly checked for the recovery of puparia which were held in cages and monitored for adult emergence. Details of the fruit incubation and insect monitoring procedures are presented in the preceding chapters.

CHAPTER FOUR

4.0 FARMERS' KNOWLEDGE, PERCEPTIONS AND PRACTICES IN THE MANAGEMENT OF FRUIT FLIES IN NORTHERN GHANA

4.1 INTRODUCTION

Sustainable management of any agricultural pest problem requires insight into the existing knowledge, perceptions and practices (KPP) of farmers in the production communities (Heong, 1985; Morse and Buhler, 1997). Mumford and Norton (1993) observed that the adoption of any pest management innovation depends on how the innovation addresses the needs of the customer. If scientists have to work with farmers to improve crop protection and productivity, they need to recognize farmers' constraints and their existing indigenous and technical knowledge base (Morse and Buhler, 1997). This is especially relevant in setting research agendas, planning IPM campaign programmes and developing the appropriate strategies for communication (Fujisaka, 1992; Escalada and Heong, 1993). Ochou *et al*. (1998) noted that the prospect of enhancing the role of the farmer as an independent decision maker requires a realistic assessment of their existing knowledge, capabilities and crop protection practices on-farm, and an understanding of the major constraints that may militate against their efforts to improve the pest management system.

Reliable information needs to be obtained in order to appreciate fruit producers' practices and to assess constraints and opportunities for decision making at the farm level so that appropriate fruit fly control decision tools and tactics can be designed to meet the needs of fruit producers. Hence, it is necessary to conduct surveys that can provide information on farmers' alternative view point on the fruit fly constraints facing them in their efforts to increase and sustain fruit and vegetable crop production in farming communities (Madisa *et al.*, 2010). It is widely acceptable that innovation communication on fruit fly research would be more robust and viable when the KPP of more farmers is taken into consideration (Heong *et al.*, 2002). There has been increasing interest in incorporation of farmers' indigenous knowledge into research and development programmes for finding workable solutions to agricultural problems in sub-Saharan Africa (Isin and Yildirim, 2007; Obopile *et al.*, 2008).

In Ghana, stakeholder awareness and training are paramount to addressing the fruit fly menace (PPRSD, 2010). At present, there is limited research information on farmer-level knowledge on fruit fly pest especially for the northern sector of the country. Abdullahi *et al*. (2011) assessed the perceptions of mango farmers on the pest status and management for the African invader fly, *B. invadens* in two districts within the south of Ghana. This study determined the key features associated with the knowledge, perceptions and practices of fruit growers regarding fruit fly pests and their management in the three administrative regions of northern Ghana. The specific objectives were to:

1. describe the demographic and production profile of fruit growers in the area;
2. determine their knowledge and perceptions regarding fruit fly pests, and
3. assess their fruit fly control practices and the way forward to addressing the fruit fly menace.

4.2 MATERIALS AND METHODS

4.2.1 Selection of respondents

The study involved a survey using questionnaires among fruit growers from the Northern, Upper West and Upper East regions of Ghana. The stratified random sampling procedure was used so that each fruit-producing district represented a stratum (sampling unit). The districts were selected based on the availability of commercial fruit and vegetable producers. A total of 15 fruit-producing districts, consisting of 5 districts from each region, were selected for the study.

The selection was done through the assistance of the Regional Directorators of Agriculture. The list of fruit producers in the selected districts were obtained from the various District Agricultural Development Units (DADU) of the Ministry of Food and Agriculture (MoFA). Target farmers were purposively selected based on the criteria that the farmer has experienced at least, three consecutive harvests from his/her farm, and that the fruits produced are the preferred host plants to fruit flies. A total of 10 fruit growers were selected from each fruit-producing district to complete the questionnaire, giving a total of 50 respondents from each region and an overall total of 150 respondents from the three regions. Selected farmers were contacted through the assistance of their respective Agricultural Extension Agents (AEAs). The list of the study regions, selected districts and number of fruit growers interviewed is presented in Table 4.1.

4.2.2 Survey methods

The methods and tools for data collection were based on procedures for analyzing agricultural problems and assessing farmers' knowledge, perceptions and practices (KPP) as documented by

Werner (1993), Munford and Norton (1993), and Mutsaers *et al*. (1997). Semi-structured questionnaire designed in a closed- and open-ended fashion were used to assess the KPP of fruit growers on fruit fly pests and their management. The questions were developed based on the following key aspects: demographic information of farmers; knowledge of fruit flies, their damage, economic impact; management strategies, and way forward to addressing the menace. Simple dichotomy and frequency determination statements coupled with multiple-point likert ratings were used to indicate the strength of responses to the questions. Colour photographs of the fruit flies mixed with other insect species were provided in charts to help verify farmers' ability to identify the fruit fly species of economic importance in the area.

Table 4.1: Study regions, selected districts and number of fruit growers interviewed.

Regions	**Districts**	**No. fruit growers interviewed**
Northern	Tamale Metropolis	10
	Savelugu-Nanton	10
	East Gonja	10
	Tolon-Kumbungu	10
	West Gonja	10
Upper West	Wa Municipality	10
	Wa West	10
	Nadowli	10
	Lawra	10
	Sissala East	10
Upper East	Bolga Municipality	10
	Bawku Municipality	10
	Bawku West	10
	Kasina-Nankani	10
	Builsa	10
Total	**20**	**150**

Content and face validity were established by a panel of experts consisting of researchers from the Department of Agricultural Extension Education, University for Development Studies (UDS), and a group of professionals in entomology from the CSIR-Savanna Agricultural Research Institute, Ghana. Instrument reliability was estimated by calculating the Cronbach's alpha (Crocker and Algina, 1986). Reliability for the overall instrument was .79. A pilot test was conducted with 20 fruit growers, not included in the sample, three weeks before the study. After the pilot test, minor changes were made in the expression of the questions. The questionnaires were administered by face-to-face interview combined with field observations from February to May, 2012. The interviews were conducted in English or appropriate local languages such as Dagbani, Frafra and Dagaare (for farmers who lack good understanding of English). Each interview lasted 40 minutes, on average. Data were analyzed using the Statistical Package for Social Sciences (SPSS for Windows version 16.0).

4.3 RESULTS

4.3.1 Demographic and production profile of fruit growers

The demographic information of the fruit growers who participated in the interview is presented in Table 4.2. The age range of the respondents was 16 to 55 years. In all regions, the majority, (over 75%) of the respondents were of the youthful group with ages between 21 and 40 years. In the Upper West and Upper East regions, no respondent was below 21 years. Also, no respondent was over 50 years in the Upper West Region. In the Northern Region, respondents with ages between 21 and 30 years were more than those between 31 and 40 years but the reverse was observed for the other regions. The educational background of the respondents indicated that 69 (46.0%) of them were illiterates, having attained only non-formal education, while a total of 42 (28%) and 27

(18%) of them had basic education, and secondary/technical education, respectively. Only 12 (8%) of the respondents had tertiary education (which comprised training college, polytechnic or university level). A similar trend was observed in the educational background of the respondents in all the three regions. Moreover, a total of 61 (40.6%) growers indicated that they were members of the various farmer-based organizations (FBOs) in the area, while majority, 89 (59.3%) of them did not belong to any of such organizations. Members of FBOs in the Northern region were found to be more than the non-members but in the other regions, the non-members were more than the members.

Table 4.2: Demographic information of fruit growers in northern Ghana in 2012.

Factors	Frequency (%)			
	Northern Region	Upper West Region	Upper East Region	All regions combined
Age range (years)				
10-20	5 (3.3)	-	-	5 (3.3)
21-30	23 (15.3)	15 (10.0)	14 (9.3)	52 (34.6)
31-40	13 (8.6)	26 (17.3)	22 (14.6)	61 (40.6)
41-50	7 (4.6)	9 (6.0)	10 (6.6)	26 (17.3)
>50	2 (1.3)	-	4 (2.6)	6 (4.0)
Educational level				
®Non-formal	26 (17.3)	19 (12.6)	24 (16.0)	69 (46.0)
Basic	10 (6.6)	14 (9.3)	18 (12.0)	42 (28.0)
Secondary	10 (6.6)	11 (7.3)	6 (4.0)	27 (18.0)
Tertiary	4 (2.6)	6 (4.0)	2 (1.3)	12 (8.0)
Membership to FBOs*				
Members	32 (21.3)	14 (9.3)	15 (10.0)	61 (40.6)
Non-members	18 (12.0)	36 (24.0)	35 (23.3)	89 (59.3)

*®Respondents who were unable to read, write, understand or speak English language were referred to as illiterates, having only non-formal education (ie. though they had some level of knowledge and experience in fruit crop production, they did not passed through any level of the formal educational curriculum of Ghana). *FBOs were the various farmer groups established under the auspices of the Ministry of Food and Agriculture (MoFA), Integrated Tamale Fruit Company (ITFC), German Technical Co-operation (GIZ), Millennium Development Authority (MiDA) and other agriculture-oriented missions in the area.*

Table 4.3 presents the fruit and vegetable production profile of the fruit growers interviewed. Various types of fruit and vegetable crops were produced by the farmers. In many of the production districts, an individual farmer may produce more than one fruit or vegetable crop. Among the fruit crops, mango was the most widely cultivated, with 61 (40.6%) producers, followed by water melon, with 33 (22.0%) producers, while other fruit crops such as pawpaw, guava and banana were grown by only a few farmers as minor crops under small scale backyard conditions. No respondent produced pawpaw in the Northern and Upper West regions, and no respondent produced banana in the Upper West and Upper East regions. Among the vegetable crops, tomato, green pepper and cucumber were the most widely produced by 50%, 28% and 26.6% of the farmers, respectively. In the Northern Region, mango was the most dominant fruit crop produced by 32 (21.3%) farmers. In the Upper West Region, both mango and tomato dominated with the same number of producers, 21 (14.6%) while in the Upper East Region, tomato featured prominently with 34 (22.6%) producers who grew it mainly under irrigated conditions.

Data on the fruit production experience of the farmers indicated that the majority of them had been in the fruit and vegetable production business for at least 20 years. In all the regions, the proportion of growers appeared to decrease with increasing number of years in production except for the fact that farmers having between 11 and 20 years experience in production were more than those having between 1 and 10 years experience. No respondent in the Northern Region had over 40 years experience in fruit production, and only 4 (2.6%) of them (all from the Upper East and Upper West regions) had over 40 years experience in fruit production. The scale of fruit crop production indicated that majority, 82 (54.6%) of the producers were small scale peasant fruit growers. Only 7 (4.6) of them (all from the Northern Region) produced fruit crops on large scale basis. Most farmers in the Upper West and Upper East regions were small scale and medium scale fruit growers, respectively. Inorganic farming was the dominant practice of the respondents in all regions, with 132 (88%) growers producing fruit and vegetable crops by the use of synthetic chemical insecticides under mixed or mono cropping systems.

Table 4.3: Fruit and vegetable crop production profile of farmers in northern Ghana in 2012.

Factor	Frequency (%)			
	Northern Region	Upper West Region	Upper East Region	All regions combined
Fruit crops grown				
Mango	32 (21.3)	21 (14.0)	8 (5.3)	61 (40.6)
Water melon	16 (10.6)	9 (6.0)	8 (5.3)	33 (22.0)
Pawpaw	-	2 (1.3)	-	2 (1.3)
Guava	2 (1.3)	1 (0.6)	1 (0.6)	2 (1.3)
Banana	2 (1.3)	-	-	2 (1.3)
Tomato	20 (13.3)	21 (14.0)	34 (22.6)	75 (50.0)
Green pepper	17 (11.3)	14 (9.3)	12 (8.0)	43 (28.6)
Chilli pepper	15 (10.0)	10 (6.6)	8 (5.3)	33 (22.0)
Cucumber	15 (10.0)	13 (8.6)	12 (8.0)	40 (26.6)
Pumpkin	7 (4.6)	9 (6.0)	10 (6.6)	26 (17.3)
Garden eggs	13 (8.6)	5 (3.3)	5 (3.3)	23 (15.3)
Okro	7 (4.6)	7 (4.6)	3 (2.0)	17 (11.3)
Years in fruit crop production				
1-10	17 (11.3)	10 (6.6)	11 (7.3)	34 (22.6)
11-20	19 (12.6)	21 (14.0)	23 (15.3)	63 (42.0)
21-30	10 (6.6)	11 (7.3)	9 (6.0)	30 (20.0)
31-40	4 (2.6)	5 (3.3)	6 (4.0)	19 (12.6)
>40	-	3 (2.0)	1 (0.6)	4 (2.6)
[1]Scale of production				
Small scale	28 (18.6)	31 (20.6)	23 (15.3)	82 (54.6)
Medium scale	15 (10.0)	19 (12.6)	27 (18.0)	61 (40.6)
Large scale	7 (4.6)	-	-	7 (4.6)
Cropping system				
Organic mono crop	8 (5.3)	-	-	8 (5.3)
Organic mixed crop	10 (6.6)	-	-	10 (6.6)
Inorganic mono crop	13 (8.6)	29 (19.3)	24 (16.0)	66 (44.0)
Inorganic mixed crop	19 (12.6)	21 (14.0)	26 (17.3)	66 (44.0)

[1]For plantation crops, large scale = >10 ha; medium scale = 2-9 ha; small scale = < 2 ha. For vegetable crops, large scale = >10 acres; medium scale = 2-9 acres; small scale = < 2 acres.

Only a total of 18 (11.9%) of farmers in the Northern Region produced organic fruits (mainly mango) in either mixed or mono cropping systems, but no respondent in the Upper West and Upper East regions practiced organic farming.

4.3.2 Fruit fly awareness and identification

Concerning fruit growers' awareness of the fruit fly problem in the area, a total of 144 (94%) of the respondents indicated that they were aware of the damage caused by fruit flies in their farms. Information on fruit fly pests was received from various sources, the most common among them included, agricultural extension officers, 84 (56.0%), fellow farmers, 63 (42.0%) and farmers' own experience, 41 (27.3%). Other sources of information on fruit flies such as fruit traders, researchers, radio/TV, relatives and friends were of minor or no importance to the farmers. Moreover, majority (88.6%) of the growers in all the regions perceived that the fruit fly problem was very serious or at least, serious, even though a few of them 15 (10%) indicated that they had no idea about the nature of the fruit fly problem in their farms or communities.

Concerning farmers' ability to identify the fruit fly pests, the results indicated that 3 (2.0%) respondents (from the Upper West Region) wrongly referred to *Apis malifera* as a fruit fly pest while 11 (7.3%) of the farmers (from the two Upper regions) wrongly referred to *Musca domestica* as a fruit fly pest. Also, 41 (27.3%) of the respondents from all the regions wrongly referred to *Drosophila melanogaster* as a fruit fly pest. The proportion of farmers who correctly referred to

Table 4.4: Awareness of fruit flies and pest identification by fruit growers in northern Ghana in 2012

Factor	Frequency (%)			
	Northern Region	Upper West Region	Upper East Region	All regions combined
Have you heard of fruit fly pests before?				
Yes	50 (33.3)	47 (31.3)	44 (29.3)	144 (94.0)
No	-	3 (2.0)	6 (4.0)	9 (6.0)
Sources of information on fruit fly pests				
Own experience	15 (10.0)	12 (8.0)	14 (9.3)	41 (27.3)
Fellow farmers	28 (18.6)	14 (9.3)	21 (14.0)	63 (42.0)
Fruit traders	5 (3.3)	8 (5.3)	-	13 (8.6)
Agric officers	31 (20.6)	26 (17.3)	27 (18.0)	84 (56.0)
Researchers	7 (4.6)	-	3 (2.0)	10 (6.6)
Radio/TV	11 (7.3)	8 (5.3)	-	19 (12.6)
[a]Others	-	4 (2.6)	2 (1.3)	6 (4.0)
Self-perceived nature of fruit fly problem				
Very serious	40 (26.6)	24 (16.0)	31 (20.6)	95 (63.3)
Serious	8 (5.3)	18 (12.0)	12 (8.0)	38 (25.3)
Not serious	-	-	2 (1.3)	2 (1.3)
No opinion	2 (1.3)	8 (5.3)	5 (3.3)	15 (10.0)
[b]Insect species considered as fruit fly pests				
Apis malifera	-	3 (2.0)	-	3 (2.0)
Musca domestica	-	6 (4.0)	5 (3.3)	11 (7.3)
Drosophila melanogaster	13 (8.6)	9 (6.0)	19 (12.6)	41 (27.3)
Ceratitis capitata[1]	6 (4.0)	10 (6.6)	2 (1.3)	18 (12.0)
Ceratitis cosyra[1]	21 (14.0)	14 (9.3)	22 (14.6)	57 (38.0)
Bactrocera invadens[1,2]	19 (12.6)	6 (4.0)	6 (4.0)	31 (20.6)
Dacus vertebratus[1]	11 (7.3)	5 (3.3)	5 (3.3)	21 (14.0)
No idea	3 (2.0)	10 (6.6)	12 (8.0)	25 (16.6)
Identity of the African invader fruit fly				
Correct	16 (10.6)	7 (4.6)	8 (5.3)	31 (20.6)
Incorrect	11 (7.3)	17 (11.3)	9 (6.0)	37 (24.0)
No idea	23 (15.3)	26 (17.3)	33 (22.0)	82 (54.0)

[a]Others included respondent's relatives and friends; [b]Colour photographs of the insects (without names) were provided for the identification; [1]True fruit fly pests; [2]The African invader fruit fly.

C. capitata, *C. cosyra*, *B. invadens* and *D. vertebratus* as fruit fly pests were 18 (12.0%), 57 (38.0%), 31 (20.6%) and 21 (14.0%), respectively. Meanwhile, 25 (16.6%) of the respondents indicated that they had no idea as to which of the insects shown to them were the true fruit fly pests.

With respect to farmers' ability to identify the African invader fly, a total of 31 (20.6%) of them correctly referred to *B. invadens* while majority, 92 (54.0%) of them indicated that they had no idea about the African invader fly. The proportion of fruit growers in the Northern Region who identified *B. invadens* correctly was more than those who wrongly identified, but the reverse was observed in the other regions (Table 4.4)

4.3.3 Pest damage and economic impact

Table 4.5 summarizes the knowledge status of the farmers regarding the damage and economic impact of fruit flies in the area. The mean value of the overall (summated across the 13 items) knowledge of farmers was 3.7; the standard deviation (SD) was 1.1. The highest mean value for an item (4.1; SD =1.0) was reported for 2 statements which were ranked 1 and 2. The second highest item mean value (4.0; SD = 0.9) was reported for statement in rank 3. All these 3 statements concerned the economic effect of the pests in fruit production. The third highest item mean value (3.9; SD = 0.8) was reported for statement in rank 4, that addressed the external fruit damage caused by fruit flies. The lowest item mean value (3.3; SD=1.5) was reported for 2 statements in the 12th rank. Both statements concerned the internal fruit damage by the pest. In general, farmers seemed to be more conversant with the resultant effects of fruit fly infestation compared to their damage mechanisms/symptoms on host fruits.

Table 4.5: Descriptive statistics summarizing farmers' knowledge of fruit fly damage and economic impact in northern Ghana in 2012.

Rank	Responses	Frequency[1]	%	Mean[2]	Std. dev.
1	Fruit fly infestation reduces farmers' income	155	91.7	4.1	1.0
2	Fruit flies are a threat to horticulture industry	153	90.5	4.1	1.0
3	Infested fruits usually attract poor market	146	86.3	4.0	0.9
4	Adult flies create punctures on fruits	130	76.9	3.9	0.8
5	Fruit fly damage reduces fruit quality	119	70.4	3.8	1.0
6	Infested fruits usually get rotten	98	57.9	3.7	1.1
7	Infested fruits may fall off the plant prematurely	97	57.4	3.7	1.1
8	Fruit fly infestation increases production cost	82	48.5	3.6	1.2
9	Fruit fly pests are a quarantine problem	81	47.9	3.6	1.2
10	Infested fruits usually contain maggots	76	44.9	3.5	1.3
11	Fruit fly maggots feed on the fruit	57	33.7	3.4	1.4
12	Fruit fly eggs are laid inside the fruit	52	30.7	3.3	1.5
12	Adult fruit flies do not feed on fruits	52	30.7	3.3	1.5

[1]Total number of agree and strongly agree responses
[2]Scale: 1 = strongly disagree; 2 = disagree; 3 = no opinion; 4 = agree; 5 = strongly agree

4.3.4 Fruit fly management practices and way forward

The various efforts made by fruit growers to control fruit flies in their farms are presented in Figure 4.1. A significant proportion (20%) of the farmers took no action to control fruit flies in their farms. The rest of the growers indicated that they adopted various practices in control of the pests. Among the control methods, the use of chemicals, prompt harvesting of fruits and regular disposal of infested fruits were the dominant methods practiced by farmers in all regions. Majority (64%) of the farmers applied synthetic chemical insecticides, mostly from the organochlorine and organophosphate groups, for the control of fruit flies in their farms. The highest number of fruit growers using these chemicals was recorded in the Upper East Region while the lowest was recorded in the Northern Region. Other control methods such as the use of pheromone traps, disposal of infested fruits and prompt harvesting of fruits recorded the highest number of farmers practicing them in the Northern Region, while the lowest was recorded in the Upper East Region. Only a few growers in the Upper West, and virtually no grower in the Upper East region practiced pheromone trapping as a fruit fly control strategy.

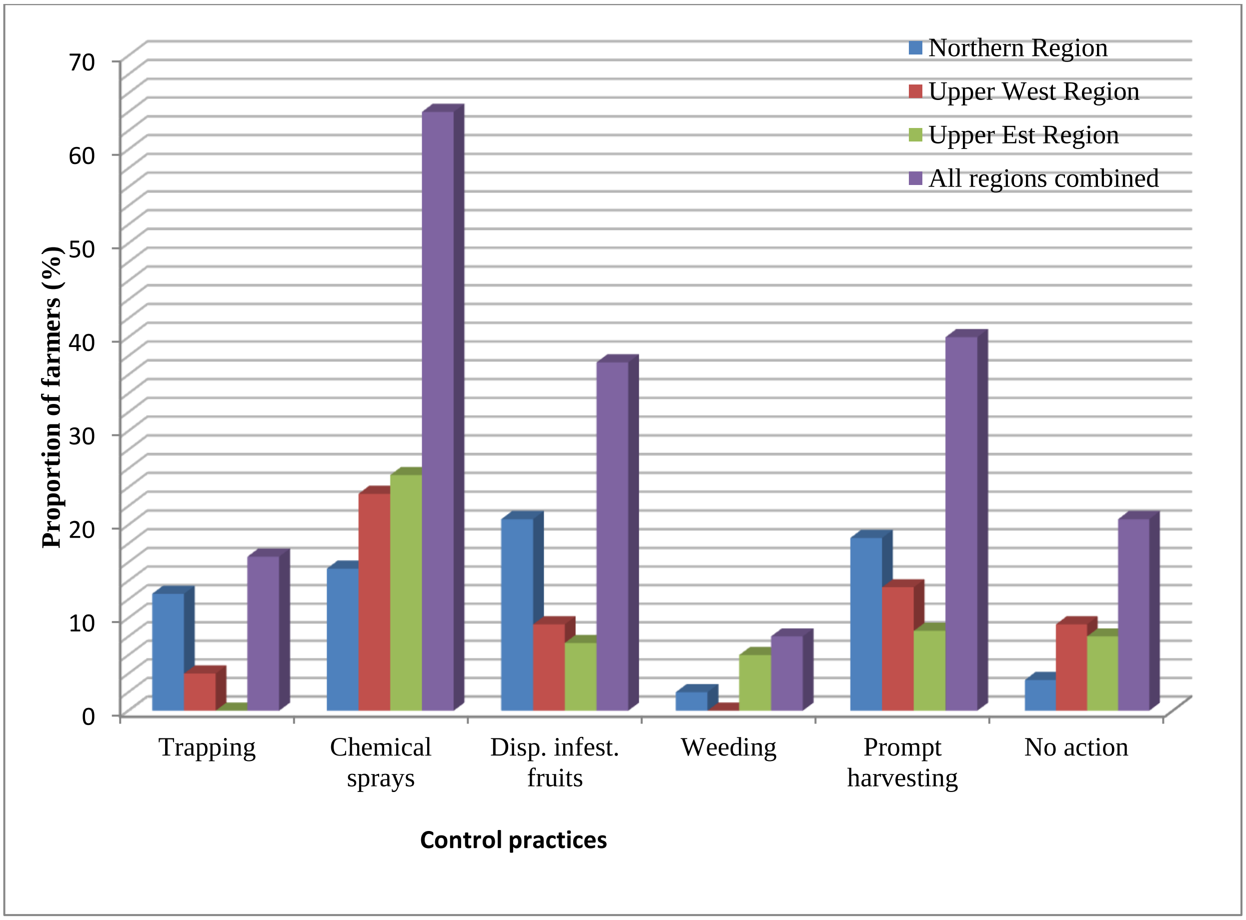

Figure 4.1: Practices adopted by fruit growers in control of fruit fly pests in three northern regions of Ghana, 2012.

The results concerning the recommended fruit fly management strategies known to the farmers showed that pheromone trapping, farm sanitation and prompt harvesting were the most well-known control methods in all the regions. Other recommended management strategies such as bait application, soil inoculation and biological control (involving the use of parasitoids and predators) were known to only a few growers. The rest of the control methods involving sterile insect technique, irradiation, heat treatment and cold treatment procedures were virtually unknown to the growers. In general, fruit growers in the Northern Region seemed to be more conversant with these recommended strategies for controlling fruit flies compared to those in the Upper West and Upper East regions where virtually no respondent was recorded to have knowledge of them. Meanwhile, 26.6% of the respondents (mostly from the 2 upper regions) indicated that they had no idea about any of such control methods (Figure 4.2).

Figure 4.3 presents the various opinions expressed by the fruit growers as ways of addressing the fruit fly problem in the area. In all the regions, majority (62.6%) of the farmers indicated that they needed training on fruit flies and their management for increased productivity. Other widely proposed ways of addressing the fruit fly problem included the need to strengthen the agricultural extension system (38.0%), provision of logistical support to farmers (30.0%) and input subsidy or availability to the growers (18.3%). It was observed that many farmers from the Upper East Region proposed the training of farmers and the strengthening of the extension system compared to those in the Northern and Upper West regions. Meanwhile, over 23% of the respondents, mostly in the Upper West Region, were unable to propose any practical way of addressing the fruit fly problem in the area.

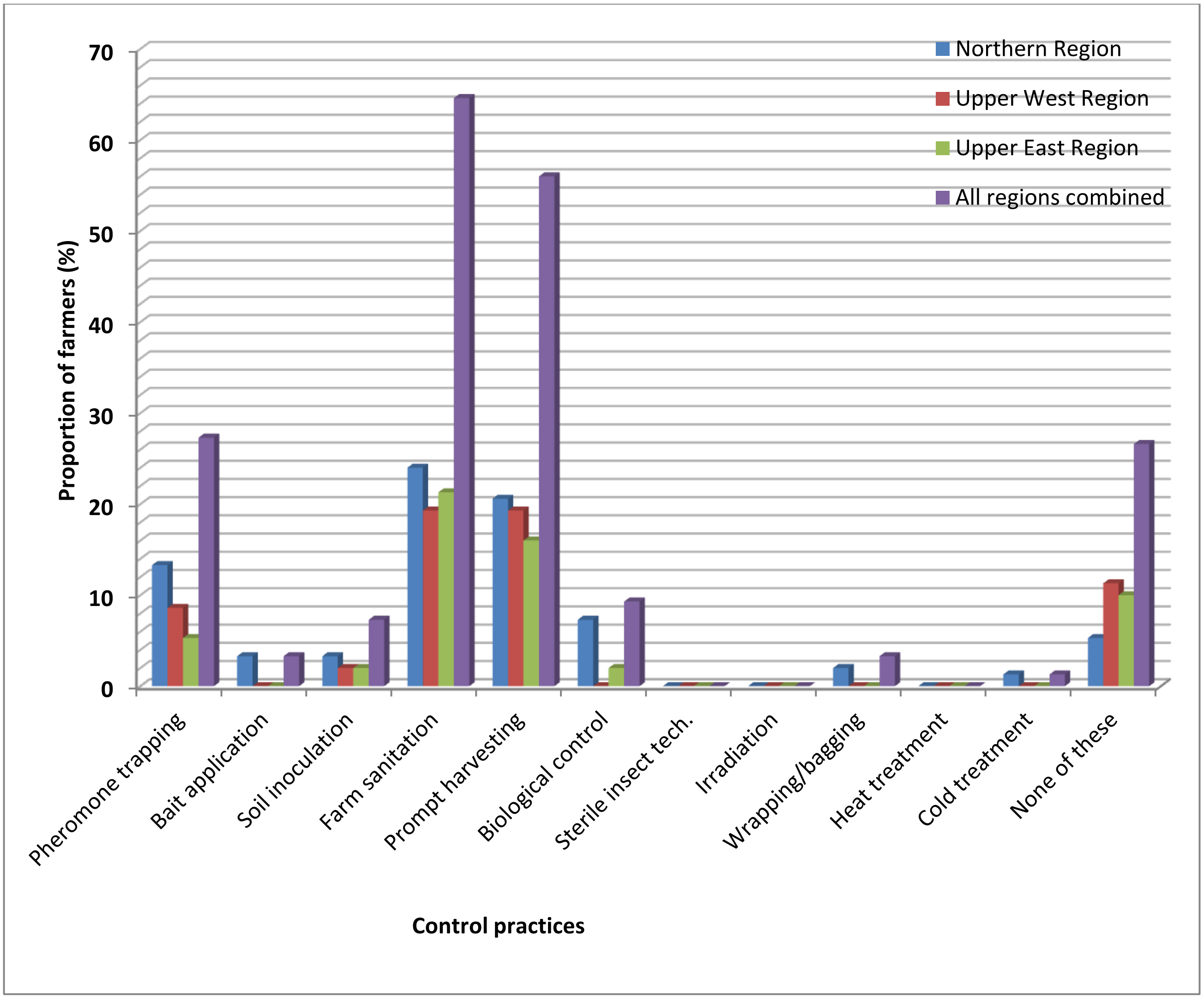

Figure 4.2: Farmers' knowledge of recommended fruit fly management strategies in three northern regions of Ghana, 2012.

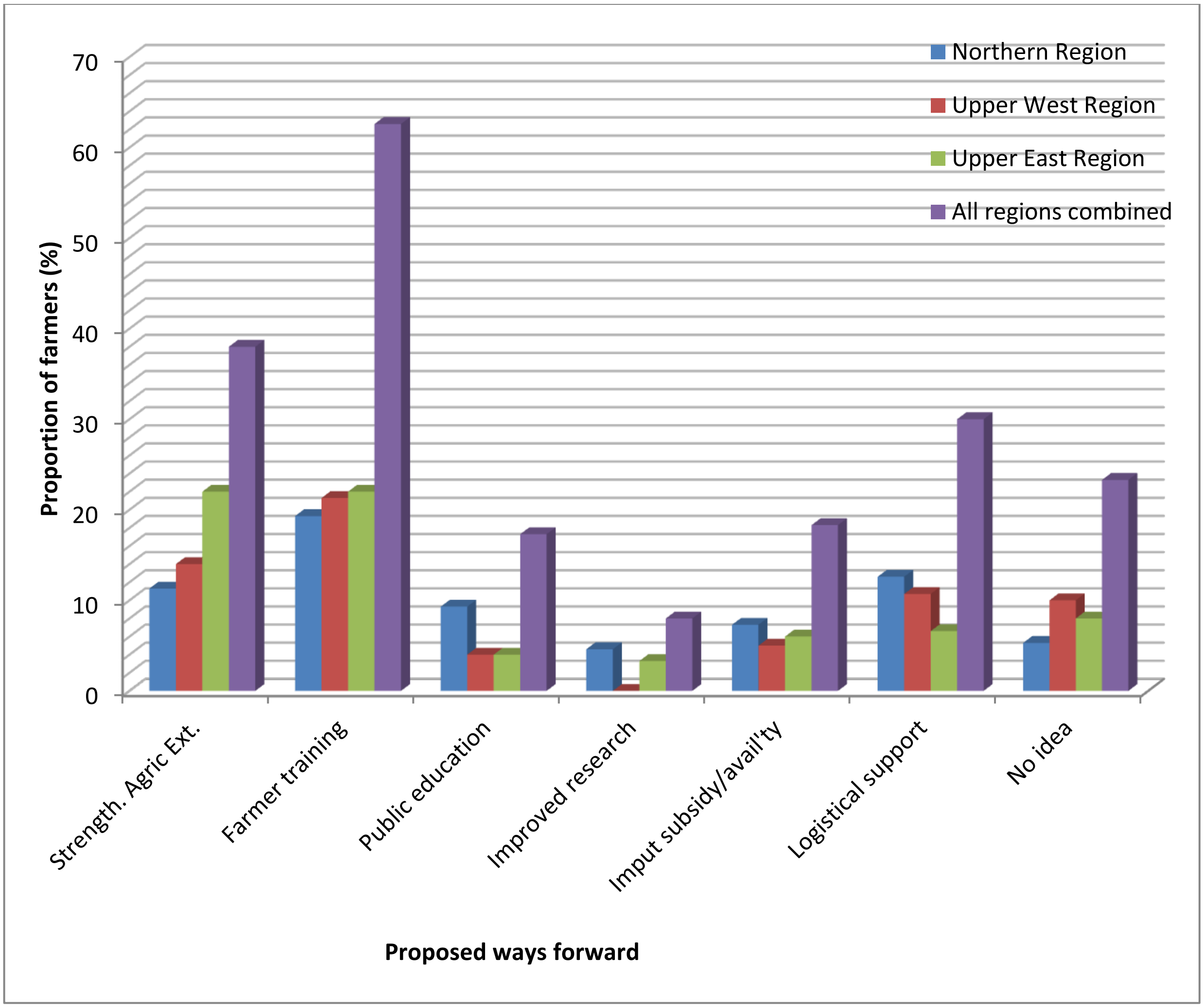

Figure 4.3: Way forward to addressing the fruit fly menace as proposed by fruit growers in northern Ghana, 2012.

4.4 DISCUSSION

The results of this study indicated that in all the study regions, majority of the fruit growers were illiterates. Crosby *et al*. (2000) showed that improved crop production requires high level of expertise from farmers in order to implement crop protection innovations effectively. Educated farmers are generally more open to innovative ideas and new technologies that promote positive change (Madisa *et al*., 2010). The higher number of young farmers involved in fruit crop production is a good sign for the future of the horticulture industry in the area. Increased and sustainable fruit crop production can therefore be enhanced if youthful group associates with the farmer-based organizations in the area.

Fruit crop production in northern Ghana is predominantly stallholder business. The fruit production profile of the farmers indicated that mango and water melon were the major fruit crops produced in the area. Among the vegetable crops, tomato, green pepper and the cucumber featured prominently. All these fruit and vegetable crops have been recognized as major hosts of both the invasive and native fruit fly species (Drew *et al*., 2005). Mango has been the most preferred host for the African invader fly, *B. invadens* (Lux *et al*., 2003b; Vayssieres *et al*., 2005) but it is also attacked by the native *Ceratitis* species (Mwatawala *et al*., 2004). Water melons, tomato, peppers and cucurbits are also known to suffer serious infestation and damage by a wide range of fruit fly species (White and Elson-Harris, 1992; Ekesi *et al*., 2006; De Mayer *et al*., 2007). In most situations, mixed cropping was a traditional practice of the farmers. Unfortunately, this practice may have the tendency to modify the microclimate in many fruit crop farms to favour multiplication of insect pests (Kalaro *et al*., 2009).

Farmers need to improve their knowledge of the fruit fly species of economic importance in the area. This is particularly so for the devastating *B. invadens*. This pest was first reported from eastern Africa in 2003 (Lux *et al*., 2003b; Mwatawala *et al*., 2004) and later reported in other parts of the continent (Drew *et al*., 2005) including Ghana in 2005 (Billah *et al*., 2006). Knowledge of the presence of this invasive pest is crucial in aiding the development of solutions to minimize its effect and/or farmers' acceptance of new innovations in combating the pests. It also has an advantage of prompting farmers to collaborate with researchers in developing sustainable on-farm strategies to combat the menace (Abdullahi *et al*., 2011).

Farmers' knowledge status of the damage and economic impact of fruit fly pests on crop production basically implied that they were aware that fruit flies cause serious damage to their crops with detrimental consequences on their earnings. Most fruit growers in the Northern region seemed to be more conversant with the economically important fruit fly species and their control strategies compared with those in the Upper West and Upper East regions. This is because in recent years, some fruit fly awareness and farmer training activities have taken place in the Northern Region particularly under the fruit fly control project of the Market-Oriented Agriculture Programme of the German International Co-operation (MOAP-GIZ) (Billah, 2012). In addition, the Integrated Tamale Fruits Company (ITFC) has promoted farmer and extension agent training on fruit crop production and protection in the region particularly through programmes that involved the provision of technical reference materials for the training of members of the Organic Mango Outgrowers' Association (OMOA) for improving their technical practices in organic mango production and pest management (ITFC, 2008). These and other initiatives were yet to be extended to the Upper regions of the country as at the time of the study.

Fruit fly damage and economic losses have been reported to impact negatively on the local economy. Smallholder farmers elsewhere have bemoaned the effects of fruit flies on their fruit production (Mwatawala *et al*., 2004; Yaya-Toure and Te'moignage, 2007). Previous studies have reported the presence of fruit flies in a wide variety of hosts and their wide infestation rates on commercial fruits such as mango, citrus and guava (Vayssieres *et al*., 2005; Rwomushana *et al*., 2008). *Bactrocera invadens*, in particular is currently considered as the major fruit pest in Africa. Its polyphagous nature, presence in several hosts and rapid spread throughout the continent makes it a devastating quarantine pest and thus, calling for its easy recognition among all fruit growers in the sub-region (Mwatawala *et al*., 2009a; Abdullahi *et al*., 2011).

Many of the recommended control methods for fruit flies were known to some growers but were not in use probably due to their unavailability or unaffordability. The use of synthetic chemicals was problematic because farmers did not know the recommended chemicals for controlling fruit fly pests. Many extension programmes in the area seemed to encourage the use of pesticides without proper consideration of their environmental and health risks (MoFA-GTZ, 1992). Farmers' decisions on what, when and how pesticides are used in fruit crop farms did not have a bearing on human health and environmental safety. The indiscriminate use of pesticides results not only in actual yield loss, but also leads to the destruction of natural enemies of fruit flies and the development of resistance by these and other pests in the agro-ecosystems (Banjo *et al*., 2010). As farmers adopt multiple efforts to minimize fruit fly infestation in an IPM fashion, there is the need to carefully study how these practices can be improved upon, where necessary to enhance their effectiveness in fruit fly suppression (Ekesi and Billah, 2006). In training farmers to improve their capacities, consideration needs to be given to fully comprehensive educational materials illustrated by simple texts and colour photographs of pest species, biology, damage and control. There is an urgent need to train fruit growers through farmers' field schools aimed at empowering receptive and illiterate farmers in appropriate local languages with the basic knowledge of fruit fly pests in such a way that they can be truly independent decision-makers at the farm level.

CHAPTER FIVE

5.0 IN-SERVICE TRAINING NEEDS OF AGRICULTURAL EXTENSION AGENTS IN THE MANAGEMENT OF FRUIT FLIES IN NORTHERN GHANA

5.1 INTRODUCTION

The fruit fly menace in sub-Saharan Africa is of great concern to all stakeholders along the fruit value chain (STDF, 2009). Addressing this menace in Ghana requires strengthening the agricultural extension system for innovation dissemination (PPRD, 2010). Rajotte *et al.,* (2005) reported that the central problem of the adoption of pest management technologies in Africa is one of transferring IPM innovations to farmers. According to Morse and Buhler (1997) deficiencies in extension systems' capacity to provide effective farmer education and training programmes is a major constraint to technology adoption by farmers. Frontline extension agents are vital to IPM implementation because they provide the necessary link with farmers and communities, manage on-farm research efforts, and deliver education and training programmes. However, many have identified extension agents' lack of awareness and understanding of IPM as an impediment to effective transfer of research technologies to farmers (Zadom, 1993; Yudelman *et al.,* 1998).

Knowledge and awareness are generally considered prerequisites to technology adoption, and change agents success in securing adoption is related to clients' perceptions of change agents' credibility and reliability. Change agent's credibility is, in turn, linked with clients' perception of change agent's knowledge and technical competence (Rogers, 1995). Thus, AEAs' knowledge and competence will serve as vital link in the implementation of IPM systems for fruit fly pests in African countries. Agunga (1995) noted that for AEAs to help with crop protection practices, they must first understand sustainable crop protection concepts. Assessing the knowledge status and educational needs of AEAs is thus, an important element in extension service delivery and a critical factor in the success of the technology dissemination process (Al-Subaiee *et al*., 2005). As AEAs face the challenge of learning new skills to maintain their proficiency or become qualified for promotions, the importance of effective staff training programmes become more evident (Bufford *et al*., 1995; Chizari *et al*., 1999). Fruit fly extension in Ghana would thus, be severely limited in its ability to plan and execute effective educational programmes and other technology transfer activities without adequate number of well trained extension agents with the requisite understanding, competence and ability to teach and communicate effectively the fruit fly management concepts to farmers and other stakeholders (Adovor *et al*., 2009; Sinzogan *et al*., 2008).

At present, there is no published research information on AEAs' in-service training needs on fruit fly pests in Ghana. Hence, to ensure that AEAs are well trained to solve fruit fly pest problems in the country, it is necessary to determine what extension agents already know and what they need to know in order to help strengthen their professional capacities for further action. In this study, baseline survey was conducted to determine the knowledge gaps, identify and prioritize the training needs of AEAs regarding fruit fly pests and their management in the three administrative regions of northern Ghana. The specific objectives were to:

1. describe the demographic and background characteristics of AEAs in the area
2. identify their perceived level of knowledge and competence on fruit fly pests, and
3. determine their in-service training needs for the pests.

5.2 MATERIALS AND METHODS

5.2.1 Theoretical framework

The study was concerned with the knowledge gaps and training needs of AEAs regarding fruit fly pests in the Northern, Upper West and Upper East regions of Ghana. Rogers (1995) noted that knowledge of a concept, tool or innovation occurs when an individual knows both its function and application. Thus, the study focused on the assessment of extension agents' knowledge and training needs for improved IPM dissemination on fruit flies in Ghana. The theoretical framework of the study is based on the procedure of Erbaugh *et al*. (2007). Since the conceptual knowledge base involving fruit fly pests is complex and multidimensional, 15 competency aspects of fruit flies (Table 5.2) were developed and combined into a summated rating scale to measure AEAs knowledge on the pests. Extension agents were requested to directly rate their perceived importance, knowledge and competence of each item by considering the characteristics or associated skill dimensions of the item.

Training needs is defined as the difference between a desired status of learners and actual status of the learners (Alibaygi and Zaraftshani, 2008). Specifically, this study was inspired by a definition of training needs proposed by Borich (1980). According to Borich, a need is described as a discrepancy or gap between "what is" (the present state of affairs in regard to the group and situation of interest), and "what should be" (desired state of affairs) (Witkin and Altschuld, 2000). This methodological model enables the design of a survey instrument that would allow one to collect data that can be weighed and ranked in order of priority. Among need assessment models, the discrepancy model proposed by Borich (1980) is widely used in agricultural education, and it was determined to be the best instrument for achieving the purpose and objectives of this study.

5.2.2 Survey methods

Based on the framework described above, questionnaires were prepared to interview selected AEAs from the three regions. In each region, AEAs were selected with the assistance of the District Director of Agriculture (DDA) in consultation with the Regional Plant Protection Officer. An introductory letter from the Ghana National Fruit Fly Management Committee (GNFFMC) was presented to facilitate the permission and assistance in the selection and contact of the AEAs. Stratified random sampling procedures were used in the selection of the districts and AEAs. The target population was the crop-based AEAs who were generally responsible for disseminating crop protection innovations to farmers. A total of 15 districts, comprising 5 districts from each region were covered. Overall, 150 AEAs, 10 from each district were involved in the survey.

The survey questionnaires were developed using a method for obtaining group consensus among purposively selected experts. The first-round questionnaires consisted of one open-ended question that solicited experts' opinions about the competencies on fruit fly pests in Ghana. Based on the summary of responses from the first round questionnaire, 20 competencies were summarized for the second-round questionnaire. Content and face validity were established by a panel of experts consisting of researchers from the Department of Agricultural Extension Education of the UDS, and a group of professionals in agricultural entomology at the CSIR-Savanna Agricultural Research Institute, Ghana. In the third round, the experts were asked to rate the same competencies as the second round again in light of a summary of the findings on the second round. Based on the responses of the final round questionnaire, the 15 competencies were identified to be included in the final questionnaire. Instrument reliability was established by calculating the Cronbach's alpha (Crocker and Algina, 1986). Reliability for the overall instrument was 0.79 for knowledge or importance level, and 0.85 for the competence level. To ascertain the reliability of the questionnaire, a pilot test was conducted with 20 AEAs not included in the sample, three weeks before the study. After the pilot test, minor changes were made in the expression of the competencies.

To determine their perceived level of knowledge of fruit fly pests, AEAs were asked to directly rate their knowledge of the 15 competencies using the following scale: Poor (M = 1.00-1.49); Fair (M = 1.50-2.49); Good (M = 2.50-3.49); Very good (M = 3.50-4.49) and Excellent (M = 4.50-5.00). To determine their perceived level of importance of fruit fly pests, AEAs were asked to rate the 15 items using the following scale: Not important (M = 1.00-1.49); Of little importance (M = 1.50-2.49); Somewhat important (M = 2.50-3.49); Important (M = 3.50-49) and Very important (M = 4.50-5.0). To determine their perceived level of competence in fruit fly pests, AEAs were asked to rate the 15 items using the following scale: Not competent (M = 1.00-1.49); Of little competence (M = 1.50-2.49); Somewhat competence (M = 2.50-3.49); Competent (M = 3.50-4.49) and Very competent (M = 4.50-5.00).

Each selected AEAs was sent an introductory letter together with a copy of the questionnaire for completion. All completed questionnaires were submitted to the offices of the DDAs where they were later received by members of the research team. The data collection lasted for a period of three months beginning from February, 2012 to April, 2012. Data were analyzed using the Statistical Package for Social Sciences (SPSS for Windows version 16.0). A Mean Weighted Discrepancy

Score (MWDS) was calculated to describe the overall rankings for each of the competencies. A discrepancy score was first calculated for each individual on each competency by taking the importance rating minus the ability (competency) rating. A weighted discrepancy score was then calculated on each individual for the professional competency by multiplying the discrepancy score by the mean importance rating. A mean weighted discrepancy score for each of the competencies was then calculated by taking the sum of the weighted discrepancy scores and dividing by the number of observations. Using the mean weighed discrepancy scores, the 15 competencies were then ranked (Borich, 1980; Bar-rick *et al*., 1983; Garton and Chung, 1997; Alibaygi and Zarafshani, 2008).

5.3 RESULTS

5.3.1 Demographic information of AEAs

The descriptive information for the AEAs' demographic and background characteristics in the three regions is presented in Table 5.1. The results showed that out of the 150 AEAs who participated in the interview, 132 (88.0%) of them were males while 18 (12.0%) of them were females. Their ages ranged between 21 and 61 years with the mean age being 37. Majority (59.3%) of the respondents was at age between 31 and 40 years while only a few (4.6%) of them were above 50 years. A total of 33 (22.0%) of the agents were 30 years and below. No respondent was above 50 years in the Upper West Region or above 60 years in the Northern Region.

The educational status of the AEAs showed that 54.7% of them held training college certificate in Agriculture while 42.5% of them were university degree holders. Only 4 respondents (all from the Northern Region) were secondary school certificate holders but no respondent from the Upper West or Upper East region had secondary school certificate as the highest level of education. None of the respondents from any of the regions had basic education certificate as the highest level of education.

The number of years in service as extension agents was found to range between 3 and 23 years. In all the regions, it was observed that the number of extension staff decreased with increasing service years with the highest number of agents being in the service for at most 5 years while the lowest number had served for over 20 years. Meanwhile, no respondent in the Northern Region had spent over 20 years the service.

Table 5.1: Demographic information of Agricultural Extension Agents (AEAs) in three northern regions in Ghana, 2012

Factors (N = 150)	Frequency (%)			
	Northern Region	Upper West Region	Upper East Region	All regions combined
Sex				
Male	46 (30.6)	42 (28.0)	44 (32.0)	132 (88.0)
Female	4 (2.6)	8 (5.3)	6 (4.0)	18 (12.0)
Age Range				
20-30	12 (8.0)	10 (6.6)	11 (7.3)	33 (22.0)
31-40	28 (18.6)	34 (24.6)	27 (18.0)	89 (59.3)
41-50	8 (5.3)	6 (4.0)	7 (4.6)	21 (14.0)
51-60	2 (1.3)	-	3 (2.0)	5 (3.3)
Above 60	-	-	2 (1.3)	2 (1.3)
*Educational level				
BSC	-	-	-	-
SSC	4 (2.7)	-	-	4 (2.7)
TCC	25 (16.8)	29 (19.5)	27 (18.2)	81 (54.7)
UD	19 (12.8)	21 (14.1)	23 (15.5)	63 (42.5)
Number of years in Service				
1-5	21 (14.2)	19 (12.6)	23 (15.3)	63 (42.0)
6-10	15 (10.1)	17 (11.3)	15 (8.6)	45 (30.0)
11-15	8 (5.4)	8 (6.3)	7 (4.6)	23 (15.3)
16-20	6 (4.1)	4 (2.6)	2 (1.3)	12 (8.0)
>20	-	2 (1.3)	5 (3.3)	7 (4.6)

*BSC = Basic school certificate, SSC = Secondary school certificate, TCC = Training college certificate, UD = University degree

5.3.2 AEAs' perceived importance of fruit fly pests

Table 5.2 presents the descriptive information for the various competency areas of the fruit flies with their associated levels of importance as perceived by the AEAs in the three regions. AEAs in the Northern Region believed that 3 of the competency areas of fruit flies were very important, 8 competencies were important, 2 competencies were somewhat important and 2 were either of little importance or not important.

Table 5.2: Mean scores for items comprising direct assessment of AEAs' perceived level of importance of 15 competency aspects of fruit fly pests in three northern regions in Ghana, 2012.

Competency aspects	Mean score*			
	Northern Region	Upper West Region	Upper East Region	Overall mean score
Economic impact	4.65	4.50	4.55	4.56
Pest status	4.65	3.90	4.95	4.50
Economically important species	4.50	4.50	4.55	4.51
National action plan	4.35	4.50	3.58	4.14
Control strategies	3.90	4.44	4.50	4.28
Detection and monitoring	4.35	3.30	4.55	4.06
Life cycle	4.35	2.50	4.50	3.78
Host plant associations	4.20	4.05	3.75	4.00
Population dynamics	3.84	3.84	3.80	3.82
Natural enemies	3.51	3.51	3.51	3.51
Directions for future research	3.00	4.50	2.70	3.40
Geographical Distributions	3.90	3.60	1.80	3.10
Behavioural ecology	3.00	2.13	3.00	2.70
Morphological characteristics	1.02	1.00	1.65	1.22
Taxonomic classification	1.50	1.35	1.50	1.45

*Scale: Not important = 1.00-1.49; Of little importance = 1.50-2.49; Somewhat important = 2.50- 3.49; Important = 3.50-4.49 and Very important = 4.50-5.00.

AEAs in the Upper West region believed that 3 competencies were very important, 6 were important, 2 were somewhat important and 3 were either of little importance or not important.

Moreover, AEAs in the Upper East Region believed that 6 of the competencies were very important, 4 were important, 2 were somewhat important and 3 were of little importance. No competency was considered as unimportant in the Upper East Region. As indicated in Table 5.2, the overall mean score for the three regions indicated that 3 competencies were perceived to be very important, 7 were perceived to be important, 5 were perceived to be somewhat important while the other 2 were perceived to be either of little importance or not important. In general, majority of the competency areas were perceived by the AEAs to be important aspects of fruit-infesting flies in northern Ghana.

5.3.3 AEAs' perceived knowledge of fruit fly pests

As presented in Table 5.3, AEAs in the Northern Region perceived that they had good knowledge in 7 of the competencies and fair knowledge in 6 competencies, but they perceived to have poor knowledge in 2 competencies. AEAs in the Upper West Region perceived that their technical knowledge base was good in 3 of the competencies, fair in 6 competencies, but poor in 3 competencies. For the Upper East Region, AEAs perceived that they had very good knowledge in only one competency area. Also, they perceived to have good knowledge in 4 competencies and fair knowledge in another 4 competencies, but they had poor knowledge in another 4 competencies. Here again, no respondent in that region perceived to have very good knowledge in any of the competency areas.

The overall mean score for the three regions indicated that AEAs perceived themselves to have good knowledge in 4 of the competencies and fair knowledge in majority (9) of the competencies. Only one competency area they perceived to have poor knowledge. No AEA in any of the regions had excellent knowledge in any of the competency areas. In general, majority of AEAs in all the regions perceived to have fair or poor knowledge in the competency areas of fruit flies.

Table 5.3: AEAs' perceived level of knowledge of 15 competency aspects of fruit fly pests in three northern regions in Ghana, 2012.

Competency aspects	Mean score*			
	Northern Region	Upper West Region	Upper East Region	Overall mean score
Morphological characteristics	3.00	2.15	3.85	3.00
Geographical distributions	1.50	1.98	2.49	1.99
Taxonomic classification	3.00	3.00	1.65	2.55
Economically important species	1.80	0.30	2.85	1.65
Life cycle	2.01	2.01	2.01	2.01
Natural enemies	2.25	1.00	1.00	1.41
Host plant associations	2.55	1.05	1.95	1.85
Population dynamics	1.50	2.25	1.20	1.65
Behavioural ecology	1.05	2.10	1.00	1.38
Pest status	3.15	2.25	3.00	2.80
Economic impact	3.15	3.00	3.00	3.05
Detection and monitoring	1.29	2.85	1.29	1.80
Control strategies	1.80	1.29	2.52	1.87
National action plan	3.00	1.00	1.00	1.66
Directions for future research	2.65	1.00	1.00	1.55

*Scale: Poor = 1.00-1.49; Fair = 1.50-2.49; Good = 2.50-3.49; Very good = 3.50-4.49 and Excellent = 4.50-5.00

5.3.4 AEAs' perceived competence in fruit fly pests

Table 5.4 presents the agent's perceived levels of competence regarding the competency areas of the fruit flies. The results indicated that AEAs in the Northern Region perceived themselves to be very competent in 2 of the competency areas. They were competent in 2 competency areas, somewhat competent in 4 competency areas, of little competent in 6 competency areas but not competent in only one competency area. In the Upper West Region, AEAs perceived that they were very competent in only one competency area, competent in 3, somewhat competent in 2, of little competent in 2 but not competent in the rest (7) of the competency areas. Also, AEAs in the Upper East Region perceived that they were competent in 4 competencies, somewhat competent in 2, of little competent in 3 but not competent in the rest (6) of the competencies. No respondent was very competent in any of the competencies in the Upper East Region.

Table 5.4: AEAs' perceived level of competence in 15 competency aspects of fruit fly pests in three northern regions in Ghana, 2012.

Competency aspects	Mean score*			
	Northern Region	Upper West Region	Upper East Region	Overall mean score
Taxonomic classification	5.00	4.30	4.49	4.61
Morphological characteristics	5.00	4.80	4.00	4.60
Behavioural ecology	2.95	3.80	4.20	3.65
Pest status	3.60	3.60	3.70	3.63
Economic impact	3.00	3.00	3.00	3.00
Geographical distribution	3.50	1.80	2.70	2.66
Economically important species	3.00	2.50	1.95	2.48
Life cycle	3.00	2.00	1.80	2.26
Host associations	1.70	1.00	1.10	1.80
Detection and monitoring	1.00	1.40	1.00	1.40
Population dynamics	1.90	1.10	1.10	1.36
Natural enemies	1.55	1.00	1.50	1.35
Directions for future research	1.75	1.30	1.00	1.35
Control strategies	1.50	1.30	1.00	1.26
National action plan	1.75	1.00	1.00	1.25

*Scale: Not competent = 1.00-1.49; Of little competent = 1.50-2.49; Somewhat competent = 2.50-3.49; Competent = 3.50-4.49 and Very competent = 4.50-5.00

In overall, AEAs perceived to be very competent, and competent in 2 competencies each, of little competent in 3 competencies but not competent in the rest (6) of the competencies. Thus, in all the study regions, majority of the AEAs generally perceived to be either of little competence or not competent in the competency areas of the fruit flies.

5.3.5 In-service training needs of AEAs for fruit flies

The rankings of the in-service training needs of the AEAs regarding fruit fly pests as determined by the Mean Weighted Discrepancy Scores (MWDS) are presented in Table 5.5. The results indicated that in the Upper West and Upper East regions, 7 competency aspects of the pests namely; economically important species, economic impact, control strategies, host associations, life cycle, pest status, and detection and monitoring emerged as the highest ranking in-service training needs of the agents. In the Northern Region, the first 4 competency areas mentioned above emerged as the highest ranking in-service training needs of the agents. Each of these competency aspects recorded a MWDS of 7 or above. The overall MWDS obtained for the three regions revealed that these top 5 key aspects were the competency areas in need for in-service training of the agents.

The 5 middle-ranking in-service training needs as perceived by the agents were; pest status, detection and monitoring, national action plan, natural enemies and population dynamics. The other aspects of the pests such as behavioural ecology, geographical distribution, directions for future research and morphological characteristic were ranked the 5 lowest in-service training needs of the agents. Each of the top 5 competency aspects mentioned above again recorded the MWDS above 7.0 while the middle 5 competency aspects each recorded a MWDS between 6.5 and 5.0. A MWDS of less than 5.00 was recorded for each of the bottom 5 low-ranking competency aspects.

Table 5.5: Mean weighted discrepancy scores (MWDS) for AEAs' perceived level of importance, knowledge and competence in 15 competency aspects of fruit fly pests in three northern regions of Ghana, 2012.

Competency aspects	MWDS*			
	Northern Region	UpperWest Region	Upper East Region	Overall mean score
Economically important species	9.00	9.20	7.50	8.60
Economic impact	9.00	8.50	8.00	8.50
Control strategies	9.00	7.50	7.50	8.00
Host plant associations	7.50	7.45	7.60	7.50
Life cycle	8.00	6.50	7.00	7.10
Pest status	7.00	7.20	5.50	6.56
Detection and Monitoring	4.00	7.00	6.50	5.82
National action plan	6.60	5.00	5.60	5.73
Natural enemies	6.40	5.50	5.00	5.60
Population dynamics	5.00	5.00	5.00	5.00
Behavioural ecology	4.50	5.00	5.10	4.86
Geographical distribution	5.00	4.00	5.00	4.66
Directions for future research	5.40	4.00	4.00	4.46
Taxonomicclassification	4.50	4.00	4.30	4.26
Morphologicalcharacteristics	3.50	3.50	4.20	3.73

*MWDS of ≥ 7.0 indicates that the competency aspect is perceived to be of critical educational need.

5.4 DISCUSSION

The high response rate in the survey suggests that the AEAs had keen interest in crop protection issues and were especially willing to support research initiatives in order to help address the fruit fly menace in the area. The sex ratio of the respondents was an indication of a gender-balanced participation. Their age range showed that the agricultural extension system in the area was dominated by personnel of the active age group, and this gives the system more prospects for the future. Majority of the respondents were graduates of universities and agricultural colleges indicating that most of the agents were adequately qualified for their job positions. Professional qualification of frontline extension agents is an important requirement for effective innovation communication and information dissemination (Erbaugh *et al*., 2007) which is vital for the sustainability of every extension delivery system (Alibaygi and Zarafshani, 2008). Enhanced professional capacity of agricultural facilitators will enable smallholder farmers address crop production constraints for increased fruit and vegetable crop production. This would lead to improved livelihoods and enhanced food security in African countries (Aggor *et al*., 2002; Norman, 2003).

Combating fruit flies in Ghana requires in-service training programmes and encouraging AEAs to collaborate for the planning and execution of these programmes. The purpose of this study was to determine the knowledge base and identify the in-service training needs of AEAs regarding fruit fly pests and their management. The AEAs in all the study regions perceived themselves to have fair or poor knowledge in majority of the 15 competencies. Almost all of the competency aspects were perceived as either very important or important components of an overall training programme. The AEAs also believed that they had little competence in most of the key aspects necessary for addressing the fruit fly menace in the area. The five main competencies of fruit flies with the greater need for in-service education were the economically important fruit fly species, their economic impact on fruit crop production, control strategies, life cycle and host plant associations. These aspects have been recognized as crucial in the development of effective and sustainable fruit fly management efforts in sub-Saharan Africa (Drew, 1992; Ekesi and Billah, 2006; IITA-CIRAD, 2008; Mwatawala *et al*., 2009a, b; PPRSD, 2010). These priority competency areas need to be addressed at training workshops conducted by experts of the fruit fly committee of

Ghana in order to meet the professional and educational needs of AEAs for addressing the fruit fly problem in the area.

The Borich's needs assessment model proved to be effective in that AEAs were given the opportunity to judge their performance objectively (Alibaygi and Zarafshani, 2008). The implications of this study are that high priority should be given to planning, development and implementation of training programmes for AEAs regarding fruit fly pests in northern Ghana. Since the urgency to address the fruit fly problem is a nation-wide challenge, the implications of the study may well extend beyond the north of Ghana. Higher educational and research institutions can cooperate with the Ministry of Food and Agriculture (MoFA) in developing these training programmes. Benchmarks need to be established to measure progress for the proposed training in meeting the goal of increasing agents' effectiveness regarding fruit fly management. According to Mumford and Norton (1993), acceptance of any pest management innovation must meet the needs of the customer. Previous study has shown that fruit growers play an important role in the IPM implementation process of fruit fly pests in northern Ghana (Badii *et al.*, 2012). Thus, planning of fruit fly management efforts based on the findings of this study can positively affect the diffusion rate of crop protection practices of farmers as the principal actors in promoting sustainable agriculture in Ghana. Therefore, staff professional capacity development programmes for AEAs should look into how these critical educational needs on fruit fly pests can be addressed in training workshops.

CHAPTER SIX

6.0 HOST RANGE AND SPECIES COMPOSITION OF FRUIT-INFESTING FLIES (DIPTERA: TEPHRITIDAE) IN NORTHERN GHANA

6.1 INTRODUCTION

Sustainable management of fruit-infesting flies involves accurate knowledge about the species concerned and their host spectrum (Aluja, 1996). This is vital in understanding the biology, ecology and behavior of the pest (Rull, 2008). Also, information about fruit fly species and their host range would be helpful in the exploration of natural enemies for biological control efforts (Stibick, 2004), in determining the type of lure to be used in trapping programmes (Lux *et al*., 2003a; IAEA, 2003) and in selecting the type of crop to be cultivated in a given agro-ecosystem (Mwatawala *et al*., 2009a; Vayssieres *et al.*, 2007). Moreover, importing countries generally require information on the tephritid species present in a particular host fruit in order to identify which species are pests, describe the host they attack and prescribe recommended post-harvest fruit treatment procedures prior to export (Ishida *et al*., 2005; STDF, 2009). Hence, accurate and reliable determination of the status of a particular plant species as a host of a given fruit fly species has become critical in this era of intensive international trade and the expansion of fruit growing regions in sub-Saharan Africa.

Unfortunately, available literature on fruit fly species and their host plants is marred with methodological flaws and inaccuracies to the extent that they have even generated long-standing commercial disputes between trade partners (Aluja, 1996). According to Norrbom and Kim (1988), a host record should only be validated if the infestation occurred under natural field conditions. Ovruski, *et al*. (2000) added that host records should also be accompanied by information on the species of fruit infested, levels of infestation, fruiting phenology and ecological distribution of the host species. According to Cowley *et al.* (1992), one has to consider the fact that host status can change over time and is influenced by environmental conditions such as drought, and the concomitant effect on primary and secondary host availability. Considering the latter, Cowley *et al.* (1992) proposed a strict experimental procedure to unequivocally ascertain host status of fruit flies through field collection and incubation of fruits.

The species diversity and host associations of fruit fly pests have been investigated in several African countries. For instance, De Meyer *et al.* (2002) provided an annotated check list of fruit fly host plants for the Afrotropical regions. However, their report was only specific to *Ceratitis* species and did not provide information on the interaction and host-resource partitioning in particular areas. Also, inventory of tephritid pests infesting various fruits and vegetable crops have been documented for Kenya (Copeland *et al.*, 2002; 2004; 2009; Copeland and Wharton, 2006; Rwomushana *et al.*, 2008), Guinea (Vayssieres and Kalabane, 2000), Benin (Vayssieres *et al.*, 2005), Tanzania (Mwatawala *et al.*, 2006b; 2009a), Mali (Vayssieres *et al.*, 2007), Cameroon (Abanda *et al.*, 2008), Nigeria (Umeh *et al.*, 2008), Cote d'Ivoire (N'depo *et al.*, 2009), Senegal (Vayssieres *et al.*, 2011a), and Burkina Faso (Ouedraogo *et al.*, 2011). For Ghana, however, there is inadequate research information on the species and host diversity of fruit-infesting flies. Afreh-Nuamah (1999) reported *C. capitata* and *C. cosyra* as major pests of citrus and mango, respectively. Billah *et al.*, (2006) reported the first detection of the African invader fly, *B. invadens* in the country while Nboyine *et al.*, (2012), Billah (2012) and Wih and Billah (2012) reported a range of fruit fly species infesting mango. Later work by Foba (2009) however observed *C. ditissima* to be the dominant species attacking citrus in Ghana. However, these studies provided no information on the associations of fruit flies with other host plants. Moreover, these reports, as in the case of the many other studies cited above, are based on trapping surveys or are mainly targeted at fruit fly species associated with one or few commercial crops such as mango and citrus. There has been no comprehensive study to catalogue the species spectrum of fruit flies and their associations with wild and cultivated plants in the country. This is particularly necessary for the northern sector of the country where fruit and vegetable production is gaining commercial advantage.

Mwatawala *et al.,* (2009a) noted that a clear understanding of the use of the different potential hosts available in a given area and the host partitioning between the different competitive fruit fly pests is necessary in developing a sustainable IPM programme. Thus, there is the need to document baseline information useful for planning an integrated fruit fly control programme to help reduce the damage caused by pestiferous fruit flies in Ghana. Copeland *et al.,* (2004, 2009) and Copeland (2006) indicated that host fruit collection and incubation has been the most reliable means of obtaining a wider range and higher diversity of tephritid species and their host associations in a given ecology. This study, involving a two-year collection and incubation of both wild and cultivated fruit, sought to document baseline information on the tephritid diversity and their host plants in the northern savanna ecology of Ghana.

6.2 MATERIALS AND METHODS

6.2.1 Field sites

For the overall survey of wild and cultivated fruits in northern Ghana, collection sites were chosen to maximize the diversity of fruit-bearing plants in the area. The survey involved extensive sampling from farmlands, backyard gardens, roadsides, woodlands and forest habitats in selected sites within the Northern, Upper West and Upper East regions of the country. GPS data were recorded at the site of each collection or at the nearest opening, if fruits were collected in dense locations. A total of 15 collection sites (5 from each region) were selected for the study. Table 6.1 presents the major areas surveyed and their approximate geo-referenced positions.

Table 6.1: Fruit collection sites with their approximate latitudes, longitudes and altitudes.

Province/ Region	Collection site	Agro-ecology	Approximate latitude	Approximate longitude	Approximate altitude, m
Northern	Tamale suburbs	Guinea savanna	N 09.39450	W 000.84777	615
	Salaga woodland	Guinea savanna	N 08.55199	W 000.51309	332
	Damongo forest	Guinea savanna	N 09.08502	W 001.81984	542
	Daboya valleys	Guinea savanna	N 09.21945	W 002.85958	000
	Gushie bushland	Guinea savanna	N 09.91872	W 020.85958	265
Upper West	Wa suburbs	Sudan savanna	N 10.02456	W 002.48916	1130
	Wahabu forest	Sudan savanna	N 10.80303	W 002.10677	1078
	Daffiama bushland	Sudan savanna	N 10.45018	W 002.54671	1040
	Wechiaw woodland	Sudan savanna	N 10.35420	W 002.56431	1200
	Babille bushland	Sudan savanna	N 10.54487	W 002.86214	909
Upper East	Bolga suburbs	Sudan savanna	N 10.86818	W 001.43251	5743
	Sandema woodland	Sudan savanna	N 10.56275	W 001.12639	627
	Navrongo bushland	Sudan savanna	N 10.94559	W 000.47069	688
	Zebilla hills	Sahel savanna	N 10.76275	W 001.12639	827
	Bawku bushland	Sahel savanna	N 10.66987	W 001.20987	756

To facilitate free and easy access to the collection localities, official permission was sought from the District Directors of Agriculture through their respective Regional Directors using an introductory letter from the National Fruit Fly Management Committee of Ghana. In some situations, verbal permission was requested before sampling on private property. Such permission also helped to eliminate suspicion of the purpose of the work and request for assistance of the local youth who would help in the location, searching, collection and carrying of the fruit samples.

6.2.2 Fruit collection

The method of fruit collection in the field generally followed the procedure of Copeland *et al.* (2002; 2004; 2009) and Mwatawala *et al*. (2009a). Collection trips were made to each selected site at two monthly intervals beginning from October, 2011 to September, 2013 using a field vehicle. The collection interval was chosen based on convenience and cost, and to ensure that all collection sites were visited in all months within the two year period. The general rule for collection was to maximize the quantity and diversity of sampled fruits so as to help increase the probability of finding even rare fruit species. In some situations, however, there were some level of selectivity among some fruits that, based on previous data from rearing of the same or related species, were not likely to produce insects.

At each site, available fruits (wild and cultivated) were collected from the ground (as 'windfalls') or from the plants. Whenever possible, mature, ripe and/or falling fruits were selected because these were generally more likely to be infested than unripe or immature fruits (Mwatawala *et al.*, 2009a). Attempts were made to sample large quantity of fruit with a minimum of 15 fruits per sample although this was dependent on fruit type, availability or accessibility. Sometimes, fruits species not encountered at the sampling site were purchased from roadside markets, and wherever possible, attempts were made to establish the place of origin. Records of collections were kept by indicating the date, site, GPS ordinates and altitudes, and plant species for each sample in a field note book.

Fruit samples were placed in individual plastic bags with the appropriate labels. Each plastic bag was put inside a piece of synthetic mesh and placed in a plastic container. The ends of the synthetic mesh was pulled and tightened over the rim of the container, lifting the fruits off the bottom of the container. They were secured in this position by fitting the plastic lid of the container over the mesh

(Plate 6.1). Elevating fruits over the bottom of the container avoids physical damage to fruits on the rough local roads. To ensure adequate ventilation, the middle portion of each lid was cut out and replaced by 10 x 15 cm piece of tight-weave synthetic mesh capable of retaining any emerged insects. During the transportation of the fruits from field to laboratory, the containers were covered with moistened cotton fabric to avoid excessive heating. Arrangements were made to ensure that sampled fruits arrive at the laboratory within 12 hours after sampling.

Plate 6.1: Sampled fruits packaged in plastic container for transport from the field to laboratory.

6.2.3 Fruit incubation

Fruit samples were transported to a rearing unit established at the AgSSIP Biology Laboratory, Faculty of Agriculture, University for Development Studies (UDS), Nyankpala, Ghana, for incubation. On arriving at the laboratory, each fruit sample was assigned a unique identifier code according to the protocol of Copeland (2006). Fruits in each sample were counted and weighed before being placed in incubation containers. Each incubation unit consisted of a 1.5-litre rectangular plastic container with 0.5 cm ellipsoid holes cut into the bottom (Plate 6.2 a). An ellipsoid-shaped hole (but not circular) prevented fruits from clogging the holes during incubation while at the same time allowing mature larvae of fruit flies to fall through after they had exited the host fruit. The lid of the container was cut open at 1.0 x 0.5 cm on the middle and covered with a synthetic mesh. The container with holes was covered with the lid and nested into a second container (without holes at the bottom) and covered with the lid (Plate 6.2 b). A layer of moistened sand was placed at the bottom of the second container to serve as pupation medium for the exiting larvae in addition to soaking up fruit juice. The sand was washed and sterilized at 120 ºC for at least 12 hours and thereafter cooled at ambient temperature before being used. An adhesive label was affixed to the outside of the second container and on this label, the same information on the label accompanying the sample from the field as well as the unique identifier code, were indicated.

The incubators of fruits were arranged on metal shelves (Plate 6.3), the legs of which were placed in a water-filled container, thus helping to supplement humidity while simultaneously acting as a effective barrier to strange insects. Each fruit sample was maintained for a minimum period of 4 weeks at 25±3 ºC and 60±10% RH.

a)  b) 

Plate 6.2: Fruit holding containers: a) A 1.5 cm container (without holes) and a 1.5 cm container (with ellipsoidal holes at bottom) and its lid: b) the containers nested together for use in holding the fruit samples.

Plate 6.3: Incubators with fruit samples arranged in metal shelves for recovery of puparia.

The 4-week holding period encompassed the period of larval pupation, and most fruits were shrunken and dry by the end of the period (Copeland *et al*., 2002). Larger moist fruits were, however, held for an additional one week. During the holding period, fruit samples were kept moist by spraying with fine mist of water as needed, but spraying was avoided on fruit samples that were prone to mouldiness. Under drier conditions, large containers were filled with water and placed around the corners of the rearing room to help maintain a relatively high humidity. After the incubation period, fruits in each sample were cut open and examined for any trapped/hidden larvae or puparia before being discarded.

6.2.4 Insect monitoring

Each incubation unit was checked every three days for the presence of puparia, which were picked up using a pair of soft forceps or by gentle sifting. These were counted before being placed in petri dishes with moistened filter paper. The petri dishes containing the puparia were placed in small ventilated transparent rectangular plexiglas (perpex) used as rearing cages (Plate 6.4). These were held at 26-28 ºC and 60-70% RH, a condition adequate for preventing pupal water loss while minimizing development of moulds (Boller and Prokopy, 1976). The puparia were held in the cages for 5 to 7 days for the emergence of adult flies. Emerging tephritids were provided with artificial diet that consisted of three parts of sugar and one part brewer’s yeast.

Plate 6.4: A puparia holding cage for checking emergence of adult fruit flies.

Droplets of pure honey were also spotted into the underside of the roof of the cage, and cotton wool soaked with distilled water placed in a small container on the cage floor to sustain the flies. Flies were allowed to feed for 3 days during which full adult development and body coloration were attained. The flies were killed (by freezing) and the number recorded in a data sheet while representative samples were preserved in vials containing 80% ethanol.

6.2.5 Plant and fly identification

At the time of each collection, photographic vouchers of plants and their respective fruits were taken for identification or confirmation of identity. Plants species were identified using the botanical keys developed by Akoegninou *et al.* (2006). Also, photographic illustrations provided by Arbonnier (2004) were consulted for confirmation of identity. All botanical names and authors for plant species followed the nomenclature and classification of the International Plant Names Index database (IPNI, 2008). The photographic vouchers of plants and fruits were deposited at the UDS Horticulture Herbarium.

Specimens of emerged fruit flies were examined using a motic SMZ-143 series light microscope in a dark room in the laboratory. Taxonomic identification of the species was done using the taxonomic keys developed by White and Elson-Harris (1992) and Billah and Mansell (2006). Identity of some species was further confirmed by Dr Maxwell K. Billah, Department of Animal Biology and Conservation Sciences (DABCS), University of Ghana, Legon. Voucher specimens of fly species were deposited at the Entomology Laboratory of the Department of Crop Science, University of Ghana.

6.2.6 Data analysis

The incidence and infestation indices were determined for each fruit species. Incidence was defined as the number of infested or positive samples in comparison to total number of samples per fruit species. In addition, the infestation level (expressed as infestation index) was calculated as the number of adult flies per 100 fruits, and per unit weight (1 kg) of fruit (Cowley *et al.*, 1992; Copeland *et al.,* 2002). The two parameters made it possible to compare infestation rate in different fruit species, despite the differences in size of individual fruit samples (both in weight and in number of fruits). Data were analyzed using GenStat (VSN International Ltd, UK) and pairwise comparison of means was done using the least significant difference (LSD) test. The infestation levels of fruit fly species (source of variation) in plant species (replicates) were compared by one-way AVOVA. Uniformity in infestation by the most abundant fruit fly species in the most attacked fruit species was determined using Chi square test.

6.3 RESULTS

6.3.1 Host plants and fruit fly species

Table 6.2 presents the list of the plant species from which fruit samples were collected, indicating their sample details and host status to tephritid pests. In overall, 1,777 samples consisting of 36,283 fruits, totalling about 1,279.71 kg were collected during the study period. These were from 80 plant species (including 14 cultivated species) belonging to 33 different families. Of these, 65 (81.5%) of the plant species, representing 952 (53.6%) samples, were found to be positive to tephritid fruit flies. A total of 12 plant species proved 100% positive (with flies emerging from all incubated samples). The results also indicated that 15 plant species were negative to the fruit flies (with no incubated sample producing flies). In comparison to known records in Africa, twelve plant species were identified as new hosts to the invader fly, *B. invadens* (Table 6.3). Photographs of the various plant species recorded during the survey are shown in Appendix 3.

The results also showed that a total of 10 different fruit fly species emanating from four genera were reared from the incubated fruits. These consisted of four *Ceratitis* species (*C. cosyra*, *C. capitata*, *C. rosa* and *C. anonae*), two *Bactrocera* species (*B. invadens* and *B. cucurbitae*), three *Dacus* species (*D. vertebratus*, *D. bivittatus* and *D. ciliatus*) and one *Trirhithrum* species (*T. nigerrimum*) (Plate 6.5). Of these, *D. ciliatus* and *T. nigerrimum* were identified as first records in the study area. In terms of relative abundance of the fruit fly species, 48.0% of them were *C. cosyra* while 36.0% were *B. invadens*. The rest of fruit fly species were relatively low in occurrence with each occupying less than 6.5% of the total tephritid diversity in the area (Figure 6.1). Significant difference in abundance was observed among *C. cosyra*, *B. invadens* and *B. cucurbitae*, ($P< 0.001$) but comparison among the minor fruit fly species did not show significant difference. The two least abundant species were *C. anonae* and *D. ciliatus* with each recording less than 0.5% of the total tephritid population. Thus, there was a general predominance of *C. cosyra* and *B. invadens* among the host fruits studied.

Table 6.2: List of fruit species collected in northern Ghana with their sample details and host status to tephritid pests

Plant family	Plant species	Common name	Habitat	No. Samples	No. fruits	Weight Fruits	No. +ve samples	% +ve samples
Anacardiaceae	*Mangifera indica* L.	Mango	Cultivated	53	265	56.25	53	100
	Anacardium occidentale L.	Cashew	Cultivated	29	429	28.75	19	65.5
	Spondias mombin L.	Tropical plum	Wild	15	630	22.00	9	60.00
	Harpephyllum caffrum B.E.A. Krause	Wild plum	Wild	21	735	13.40	12	57.1
	Haematostaphis barteri Hook. F.	Blood plum	Wild	11	330	15.00	7	63.6
	Lannea acida A. Rich.	African grape	Wild	19	1425	10.25	1	5.2
	Lannea microcarpa L.	African grape	Wild	29	2775	12.00	-	-
	Sclerocarya birrea A. Rich.	Marula plum	Wild	8	176	9.26	7	87.5
Annonaceae	*Annona senegalensis* Pers.	Sour sop	Wild	30	368	40.88	30	100
	Annona muricata L.	Custard apple	Wild	9	175	9.37	3	33.3
	Annona squamosa L.	Sugar apple	Wild	5	83	3.66	1	33.3
	Artabotrys monteiroae Oliv.	-	Wild	6	66	7.30	1	16.6
Apocynaceae	*Saba senegalensis* (A. DC.) Pichon	Saba nut (smooth)	Wild	28	196	28.00	25	89.2
	Saba comorensis (Boj) ex DC. Pichon	Saba nut (rough)	Wild	18	108	18.00	7	38.8
	Thevetia peruviana (Pers.) Schuman	Yellow oleander	Wild	18	648	18.51	3	16.6
	Carissa grandiflora (Forssk) Vahl.	Natal plum	Wild	12	228	4.51	-	-
Caricaceae	*Carica papaya* L.	Pawpaw	Cultivated	22	22	21.70	6	27.2
Combretaceae	*Terminalia catapa* L.	Tropical almond	Wild	53	1075	29.86	43	100
Cucurbitaceae	*Citrulus lunatus* (Thunb.) M & N	Water melon	Cultivated	32	32	23.90	32	100
	Citrulus sativus L.	Cucumber	Cultivated	29	87	29.00	20	68.9
	Citrulus colocynthis L. Schrad.	Egusi	Cultivated	25	50	25.45	18	72.0
	Cucurbita maxima Duchesne ex Lam.	Pumpkin	Cultivated	17	17	8.50	3	11.7

Table 6.2 Cont.

Cucurbitaceae	*Cucurbita pepo* L.	Squash gourd	Cultivated	14	14	21.60	3	7.14
	Leganaria siceraria Molina Standl.	Bottle gourd	Cultivated	11	11	17.60	3	18.18
	Luffa cylindrica L.	Luffa	Wild	18	18	21.75	18	100
	Luffa acutangula (L.) Roxb.	Angled luffa	Wild	10	10	16.60	2	20.0
	Coccinia microphylla Gilg.	Coral vine	Wild	7	231	1.92	-	-
Ebenaceae	*Diospyros mespiliformis* A. DC.	Persimmon	Wild	38	1330	36.94	38	100
	Ivingia gabonensis (A-L) Baill.	African wild mango	Wild	20	100	23.33	11	55.0
Moraceae	*Ficus platyphylla* Del.	Flake rubber tree	Wild	17	592	12.48	-	-
	Ficus syncomosus L.	Syncomore fig	Wild	25	425	20.33	25	100
	Ficus asperifolia (Miq.)	Sandpaper tree	Wild	31	992	32.00	3	9.6
	Ficus sur Forssk	Bush fig	Wild	41	697	26.46	11	26.8
	Ficus recemosa L.	Cluster fig	Wild	27	675	29.70	21	77.7
	Artocarpus altilis (Parkins.) Fosb.	Bread fruit	Wild	19	228	6.73	9	47.3
Myrtaceae	*Psidium guajava* L.	Common guava	Wild	26	416	21.71	26	100
	Syzigium cumini (L.) Skeels	Jambolan	Wild	8	256	7.28	2	25.0
	Feijoa sellowiana (O. Berg.)	Feijoa	Wild	5	85	2.31	1	20.0
Rhamnaceae	*Ziziphus mauritiana* Lamk.	Buffalo thorn	Wild	23	1035	10.53	3	13.0
	Ziziphus mucronata Willd.	Jujube	Wild	19	912	27.63	19	100
Rubiaceae	*Gardenia erubescens* (Stapf & Hutch)	Cape jasmine	Wild	20	180	25.71	-	-
	Sarcocepholus latifolium (Smith) Bruce	African peach	Wild	71	568	37.33	71	100
Sapindaceae	*Blighia sapida* (Koenig)	Akee	Wild	42	336	25.84	19	45.2
Sapotaceae	*Vitellaria paradoxa* (CF Gaertn.)	Shea nut	Wild	69	1173	45.11	69	100
	Pouteria campechiana (Kunth) Baehni	Egg fruit	Wild	17	221	13.78	11	64.7
	Mimusops bagshawei S. Moore	Red coondoo	Wild	11	275	7.80	8	72.7

Table 6.2 Cont.

Caesalpinaceae	*Tamarindus indica* L.	Tamarind tree	Wild	11	209	6.53	-	-
	Detarium senegalense Gmel.	Tallow tree	Wild	13	195	6.80	4	20.7
	Detarium microcarpum Guill. & Perr	Tallow tree	Wild	18	252	8.08	-	-
Solanaceae	*Capsicum fructescens* L.	Chilli pepper	Cultivated	37	1665	20.00	9	24.3
	Capsicum anuum L.	green pepper	Cultivated	32	483	16.10	30	93.7
	Lycopercicon esculentum Miller	Tomato	Cultivated	54	378	21.0	45	83.3
	Solanum melongena L.	Egg plant	Cultivated	33	264	20.30	3	9.0
	Solanum aethiopicum L.	African egg plant	Cultivated	16	128	10.66	7	43.7
	Abelmoschus esculentus L.	Okra	Cultivated	18	162	10.80	1	5.5
	Lycium campanulatum E. Mey. Ex CH. Wr.	African boxthorn	Wild	24	576	6.54	3	12.5
Verbenaceae	*Vitex doniana* Oliv.	Black plum	Wild	29	872	21.80	-	-
Icacinaceae	*Icacina senegalensis* Juss.	Icacina, false yam	Wild	59	1003	25.07	59	100
Bignoniaceae	*Crecentia cujete* L.	Calabash tree	Wild	10	10	28.38	2	20.0
Boraginaceae	*Cordia myxa* L.	Sebasten plum	Wild	13	429	6.29	-	-
	Bourreria petiolaris (Lam.) Thulin	-	Wild	7	81	2.70	2	28.5
Meliaceae	*Trichilia emetica* Vahl.	Roka tree	Wild	8	83	3.18	-	-
Mimosoideae	*Parkia biglobosa* (Jacq.) R. Br. Ex G. Don.	Dawadawa	Wild	19	190	10.57	11	57.8
Averrhoaceae	*Averrhoa carambola* L.	Star fruit	Wild	15	135	4.50	4	26.6
Rosaceae	*Eriobotrya japonica* (Thunb.) Lindley	Loquat	Wild	14	350	5.90	6	42.8
	Malus domestica Borkh.	African apple	Wild	10	78	6.00	-	-
Flacourtiaceae	*Flacourtia indica* Burman. F.) Merr	Governor's plum	Wild	10	490	7.56	4	40.0
	Dovyalis caffra Hook. F. & Harv.	Wild apricot	Wild	9	81	6.75	2	22.2
Goodenaceae	*Scaevola plumeri* (L.) Vahl.	Beach naupaka	Wild	21	441	4.45	3	14.2

Table 6.2 Cont.

Rutaceae	*Fortunella margarita* (Thunb.) Swingle	Kumquat	Wild	15	225	8.03	10	66.6
	Vepris nobilis (Delile) Mziray	Teclea	Wild	8	328	6.83	-	-
Vitaceae	*Vitis vinifera* L.	Grape	Wild	12	300	3.70	-	-
Loganiaceae	*Strychnos spinosa* Lam.	Monkey ball	Wild	24	96	24.00	20	83.3
Euphobiaceae	*Drypetis natalensis* (Harv.) Hutch.	Stem fruit	Wild	16	192	7.38	7	43.7
	Jatropha curcus L.	Physic nut	Wild	23	690	7.84	-	-
	Antidesma venosum E. Mey. Ex Tul.	Lamb's tail	Wild	20	2200	5.55	-	-
Olacaceae	*Ximenia americana* L.	Albarillo	Wild	41	1025	14.50	41	100
Oleaceae	*Olea africana* (Mill.) P. Green	African olive	Wild	26	676	7.51	2	7.6
Opiliaceae	*Opilia amentacea* Roxb.	Opilia	Wild	23	713	8.38	2	8.6
Tiliaceae	*Grewia trichocarpa* Hochst ex A. Rich.	Cross-berry	Wild	11	583	5.83	2	18.1
TOTAL = 33	**80**			**1,777**	**36,283**	**1279.71**	**952**	**53.6**


Mango fruit fly, *Ceratitis cosyra* (Walker)


Ceratitis anonae (Graham)


Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann)


African invader fly, *Bactrocera invadens* (Drew, Tsuruta and White


Natal fruit fly, *Ceratitis rosa* (Karsch)


Melon fly, *Bactrocera cucurbitae* (Coquillet)

Plate 6.5: Tephritid species reared from fruit samples collected in nortern Ghana.

Pumpkin fruit fly, *Dacus bivittatus* (Bigot)

*Lesser pumpkin fly, *Dacus ciliatus* (Loew)

Jointed pumpkin fly, *Dacus vertebratus* (Bezzi)

**Trirhithrum nigerrimum* (Bezzi)

**New records in the study ecology.*

Plate 6.5 Cont.

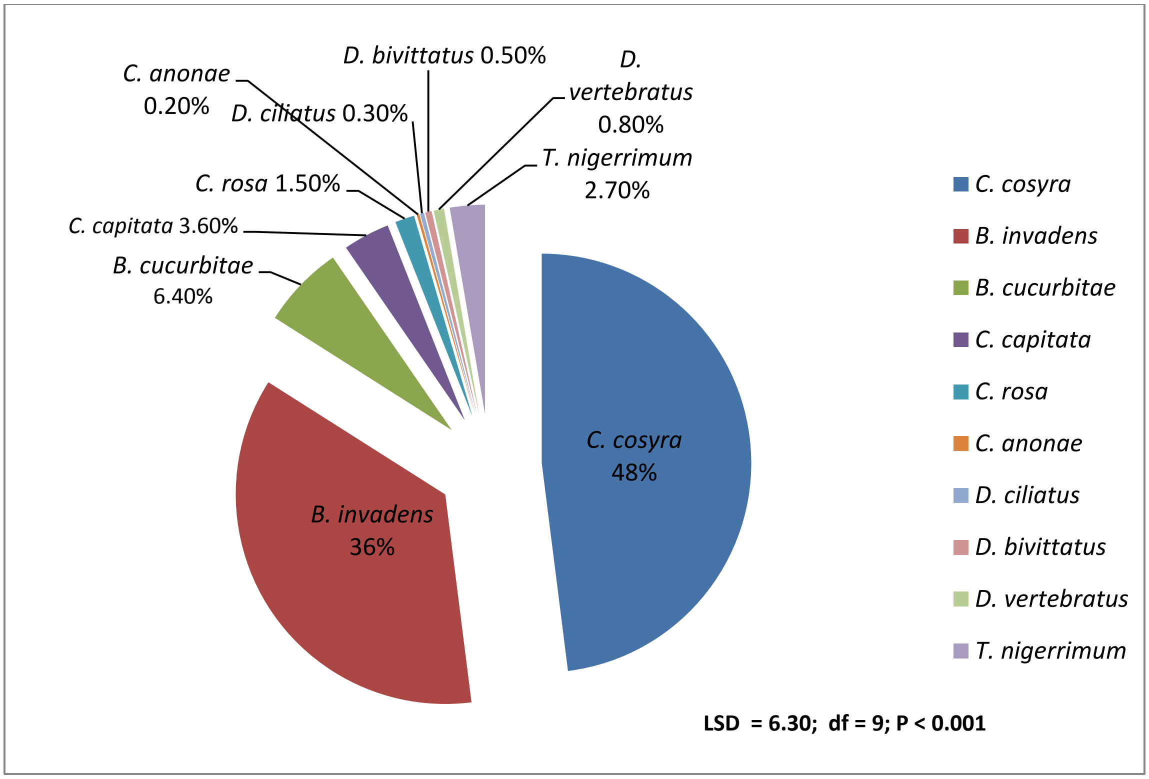

Figure 6.1: Tephritid species and their relative abundance in host fruits in northern Ghana.

6.3.2 Incidence and infestation indices

Among the tephritid-positive fruit species, an average of 36.9 puparia were recovered per fruit sample. Host species that recorded maximum puparia (above 50 puparia/sample) included mango, marula plum, sour sop, tropical almond, luffa, persimmon, syncomore fig, jujube, African peach, sheanut, green pepper, icacina and albarillo. Among these, jujube, sheanut, persimon, tropical almond and African peach proved to be the most heavily infested. Moreover, 7 plant species were found to be poor hosts to the fruit flies with each recording less than 3 puparia per sample (Table 6.3). Meanwhile, total number of puparia per 100 fruit was highest in luffa, followed by mango and African peach.

Table 6.3: Host plants of tephritid pests in northern Ghana and their infestation indices.

Plant species	Av. no. puparia /sample	No.puparia /100 fruit	No. puparia /kg fruit	No.flies /100 fruit	No. flies / kg fruit	Fruit fly species that emerged
Mangifera indica	87.2	1745.2	82.2	1576.5	78.6	*B. invadens, C. cosyra, C. capitata, C. rosa*
Anacardium occidentale	24.7	167.5	25.2	138.3	23.5	*B. invadens, C. cosyra, C. capitata*
Spondias mombin	46.0	109.6	4.9	89.6	4.0	*C. cosyra, C. capitata*
Harpephyllum caffrum	28.0	80.1	43.9	68.0	39.6	*C. cosyra*
Haematostaphis barteri *	24.0	79.9	17.6	65.5	15.9	*B. invadens, C. cosyra*
Lannea acida	1.5	2.0	2.8	2.0	2.3	*T. nigerrimum*
Sclerocarya birrea	126.0	572.7	109.5	509.6	99.9	*B. invadens, C. cosyra*
Annona senegalensis	98.1	799.9	72.1	655.9	69.9	*B. invadens, C. cosyra*
Annona muricata	33.3	171.4	32.2	140.5	29.7	*B. invadens*
Annona squamosa	27.6	166.2	38.3	136.2	34.0	*B. invadens*
Artabotrys monteiroae *	16.3	148.2	13.4	121.6	12.0	*B. invadens*
Saba senegalensis	21.6	309.1	21.6	253.3	19.9	*B. invadens*
Saba comorensis *	12.8	214.8	12.8	175.4	11.2	*B. invadens*
Thevetia peruviana	16.7	46.4	16.2	37.7	14.9	*C. cosyra, T. nigerrimum*
Carica papaya	3.9	390.9	3.9	319.9	3.3	*B. invadens, D. bivittatus*
Terminalia catapa	132.2	529.0	190.8	513.7	185.9	*B. invadens, C. cosyra, C. capitata*
Citrulus lunatus	31.5	1942.3	50.9	1592.4	50.0	*B. invadens, C. cucurbitae, D. bivittatus*
Citrulus sativus	9.7	325.2	9.7	266.5	9.5	*B. invadens, B. cucurbitae, D. bivittatus*
Citrulus colocynthis	7.0	350.0	6.8	287.0	6.6	*B. cucurbitae, D. ciliatus , D. vertebratus*
Cucurbita maxima	2.5	258.8	5.1	211.5	4.8	*D. vertebratus, D. ciliatus, D. bivittatus*
Cucurbita pepo	3.0	300.0	1.9	246	1.6	*B. cucurbitae, D. ciliatus, vertebratus*
Leganaria siceraria	3.2	327.2	2.0	268	2.0	*B. invadens, B. cucurbitae, ciliatus*

Table 6.3 Cont.

Luffa cylindrica	66.5	6650.0	55.1	501.6	54.8	*B. invadens, D. vertebratus, D. bivittatus*
Luffa acutangula *	3.0	290.0	1.7	237.8	1.6	*B. invadens, D. ciliatus, D. vertebratus*
Diospyros mespiliformis	134.9	611.1	138.9	501.0	126.5	*B. invadens, C. cosyra, C. rosa*
Ivingia gabonensis	13.0	260.0	11.1	213.2	9.9	*B. invadens, C. cosyra*
*Ficus syncomosus**	105.4	619.9	129.8	507.5	125.5	*B. invadens, C. cosyra, C. anonae*
Ficus asperifolia	22.7	71.0	22.0	58.2	20.9	*C. cosyra, C. anonae*
Ficus sur	13.6	80.2	21.1	69.9	19.9	*C. anonae, C. rosa*
Ficus recemosa	33.4	133.7	30.4	109.0	28.8	*C. cosyra, C. anonae*
Artocarpus altilis *	10.4	86.8	29.5	80.4	27.8	*B. invadens*
Psidium guajava	30.8	193.0	37.0	158.2	36.0	*B. invadens, C. cosyra, C. cosyra*
Syzigium cumini	37.5	117.1	41.6	95.9	39.8	*B. invadens, C. cosyra, C. capitata*
Feijoa sellowiana	17.4	102.3	37.8	83.6	35.9	*B. invadens, C. cosyra*
Ziziphus mauritiana	4.8	10.8	10.6	10.2	9.8	*C. cosyra, C. Rosa*
Ziziphus mucronata *	253.8	528.9	174.7	500.5	168.9	*B. invadens, C. capitata*
Sarcocepholus latifolium	120	1499.9	228.4	1229.1	215.9	*C. cosyra, C. Rosa*
Blighia sapida	9.6	120.2	15.6	98.4	12.9	*C. cosyra, T. nigerrimum*
Vitellaria paradoxa	136.0	800.0	208.0	656.0	199.6	*B. invadens, C. cosyra, C. capitata*
*Pouteria campechiana**	26.0	200.0	32.2	164.0	39.8	*B. invadens*
Mimusops bagshawei	31.8	127.2	44.8	104.1	42.7	*C. cosyra, C. capitata*
Detarium senegalense	2.9	21.0	6.0	17.2	6.0	*T. nigerrimum*
Capsicum fructescens	19.1	42.6	35.5	34.4	33.6	*C. cosyra*
Capsicum anuum	78.5	520.7	156.2	501.4	148.8	*B. invadens, C. cosyra*
Lycopercicon esculentum	21.5	204.5	32.6	151.0	48.7	*B. invadens, C. cosyra*
Solanum melongena *	7.6	95.8	12.4	77.9	11.9	*B. invadens, C. cosyra*
Solanum aethiopicum	12.6	158.5	19.1	129.6	18.7	*B. invadens*
Abelmoschus esculentus	1.7	19.1	2.8	18.2	2.7	*B. invadens*
Lycium campanulatum	12.9	53.8	47.6	45.0	46.6	*C. cosyra*

Table 6.3 Cont.

Icacina senegalensis	103.5	608.9	244.3	548.5	220.9	*B. invadens, C. cosyra, C. rosa, C. anonae*
Crecentia cujete *	2.8	440.0	1.5	360.8	1.5	*B. invadens*
Bourreria petiolaris	13.2	144.4	34.4	119.9	33.0	*C. cosyra, C. capitata*
Parkia biglobosa *	20.6	206.3	37.3	199.5	35.0	*B. invadens*
Averrhoa carambola	7.2	80.7	24.2	73.0	23.5	*B. invadens, C. cosyra*
Eriobotrya japonica	20.5	82.0	48.6	79.0	46.1	*C. cosyra*
Flacourtia indica	12.9	26.3	17.2	24.9	16.8	*C. cosyra*
Dovyalis caffra	10.7	119.7	14.4	100.0	13.9	*C. rosa, C. Anonae*
Scaevola plumeri	3.0	12.2	12.2	12.0	11.9	*C. cosyra*
Fortunella margarita	14.0	93.7	26.3	89.0	24.9	*C. cosyra, T. nigerrimum*
Strychnos spinosa	17.5	437.5	17.5	358.3	15.8	*B. cucurbitae*
Drypetis natalensis	12.3	102.6	26.9	96.7	24.0	*C. cosyra*
Ximenia americana	146.3	585.4	413.8	507.8	201.4	*B. invadens, C. cosyra*
Olea africana	1.4	5.6	5.0	5.3	5.0	*T. nigerrimum*
Opilia amentacea *	2.5	8.2	7.1	8.0	7.0	*B. invadens*
Grewia trichocarpa	6.8	12.8	12.8	12.0	11.8	*C. cosyra, T. nigerrimum*

**New hosts to Bactrocera invadens (some samples were infested by more than one fruit fly species, hence the sum of the individual positive samples can be higher than the total of positive samples in general). Records of new hosts were based on comparison with records from Ekesi and Billah, 2006 Vayssieres et al., 2009, Mwatawala et al., 2009a and Georgen et al., 2011.*

The African grape *(Lannia acida*) recorded the lowest puparia per 100 fruit. Also, total number of puparia per kg fruit ranged from 413.8 in albarillo to 1.5 in calabash tree. Other host species recording maximum puparia in fruit weight basis (> 50 puparia/kg) were: icacina, African peach, sheanut, tropical almond, jujube, green pepper, persimon, syncomore fig, marula plum and mango.

Adult fly emergence was found to follow similar trend as in the case of puparia recovered even though some levels of pupal mortality could be observed among the samples. *Ceratitis cosyra* and *B. invadens* were the most abundant and polyphagous fruit fly species in the area, emerging from fruits of most plant families and species. Generally, *B. invadens* was more dominant in the cultivated fruits while *C. cosyra* dominated the fly species among the wild fruits. A total of 19 plant species acted as hosts to both *B. invadens* and *C. cosyra*. Also, 11 plant species were hosts to *B. invadens* only whereas 7 species were hosts to *C. cosyra* only. All species of *Dacus* and *B. cucurbitae* were reared from the cucurbits. Moreover, *C. capitata* emerged mainly from mango, cashew, tropical almond, jambolan, jujube, and sheanut. *Ceratitis rosa* also emerged from mango, as well as persimon, cluster fig, buffalo thorn, African peach, icacina and wild apricot, while *C. anonae* emerged from syncomore fig, sand paper tree, cluster fig, icacina and wild aprocot. *Trirhithrum nigerrimum* was reared from African grape, yellow oleander, akee apple, tallow, kumquat, opilia and cross-berry. In many situations, two or more species of fruit flies were found to co-emerge from the same fruit sample. In effect, co-existence of *Ceratitis* and *Bactrocera* species was particularly a common observation among fruit samples obtained from Annonaceae, Apocynaceae, Ebenaceae, Myrtaceae and Solanaceae.

Figure 6.2 shows the average infestation levels of the 10 fruit fly species recorded in the different host plants in relation to the study regions. The results showed significant variations in the levels of infestation of the fruit flies (LSD = 29.7; df = 9; P-value < 0.001). In all the regions, the highest level of infestation was recorded for the 2 most abundant fruit fly species namely, *C. cosyra* and *B. invadens*, with significant difference between them. Infestation levels among the minor fruit fly species was relatively very low with no significant variations (p < 0.10) eventhough *B. cucurbitae* was the most serious infestor of this group.

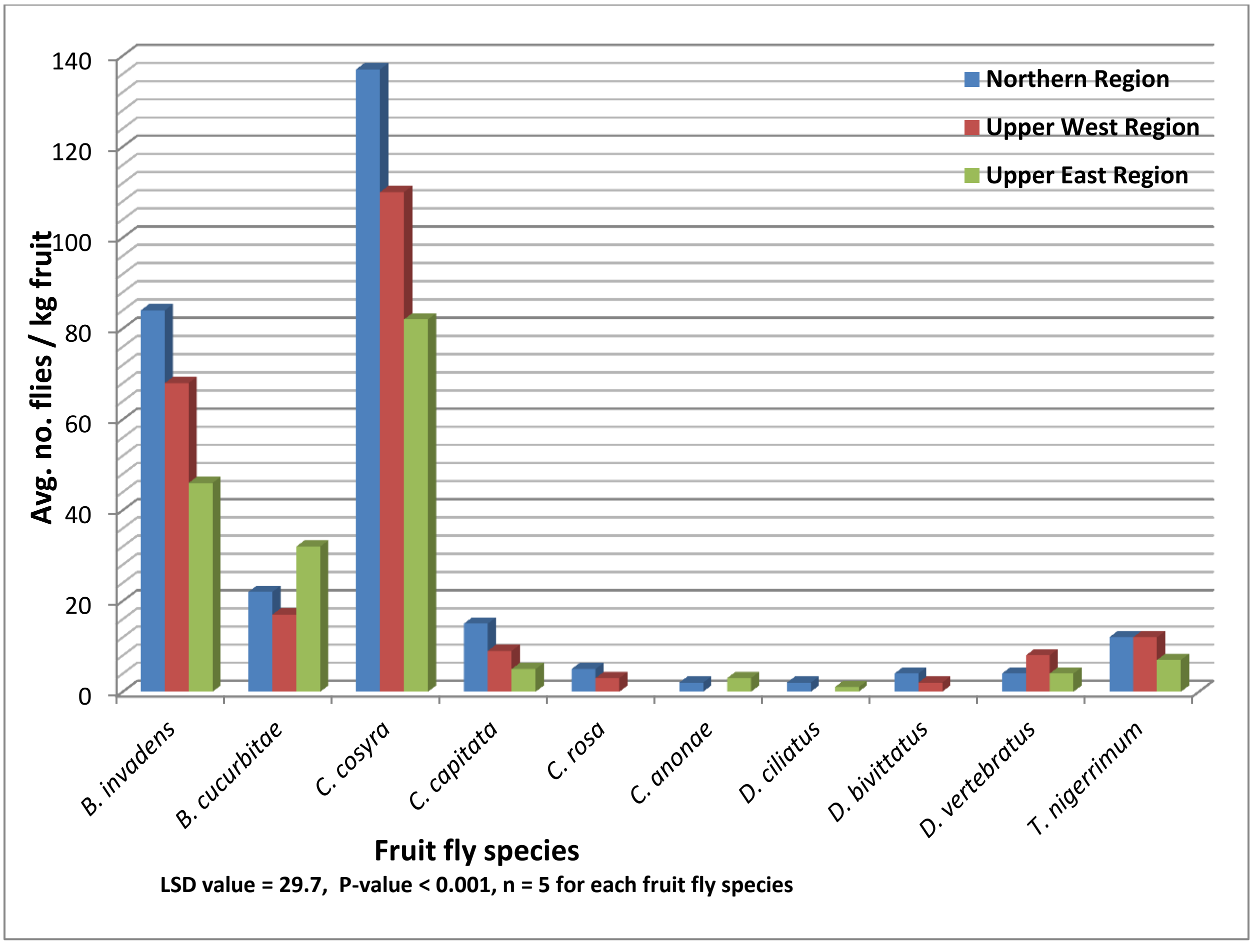

Figure 6.2: Infestation indices (number of flies per kg fruit) of each of the fruit fly species recorded in the host plant species (pooled data) in relation to the study regions

Moreover, some species of *Ceratitis* (eg *C. rosa* and *C. anonae*) and *Dacus* (eg., *D. ciliatus* and *D. bivittatus*) were not recorded in fruit samples from the Upper West and Upper East regions. In general, fruit samples from the Northern Region recorded the highest level of infestation for most of the fruit fly species compared to the other regions. This was however with the exception of *B. cucurbitae* whose infestation level was highest in the Upper East region as was recorded mainly in samples of Cucurbitaceae.

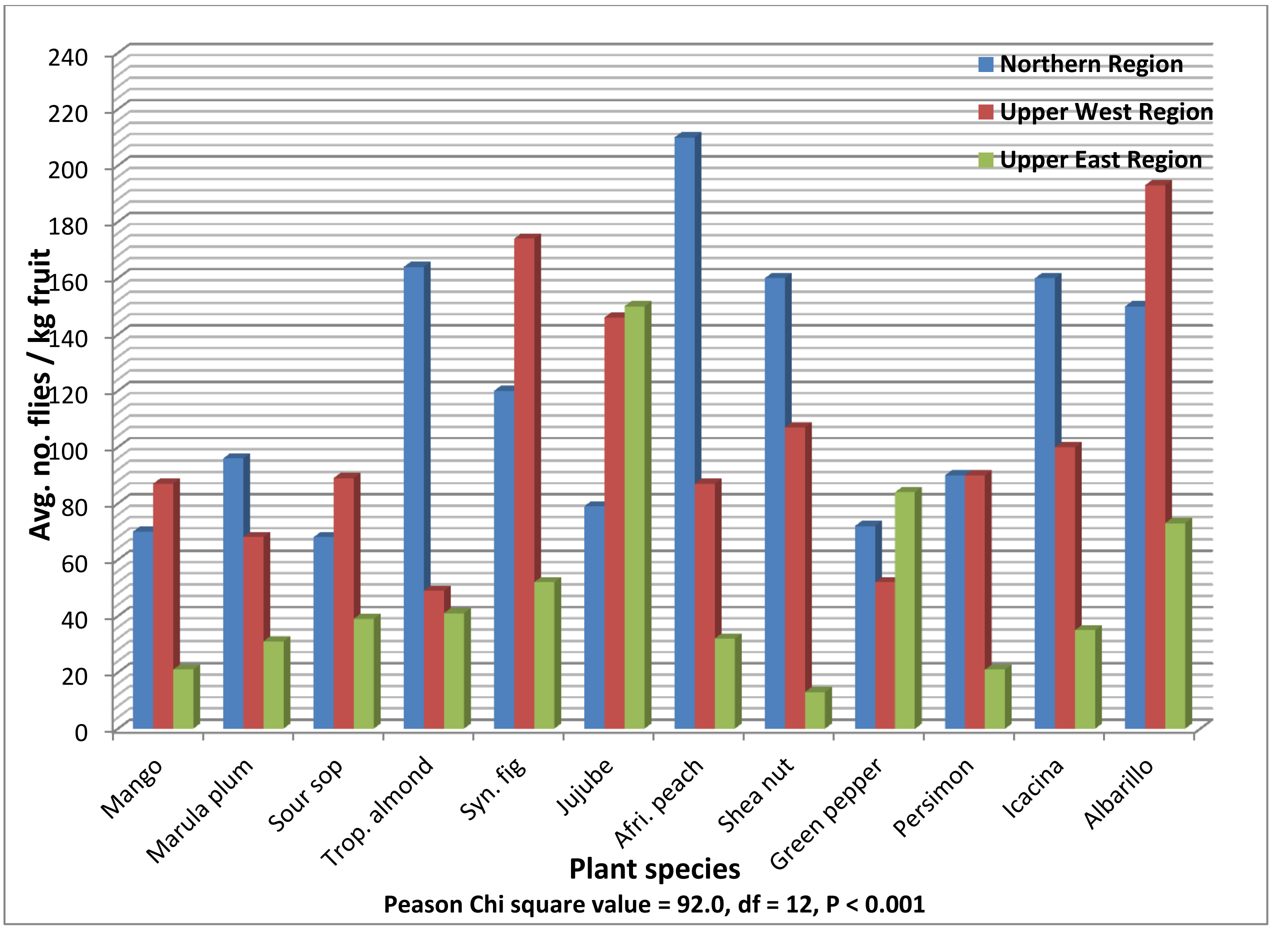

Figure 6.3: Infestation indices (number of flies per kg fruit) of the 12 most attacked plant species by the fruit fly species (pooled data) in relation to the study regions.

As shown in Figure 6.3, the 12 main reservior plants were analyzed separately for their infestations by the fruit fly species. Infestation levels differed significantly among the various host plants in the study regions (Chi square value = 92, p < 0.001). In the Northern region, host plants such as marula plum, tropical almond, African peach, shea nut and icacina recorded the heaviest tephritid infestation. In the Upper West Region, fruit fly infestation was highest in mango, sour sop, syncomore fig, and albarillo, whereas in the Upper East Region the highest fruit fly infestation was recorded in Jujube and green pepper.

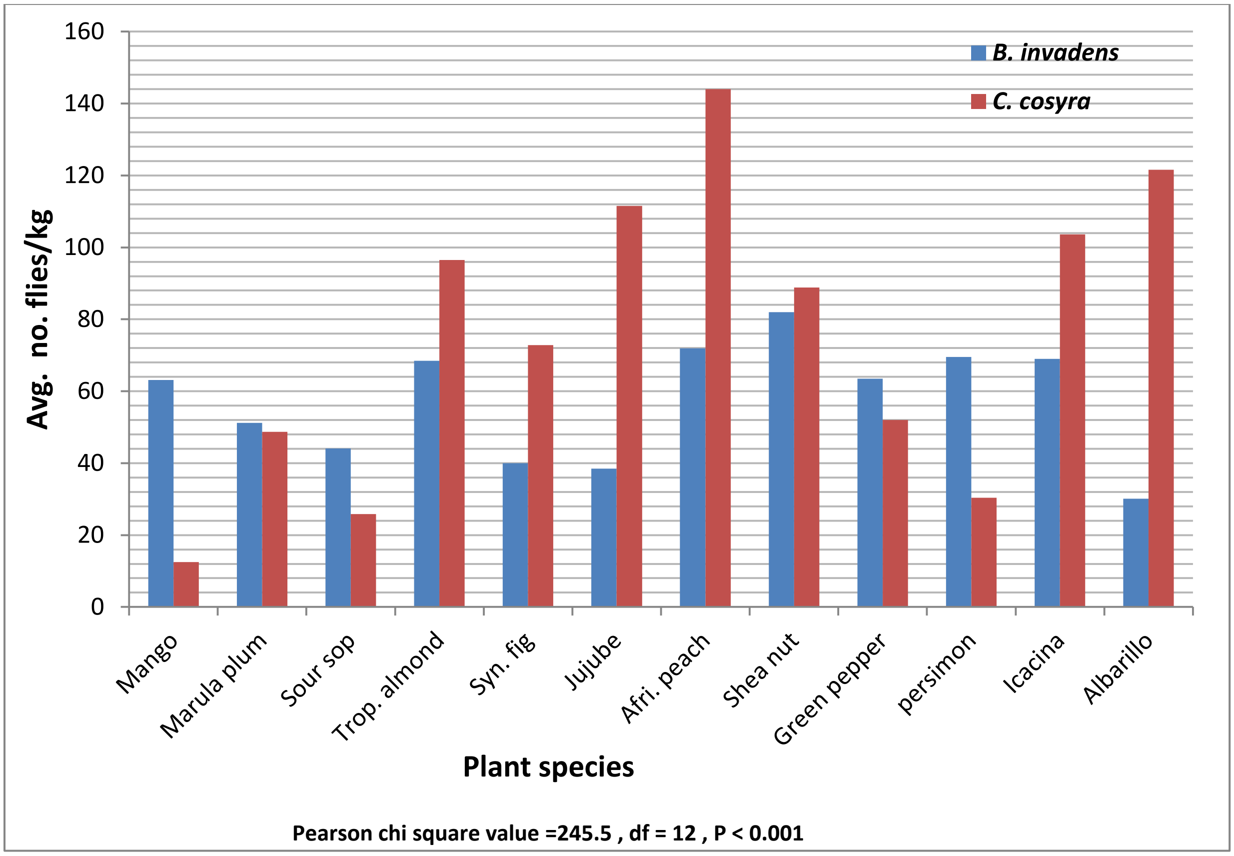

Figure 6.4: Average infestation index of the 12 most attacked plant species by the 2 major fruit fly species (*B. invadens* and *C. cosyra*).

Considering the infestation levels of the 12 most attacked plant species by the 2 major species of fruit fly, the results showed that *B. invadens* was the main infestor in reservoirs hosts such as mango, marula plum, sour sop, green pepper and persimon whereas *C. cosyra* dominated the rest of the host species. The infestation levels of each species of fruit fly were not uniform across host plants, i.e. there was a relationship between fruit fly species and host plants. With particular reference to *B. invadens*, despite being polyphagous and showing high infestation for some crops, not all potential hosts appeared to be equally vulnerable to infestation by this species. In general, however, cultivated host species such as mango and green pepper recorded higher infestation levels for this pest than for *C. cosyra* but the vice versa was observed among most of the wild reservoir hosts (Figure 6.4).

6.4 DISCUSSION

The results of this study have demonstrated that the widespread availability of host plants in the savanna ecology of Ghana provides suitable reserviors for the high diversity of tephritid species resulting in their significant impact on fruit crop production. Eleven wild fruit species were reported as new hosts to *B. invadens* in Africa. Also, two fruit fly species namely, *D. ciliatus* (Loew) and *T. nigerrimum* (Bezzi) were identified for the first time in northern Ghana. In terms of positive hosts, abundance and infestation levels, *C. cosyra* and *B. invadens* were the most dominant and polyphagous fruit fly species in the study area. The dominance of these two species in the area has earlier been reported in a trapping experiment on mango by Billah (2012) and Nboyine *et al*. (2012). According to Mwatawala *et al*. (2009a), *C. cosyra* is a widespread species found throughout the African continent. It is a polyphagous pest, attacking over 30 different fruit species. Before 2006, it was considered the main fruit fly found in mangoes, accounting for the major losses in production (De Meyer *et al*., 2002, Mwatawala *et al*., 2006a).

In these results, most wild host species constituted favourable reservious for *C. cosyra* whereas the major commercial or economic crops were found to show high incidence for *B. invadens*. This host eclosion behaviour could be an indication of the competitive displacement of *C. cosyra* from its major hosts by the invasive *B. invadens*. According to Ekesi *et al*. (2009), before the arrival of *B. invadens*, the indigenous species *C. cosyra* was the predominant fruit fly pest of mango but within four years of invasion, *B. invadens* had displaced *C. cosyra* and had become the predominant fruit fly pest of mango and marula in the Nguruman province of Kenya. Duyck *et al.* (2006a, b) observed that exploitative competition through larval scrambling for resources and interference competition through aggressive behaviors of the invader are important mechanisms contributing to the displacement of *C. cosyra* by *B. invadens* in fruit agroecosystems.

In general, most species of Cucurbitaceae did not constitute a favourable host for *B. invadens*. The fly seemed to prefer hosts from Anacardiaceae, Annonaceae, Apocynaceae Myrtaceae and Solanaceae. In a similar study by Mwatawala *et al*. (2009a), the number of positive *B. invadens* plants was relatively lower among the cucurbits. Mwatawala *et al*. (2006a) and Goergen *et al*. (2011) recorded *B. invadens* in eight different cucurbit species but observed that the fly occasionally utilizes the plants with relatively lower infestation rate. In northern Ghana which covered a wider spectrum of potential host fruit, this study identified several other plant families including representatives of Anacardiaceae, Annonaceae, Apocynaceae, Rhamnaceae, Bignoniaceae, Mimosoideae, Moraceae, Cucurbitaceae, Sapotaceae, Solanaceae and Opiliaceae as new hosts for *B. invadens* compared with existing records in Africa (Ekesi and Billah, 2006; Mwatawala *et al*., 2009b; Goergen *et al*., 2011). Studies have shown that *B. invadens* possess some characteristics of both k-strategy (i.e. very aggressive, adaptation to new environments, strong competitor) (Rwomushana *et al.*, 2008) and some traits of r-strategy of being highly fecund (Ekesi *et al*. 2006). These traits contribute to the polyphagous nature of the pest. Moreover, niche overlap among *B. invadens* and other aggressive and destructive frugivorous tephritid species was observed in some commercial and wild host plants. The ability of *B. invadens* to co-exist with highly aggressive invasive species (such as *B. cucurbitae*) as well as major indigenous pests (such as *C. cosyra*, *C. capitata* and *Dacus* spp.) could be of ecological interest. Apparently, this polyphagous and versatile behavior of the fly may contribute to its ability to establish in niches less utilized by other frugivorous tephritids and therefore facilitating its spread and exacerbating its damage and losses to horticulture industry in the region.

In Kenya, Rwomushana *et al.* (2008), reported 14 cultivated and wild fruit species as hosts of *B. invadens*. Among the cultivated fruit that were found to be heavily infested were mango (Anacardiaceae); banana (Musaceae); and oranges (Rutaceae). Marula and tropical almond (Combretaceae) were the most preferred among the wild host plants. In Tanzania, Geurts *et al*. (2012) in a study along attitudinal gradients, added several host plant species to the list, most important of which is avocado *Persea americana* (Lauraceae). Other plants found to be infested with *B. invadens* in Tanzania were in the family Cucurbitaceae (watermelon, cucumber, pumpkin, kumquat), Rutaceae (pomelo, grape fruit), Rosaceae (peach, loquat), Rubiaceae (robusta coffee) and Flacourtiaceae (governor's plum) (Geurts *et al*., 2012). In the present study, a total of 12 plant species from 9 different families were recorded as potentially new hosts for *B. invadens*. The study also established that in addition to mango, sweet pepper and tomato were the most preferred among the commercial hosts. In Benin, *B. invadens* has also been reared from citrus, cashew, papaya, guava and several wild host plants (Goergen *et al.*, 2011).

The study also indicated that in terms of diversity, relative abundance and infestation levels of the tephritid species, the Northern region generally proved to be the most favourable reserviour.

According to Piedra and Zuniga (1993), the degree of species dominance is influenced by ecological background (i.e. host plant species richness and diversity) and by altitudinal gradients. The Northern region is predominantly Guinea savanna ecology whereas the Upper West and Upper East regions, are predominantly Sudan savanna and partly Sahel savanna, respectively. These Upper regions of the country are of relatively higher altitudes (Table 6.1) and thus may not constitute favourable ecological niches for the major host and fruit fly species. Geurts *et al.* (2012) observed a spatial increase in diversity and population density of tephritid species along lower elevations (below 581 m) in the Morogoro mountains of Tanzania and concluded that host availability and climatic differences were the determining factors for explaining variations in tephritid occurrence and abundance in time and space.

Among the minor fruit fly species, *D. ciliatus* and *T. nigerrimum* were reared as first record in the ecology. *Bactrocera cucurbitae,* another invasive species of Asian origin, is known to mainly attack representatives of the family Cucurbitaceae although polyphagy is reported in some areas of Asia and the Pacific (White and Elson-Harris, 1992; White, 2006). All records by White (2006) were from cultivated cucurbits. In the present study, *B. cucurbitae* infested five species of Cucurbitaceae, usually with much higher infestation rates than any of the other minor fruit flies. Moreover, *C. capitata,* the most polyphagous species within the genus *Ceratitis* (White and Elson- Harris, 1992) and one of the most polyphagous fruit fly species worldwide (De Meyer *et al*., 2002) was reared in 9 host plants. Even though this fly showed limited host range in this records, it has recently been reported from a wide variety (55 species) of indigenous host plants in Kenya (Copeland *et al*., 2002) where it showed larger host spectrum than other fruit fly pests, including *C. cosyra* and *C. rosa* (Copeland *et al*., 2006). However, the host range of *C. rosa* in this study was more diverse than *C. capitata*. So far, *C. rosa* has been reared from close to 100 hosts, belonging to 30 plant families (De Meyer *et al*., 2002; Geurts *et al.*, 2012). Although *C. capitata* is often considered the most harmful fruit fly with an African origin (De Meyer *et al*., 2002b) but spread over five continents and close to 400 host plants (Liquido *et al*., 1998; De Meyer *et al*., 2002), its presence in the savanna ecology of Ghana seems to be limited, based on the incubation results. Whether this is due to environmental factors unfavorable to the establishment of this species or a recent phenomenon due to displacement by other polyphagous species, needs to be assessed. Comparing the impact and host range so far, it appeared that widespread native pests, such as the Medfly now seems to be restricted to a more limited commercial host range in areas where it co-occurs with *B. invadens*.

The pumpkin fly, *D. bivittatus*, one of the most common and widespread species of the genus *Dacus*, has been reported in cucurbits in 28 African countries (White, 2006). The lesser pumpkin fly, *D. ciliatus* is a widespread species also found throughout the African continent (White and Elson-Harris, 1992). It attacks a wide variety of cucurbit fruits such as cucumber, pumpkin and *Momordica* spp, but there are also some records from non-cucurbit hosts such as tomato or beans that need confirmation (White and Elson-Harris, 1992). The melon fly, *D. bivittatus*, also a known pest of cucurbits, is found throughout Africa and the Middle East. According White and Elson-Harris (1992), this species differs from *D. ciliatus* in usually having the laterotergal xanthine across the anatergite as well as katatergite, which was the case in these present collections. *Trirhithrum nigerrimum* is known to mainly attack berries, but its infestation does not seem to have a detrimental effect on fruit production in many areas of its occurrence in Africa (White, 2006). Its taxonomic position and confusion with other *Trirhithrum* species such as *T*. *coffeae* Bezzi and *T*. *inscriptum* (Graham) have only recently been clarified (White, 2006). All these species were present in very low numbers in this incubation results. In conclusion, the widespread availability of host plants and the incidence of diverse fruit fly species call for particular attention to their impact on commercial fruits and development of sustainable management strategies against the economically important fruit fly pests in the region.

CHAPTER SEVEN

7.0 SEASONAL PHENOLOGY OF *BACTROCERA INVADENS* (DREW, TSURUTA AND WHITE) AND *CERATITIS COSYRA* (WALKER) (DIPTERA: TEPHRITIDAE) IN NORTHERN GHANA

7.1 INTRODUCTION

Plant susceptibility to insects depends on the phenological synchrony between the insect and the host plant (Harrington *et al*., 1999). In turn, a suitable plant for the development of insect populations can often escape herbivory infestation and damage by its occurrence in time and space (Fahrig, 2003; Klapwijk and Lewis, 2008). This might be because the seasonal pattern of the insect may not coincide with the plant susceptible stage or period of occurrence (Messina and Jones, 1990). Knowledge about fruit fly species and their respective seasons of occurrence in relation to host plant phenology is crucial to understanding the population dynamics of these economically important insects (Souza-Filho *et al.*, 2009). According to Messina and Jones (1990), fruit infestation by tephritid pests is influenced by its degree of maturation during the fruit fly oviposition period. Foraging differences can be observed as fruit flies make incursions into fruits of certain developmental stage. According to Dias and Vásquez (1993), such information can be obtained by collecting and incubating host fruits throughout their development or maturation periods. Papadopoulos *et al.* (2001) noted that in the tropics, the phenology and abundance of fruit flies is determined by environmental temperature, rainfall, relative humidity, and host fruit availability. These environmental variables show annual fluctuations within optimum levels and are therefore, much of limiting factors in population establishment and persistence of tephritid species (Lv *et al*., 2008).

The African invader fly, *B. invadens* and the mango fruit fly, *C. cosyra* have been considered the most economically important fruit fly pests in sub-saharan Africa (Lux *et al*., 2003; Ekesi, 2006) owing to their quarantine status and losses recorded in fruit and vegetable crops (STDF, 2009). The seasonal occurrence of these pests in relation to host phenology and abiotic factors in the sub-region is yet to be fully optimized. In fact, only few studies in Africa have examined the effect of host fruit and weather variability on population fluctuations of *B. invadens* and *C. cosyra* (Mwatawala *et al.*, 2009a; Vayssieres *et al.*, 2009c; N'diaye *et al*., 2012). N'diaye *et al.* (2012) found that the dynamics of emergence of tephritid species in mango orchards in the Niayes and the Thies Plateau of Senegal fluctuated in response to the occurrence and ripening periods of the main host plants. Fruit fly populations outside mango season was sustained at various levels by the diversity of fruit trees, changes in weather factors, lack of pest control and poor orchard care. Vayssieres *et al*. (2009c) in a correlation study of fruit fly infestation of major mango cultivars reported that temperature, relative humidity and rainfall were the major factors influencing fruit fly populations in the savanna ecology of Benin. Mwatawala *et al.* (2009a) observed that widespread variability and abundance of fruit species in certain localities of central Tanzania ensured year-round breeding of the African invader fly, *B. invadens*, with different seasonal population levels. They noted that a clear understanding of the occurrence periods of the different potential hosts available in a given area and their influence on fruit fly population patterns is necessary for the development of a sustainable IPM program.

At present, no known studies have been conducted in Ghana to monitor the seasonal occurrence and phenological patterns of these species through the host fruit collection and incubation approach. Preliminary trapping by Billah (2012), Wih and Billah (2012) and Nboyine *et al.,* (2013) in the Guinea savanna ecology of Ghana revealed the presence of high populations of *B. invadens* and *C. cosyra* in mango orchards. Updated reports have confirmed that *B. invadens* and *C. cosyra* still remain the most dominant and damaging fruit fly species in both cultivated and wild fruit crops in northern Ghana (B. K. Badii, Unpubl. data). It was imperative to obtain baseline data on the seasonal occurrence pattern of fruit flies and the influence of host phenology and abiotic factors on the activity of these pests in the ecology. This would be helpful in developing and implementing management programmes for tephritid pests in the country. The present study determined the seasonal pattern of occurrence of *B. invadens* and *C. cosyra* as affected by availability of major hosts and abiotic parameters in the northern savanna ecology of Ghana. The primary goals were to monitor the seasonality of the pests, and establish the importance of the different host fruits for population development in relation to temperature, rainfall and relative humidity.

7.2.0 MATERIALS AND METHODS

7.2.1 Fruit collection and processing

To determine the seasonal phenology of *B. invadens* and *C. cosyra* in the savanna ecology of Ghana, fruit samples were collected from predetermined host plants in the area. Collections were made from multiple sites between October, 2011 and September, 2013. The sampling localities indicated in Table 6.1 were used for the study. Fruit species included in the study were those that proved to be the main hosts of *B. invadens* and *C. cosyra* based on previous survey records in the area (B. K. Badii, Unpubl. data). Details of the selected fruit species sampled for the study are shown in Table 7.1. Fruit samples were taken based on their availability in the sampling localities. Ripe, semi-ripe and mature fruits as well as fruits from underground as windfalls or senescence were collected.

The number of fruits in a sample varied according to the species and their on-site abundance. Fruit samples were packed in plastic bags and labeled according to the protocol of Copeland *et al*. (2002).

These were then transported to the laboratory for processing. In the laboratory, the fruit samples were kept in individual rearing containers and provided with appropriate medium for pupation. The puparia recovered were handled based on the procedure of Mwatawala *et al*. (2009a) for adult emergence. Emerged adults were monitored following the procedure described by White and Elson-Harris (1992) and N'diaye *et al*. (2012). Details of the fruit collection, processing and fly handling procedures are described in Chapter six.

7.2.2 Meteorological data

Meteorological data on mean monthly precipitation, air temperature and relative humidity for the study period were obtained from the various Meteorological Units under the Savanna Agricultural Research Institute (SARI), Ghana. The meteorological stations for the Guinea savanna, Sudan savanna and Sahel savanna zones were located in Nyankpala (Northern Region), Wa (Upper West Region) and Manga (Upper East Region), respectively.

Table 7.1: List of the studied fruit species indicating their habitats and sample details.

Fruit species	Common name	Habitat	Total no. samples
Mangifera indica L.	Mango	Cultivated	53
Sclerocarya birrea A. Rich.	Marula plum	Wild	19
Annona senegalensis Pers.	Sour sop	Wild	30
Terminalia catapa L.	Tropical almond	Wild	53
Diospyros mespiliformis A. DC.	Persimon	Wild	38
Ficus syncomosus L.	Syncomore fig	Wild	25
Ziziphus mucronata Willd.	Jujube	Wild	19
Sarcocepholus latifolium Smith. Bruce	African peach	Wild	71
Vitellaria paradoxa C.F. Gaertn	Sheanut	Wild	69
Capsicum anuum L.	Green pepper	Cultivated	32
Icacina senegalensis Juss.	Icacina, false yam	Wild	59
Ximenia americana L.	Albarillo	Wild	41

7.2.3 Data analysis

Fruit infestation data were processed using Microsoft Excel and XL Stat for the analysis of variance and mean comparisons. Infestation level (number of flies per unit weight of fruit) was determined according to the procedures given by Copeland *et al*. (2002). The ANOVAs for fruit species in relation to emergence of *B. invadens* and *C. cosyra* took particular account of various sampling seasons (months) and the weather parameters (precipitation, air temperature and relative humidity). Relationship between fly emergence and weather variables was tested using multiple linear regression analysis following the procedure of Yonow *et al*. (2004) to look at the changes in fruit fly abundance across host fruits, seasons and climatic factors.

7.3 RESULTS

7.3.1 Host infestations

The infestation data for the 12 main host reservoirs of *B. invadens* and *C. cosyra* recorded in the study indicated that infestation level varied significantly with type of fruit ($P < 0.001$). Mean number of *B. invadens* per kg fruit was highest in sheanut, followed by African peach, tropical almond, persimmon, icacina and mango. Albarillo and jujube recorded the lowest infestation for *B. invadens* while the rest of the fruit species recorded moderate infestations with significant variations among them. On the other hand, mean number of *C. cosyra* was highest in African peach, followed by albarillo, jujube and icacina with significant differences among them. Mango and sour sop recorded the lowest number of *C. cosyra* per unit weight of fruit. It general, fruit species that suffered heavy infestation by *C. cosyra* were slightly infested by *B. invadens*, and vice versa (Table 7.2).

Table 7.2: Infestation data for the main hosts of *B. invadens* and *C. cosyra* in northern Ghana.

Fruit species	Avg. no. fruits /sample	No. *B. invadens*/kg fruit	No. *C. cosyra*/kg fruit
Mango	4.0	60.1 ± 3.0 d	11.5 ± 1.7 a
Marula plum	25.5	51.3 ± 2.8 c	47.7 ± 3.0 d
Soursop	19.8	45.2 ± 3.1 b	24.2 ± 2.6 b
Tropical almond	30.6	65.5 ± 4.4 e	85.4 ± 10.0 f
Persimmon	59.4	65.0 ± 6.8 e	36.3 ± 2.9.1 c
Syncomore fig	35.0	42.5 ± 1.4 b	72.4 ± 7.2 e
Jujube	177.5	37.4 ± 2.0 a	122.0 ± 11.1 h
African peach	18.5	70.7 ± 9.6 f	143.0 ± 19.0 i
Shea nut	23.7	80.1± 11.0 g	90.6 ± 12.1 f
Green pepper	20.7	47.8 ± 2.4 bc	32.4 ± 2.7 c
Icacina	35.5	64.4 ± 4.4 e	111.7 ± 15.8 g
Albarillo	167.0	35.6 ± 2.0 a	128.8 ± 12.0 h

Means with same letters within columns are not significantly different at p = 0.05

7.3.2 Seasonal fluctuations

Suitable hosts were available throughout the year for both *B. invadens* and *C. cosyra*. Figure 7.1 shows the seasonal trends of occurrence and infestation levels of the 12 main host species recorded in the area. Green peppers were available during both dry and wet seasons under irrigated and rainfed conditions. During the major dry season (December-March), persimmons and syncomore figs dominated the wild fruit flora with infestation peak reaching 200 flies per kg fruit. During the early dry season (April-June), the host flora was succeeded by both cultivated and wild species dominated by mango, icacina, albarillo, marula plum, tropical almond and sheanut. The peak infestation of these species occured in alternation over the months with each fruit species recording not less than 100 flies per kg fruit at the peak fruiting period. The mango season stretched from mid March to early July with peak infestation in April and June for the early and late season mangoes, respectively. These fruit species were widely distributed in the ecology, providing fertile breeding grounds for the resurgence of both *B. invadens* and *C. cosyra*. Moreover, the occurrence of other wild fruits such as syncomore figs and sour sops generally overlaped the early rainy season, serving as important survival niches especially through the prolonged spells in parts of May and June.

The mid season period, which stretched from July to September, was dominated by tropical almonds, peaches and sour sops, with some patches of late mangoes, sheanut and albarillos. Tropical almonds and peaches appeared to be the major reservoir hosts for the flies during this period. The major peach season began in August and extends through the end of the year. This species proved to be the most abundant, persistent and widely distributed hosts in the ecology accounting for the highest populations of *B. invadens* and *C. cosyra* during September and October. Wild jujube also becomes available as alternative reserviours for the flies from September until the end of December during which time syncomore figs and persimmons begin their re-apperance as suitable hosts for the flies through the drier periods of the new year.

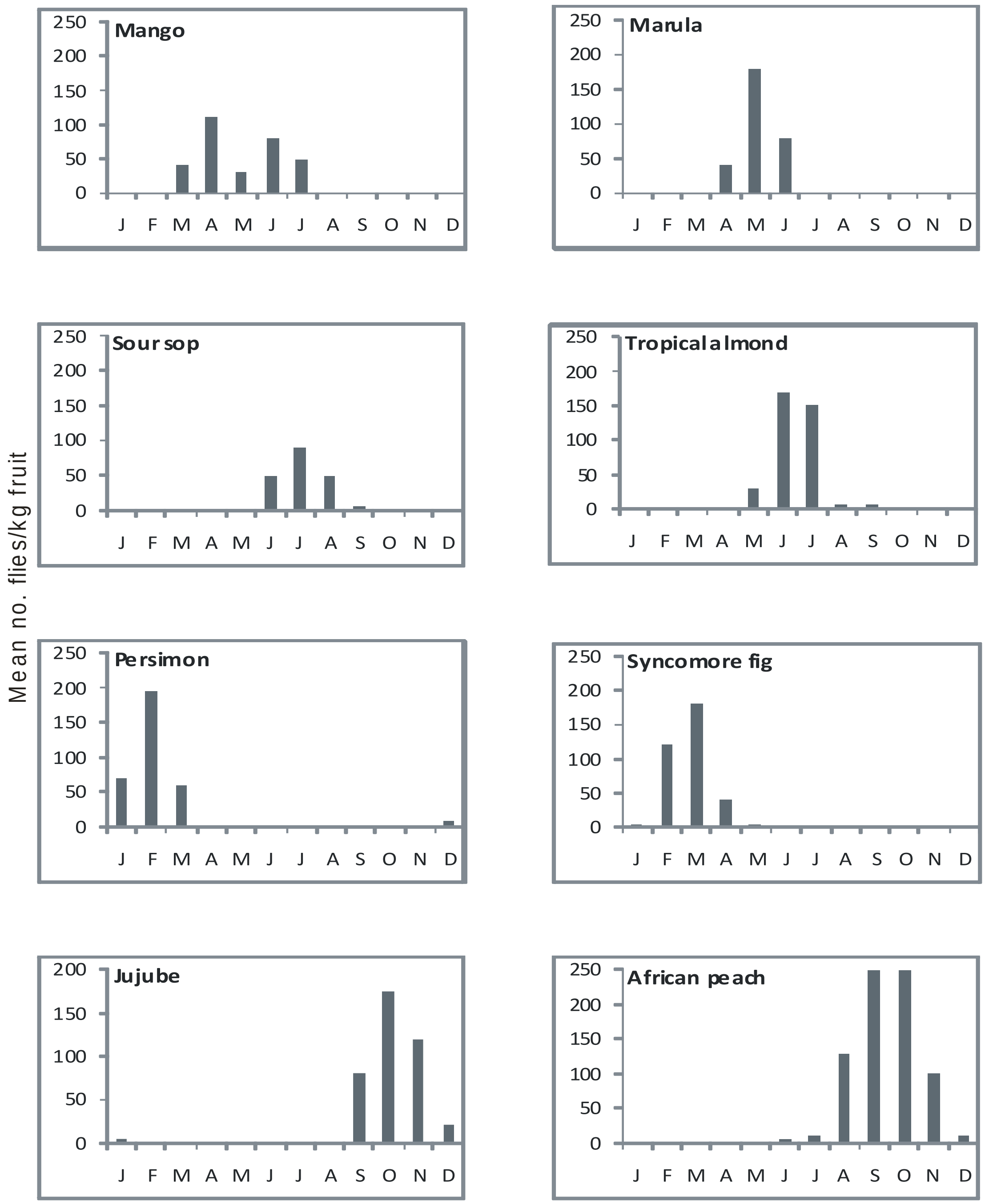

Figure 7.1: Seasonal trends in infestations by *B. invadens* and *C. cosyra* (pooled data) in12 main host plants in northern Ghana.

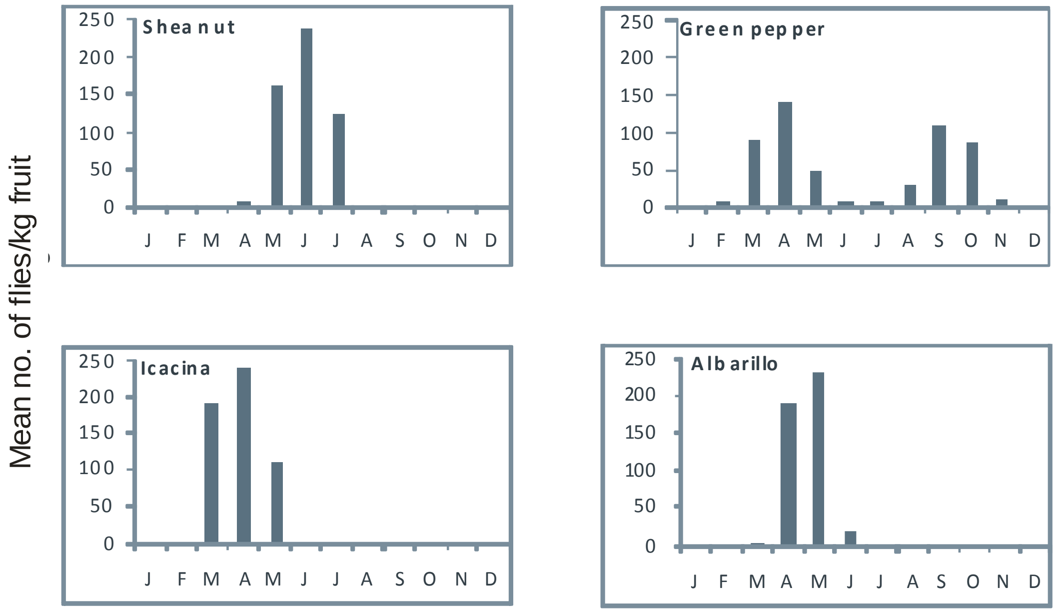

Figure 7.1 Cont.

The results obtained relating to the emergence of the fruit fly species from the main hosts compared as a function of the study regions and seasons are shown in Figure 7.2. It was observed that fruit fly infestation was generally highest in the Northern region and lowest in the Upper East Region while the Upper West Region experienced moderate infestation. In all regions, emergence of both fruit fly species was at the lowest level at the beginning of the year, but this assumed a sharp increase after February, reaching a peak around August. Thereafter, tephritid emergence dropped steadily to very low level by December. During the first four months, rate of emergence of *C. cosyra* was found to be higher than that of *B. invadens*, but the reverse occurred from April until August when *C. cosyra* becomes dominant again for the rest of the season.

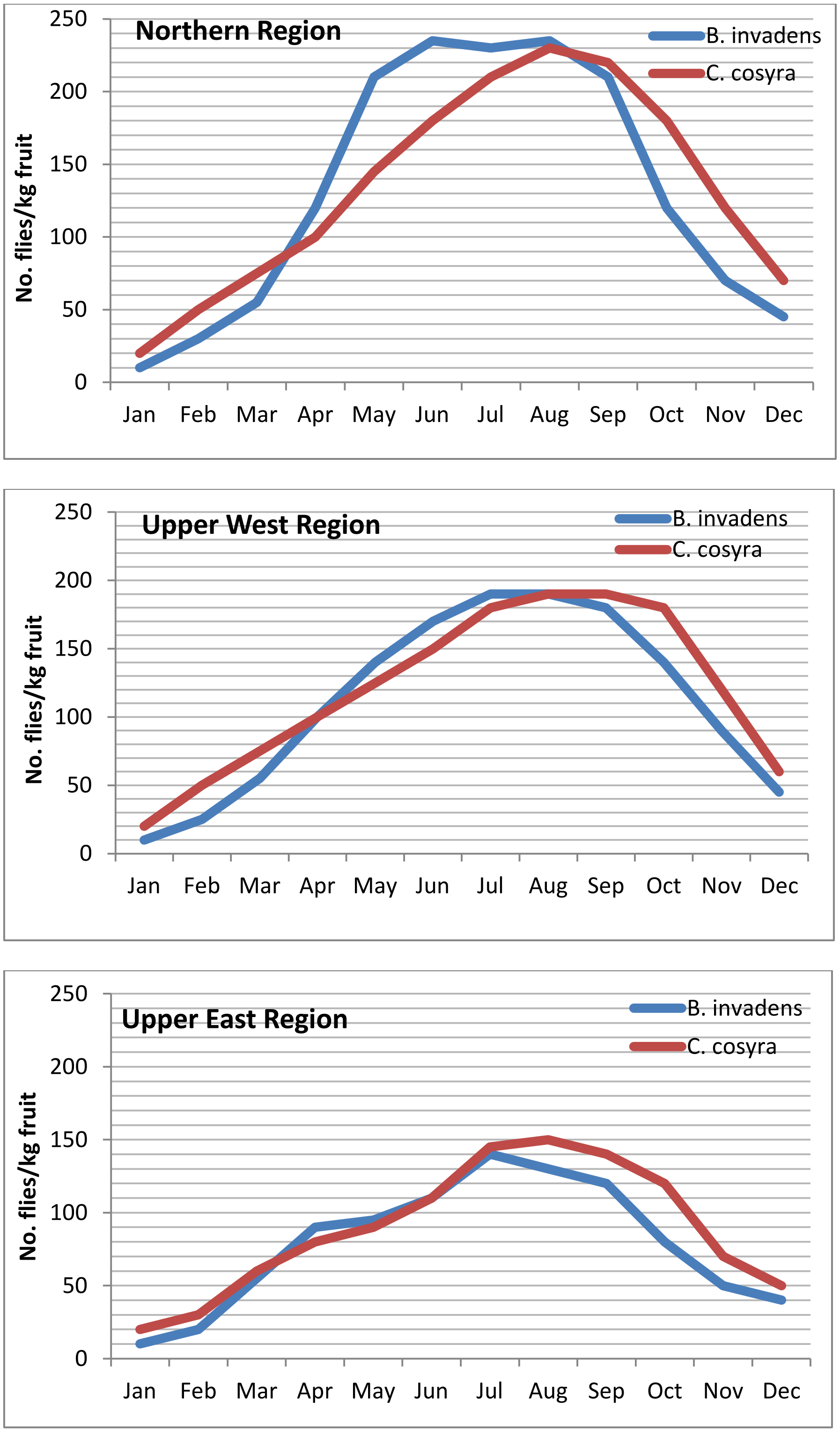

Figure 7.2: Emergence dynamics of *B. invadens* and *C. cosyra* from the 12 main hosts (pooled data) in relation to the study regions.

7.3.3 Effect of abiotic factors

The relationship between the climatic factors and fruit fly population dynamics is shown in Figure 7.3. Tephritid populations were generally regulated by changes in rainfall, temperature and relative humidity. The fly species generally appeared at low numbers at the start of the rainy season, became more abundant at the peak of the rains and drastically declined at the end of the rains. Between the months of January and March, low precipitation coincided with minimum relative humidity with increasing air temperature. During this period, average infestation levels of both *B. invadens* and *C. cosyra* were as low as 10.0 and 20.0 flies per kg fruit, respectively. However, as precipitation increased from 50 mm in April to the peak of about 240 mm in September, there was a consistent increase in relative humidity (from 45.5 to 59.0 %) with a decrease in air temperature (from 34.9 to 29.8ºC). These conditions greatly favoured tephritid populations, with infestation levels of *B. invadens* and *C. cosyra* increasing to the peak of about 186 and 210 flies per kg fruit, respectively. However, as average precipitation assumed its sharp drop between October and December, there was a corresponding decrease in relative humidity with some fluctuations in average air temperature. During this period, tephritid numbers dropped steadily to their lowest levels.

Table 7.3 shows the results of the regression analysis of counts of *B. invadens* and *C. cosyra*. Regression between the climatic factors and infestation levels of the fly species indicated that temperature, mean relative humidity and rainfall all had positive relationship (r^2 =0.58) with *B. invadens* numbers. As described previously, these parameters increased during the fruiting season of many host plants. At the onset of the first effective rains in April, and with a considerable increase in relative humidity, the population of *B. invadens* rapidly resurged and became widely predominant from April to July. The first effective rain at 50 mm probably led to a very rapid increase in the population of *B. invadens* to a level higher than *C. cosyra* until August (Figure 7.3). Moreover, the high season x mean relative humidity interactions showed that as fly populations declined towards the late season, the mean relative humidity begun to decrease. Thus, temperature and rainfall had positive relationship (r^2 = 0.60) with the upsurge of *C. cosyra* population while relative humidity had negative correlation (r^2 = 1.98). For both fruit fly species, only rainfall showed positive relationship (r^2 = 0.77) with total average infestation levels (Table 7.4).

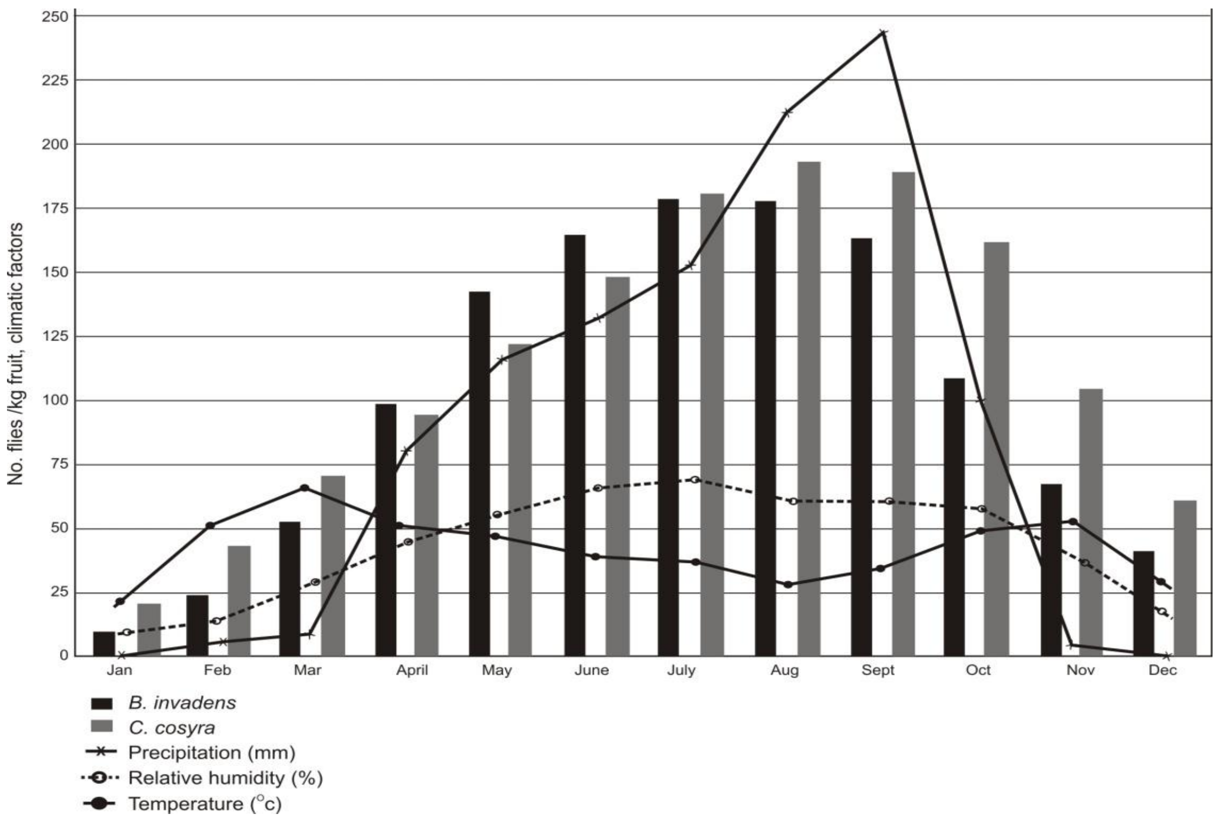

Figure 7.3: Relationship between climatic factors and infestation levels of *B. invadens* and *C. cosyra* on the 12 main host plants (pooled data).

Table 7.3 Regression analysis of counts of *B. invadens* and *C. cosyra* with climatic factors.

Covariates	Likelihood ratio chi-square (p<0.05)		
	B. invadens	*C. cosyra*	Both species
Month (12-lev. factor)	57.34	206.13	63.30
Max. Temp	(+) 11.00	ns	(-) 30.06
Min. Temp.	(+) 0.64	(+) 71.06	(-) 34.12
Mean-RH	(+) 31.00	(-) 46.00	(-) 130.00
Rainfall	(+) 601.23	(+) 12.05	(+) 110.68
Month x Max. Temp.	(-) 398.50	ns	(-) 113.40
Month x Min. Temp.	(-) 59.07	ns	(-) 245.95
Month x Mean RH	ns	(-) 329.90	(+) 143.05
Month x Rainfall	ns	ns	(-) 105.25
Max. Temp. x Min. Temp.	ns	ns	(+) 11.20
Max. Temp. x Mean RH	ns	ns	(+) 105.99
Max. Temp. x Rainfall	ns	ns	ns
Min. Temp. x Mean RH	ns	ns	(+) 86.60
Min. Temp. x Rainfall	ns	ns	(-) 111.87
Mean RH x Rainfall	(-) 540.48	ns	ns

(+) or (-) indicates the sign of the regression coefficients. ns = not significant at p = 0.05.

7.4 DISCUSSION

The results of this study have shown that suitable hosts are available all-year-round for *B. invadens* and *C. cosyra* in the savanna ecology of Ghana. From the sampling of the major and economically important fruits species, it was evident that this host range provided suitable reservoir for the fruit flies throughout the full year cycle but with fluctuating importance, depending on the fruit availability. Non-commercial fruits such as African peach, sheanut, tropical almond, jujube and albarillo played a key role in bridging the period between the fruiting season of mango and other cultivated crops. The mechanisms behind the decline of incidence and infestation rate of *B. invadens* and *C. cosyra* as the rains subsided could either be due to the absence of suitable hosts or unfavourableness of available fruits for oviposition. Mwatawala *et al*. (2006a) showed that *B. invadens* populations increase from the onset of the short rains period onwards to reach a maximum at the long rains period. This observed patterns need to be confirmed through continuous sampling over successive years prior to any control programme.

The relationship between the start of the rainy season, and the increase of *B. invadens* with heavy fruit infestation, was observed on mango in Benin (Vayssie`res *et al.*, 2005). The period of short rains was followed by a shorter period of drier conditions (but with high relative humidity) in February-March, to be followed by a period of higher rainfall during a more extended period (long rains season). The average temperature remained high but gradually decreased during the long rains. This season was the main fruiting season for tropical almond, sheanut, marula plum and albarillo. Populations of *B. invadens* remain high during this period but seem to infest mainly sheanut and tropical almond, as well as other non-commercial fruits that were available around that time. When temperature and rainfall decrease during the dry season, the populations of *B. invadens* also decrease dramatically (Mwatawala *et al*., 2006a), but viable populations can be maintained in noncommercial hosts, such as persimmon, jujube and figs, till the next short rains period. Host availability for *C. cosyra* seemed a little more ambiguous from the analysis. It was unclear what the predominant hosts are for this species in the dry season since only sporadic records were obtained from icacina and persimons during that period.

Bactrocera invadens is currently considered as one of the major tephritid pest in Africa. Its polyphagous nature, predominance in certain hosts and rapid spread throughout Africa (Drew *et al*., 2005) makes it a devastating pest. Local farmers have indicated that there is a huge impact of this fruit fly on their fruit production (Yaya Toure´ and Temiognage, 2007). Besides being an important pest, it also seems to have an impact on the indigenous fruit fly fauna in commercial fruit produce. Although pre-invasion data are generally lacking, there is some indication that the pest could have an impact on the presence of major indigenous pests, such as C. *cosyra*. Duyck *et al*. (2004, 2007) indicated that K-selected tephritid species could be better invaders, and through interspecific competition, decrease the number and niches of pre-established species. *Bactrocera* species appeared to have K-selected traits and to dominate representatives of the genus *Ceratitis*, as in a case study in La Re´union (Lv *et al*., 2008). It is not unlikely that similar trends can be observed on mainland Africa in environments such as northern Ghana.

The study further demonstrated a distinct seasonal pattern in the population fluctuations of *C. cosyra* in the ecology. Infestation rate for this pest was relatively low during the early and mid rains period, increased in June, reaches high levels in July and peaks in August. Larval activity becomes low at end of November, during which period, the fly survives as a larva inside host fruits which either remain on the trees or fall to the ground (Papadopoulos *et al*., 1996). Though the mortality of larvae and pupae during winter may be very high, proportion of the population survives and yields a small number of adults in spring (Papadopoulos *et al*. 2000). Although not detected by fruit sampling or trapping, these adults appear in December and a proportion of them may live until the end of February (Papadopoulos *et al.*, 1998). Reproduction is thus, possible during the early rains when host conditions become favourable giving rise to the following generation.

The influence of abiotic factors is closely related with fly abundance (Vera *et al*., 2002; Duyck *et al.*, 2006) and on their population dynamics (Amice and Sales, 1997). With *B. invadens*, temperature (min–max), RH and rainfall all had positive relationship with infestation rate. Among them, daily rainfall was the factor showing the strongest positive correlation with *B. invadens* populations. The population dynamics of *B. invadens* in northern Ghana appeared very similar to those of *B. cucurbitae* in Benin (Vayssieres *et al.*, 2005) and *B. dorsalis* in Asia (Chen *et al.* (2006). Han *et al.* (2011) underlined that the monthly rain days are the strongest ones among all the climatic factors. Similar studies with abiotic factors were carried out on *B. dorsalis*, *B. zonata* and *B. correcta* in India (Sarada *et al*., 2001). They showed a positive correlation for *B. dorsalis* populations captured partly at periods of high RH, but also with the onset of the rains. Shukla and Prasad (1985) however, observed a negative correlation between the populations of *B. dorsalis* captured and temperature, and maximum RH. According to Agarwal and Kumar (1999), *B. zonata* populations have positive correlation with temperature and rainfall in India. With *C. cosyra* in northern Ghana, minimum temperature and rainfall had positive relationships with infestation level. Vayssieres *et al*. (2009c) recorded the similar positive correlation of *C. cosyra* with minimum temperature and RH on mango and guava. Positive relationship with minimum temperatures was also recorded in India on the oriental fruit fly, *B. dorsalis* (Kannan and Venugopala, 2006) and guava fruit fly, *B. correcta* (Jalaluddin *et al*., 2001).

These results suggest that climatic factors such as temperature, RH and rainfall play an important role in regulating populations of *B. invadens* and *C. cosyra*. Rainfall makes the soil moist and thus provides some favourable conditions for eclosion of adults from their puparia. The first important rains, and increasing relative humidity are important factors favouring the sudden outbreak of *B. invadens* especially as it coincides with the fruiting seasons of the major host plants. Other reasons could be proposed such as the quasi-absence of natural enemies and the polyphagous status of this formidable invasive species (about 40 host plant species recorded in the study ecology) (B. K. Badii, Unpubl. data). It could be proposed that the three main factors involved in population dynamics are the reduced availability of fruits (due to trees bearing in alternate seasons), the fruit sampling method, and the impact, albeit to a lesser extent, of incubating fruits. Further research is actually needed to estimate their respective importance. These findings generally imply that programs that aim at suppressing of fruit fly populations could focus on the hosts with high infestation rates with respect to particular fruit fly species. In export situations, fruits with a higher incidence of fruit flies become a major concern because of strong quarantine regulations imposed by importing countries. Non-commercial hosts with high incidence and infestation rates, and found in the vicinity of commercial orchards, should be removed to reduce the alternative reservoirs of fruit fly population build up in between crop peaks. In addition, any suppression of pest population should be conducted at the start of the growing season in order to curb the population peaks.

CHAPTER EIGHT

8.0 HYMENOPTERAN PARASITOIDS ASSOCIATED WITH FRUIT-INFESTING FLIES (DIPTERA: TEPHRITIDAE) IN NORTHERN GHANA

8.1 INTRODUCTION

Fruit flies are pests of economic importance in Africa due to their quarantine status and losses recorded in fruits and vegetables (Lux *et al*., 2003a). Surveys of tephritid fruit flies and their parasitoids are important steps to a better understanding of the ecology of these economically important taxa (Zucchi, 2000). Over the past two decades, there has been an increasing drive in the practice of biological control in various parts of Africa where production and commercialization of fruit and vegetable crops are affected by fruit-infesting flies. Ovruski *et al.* (2000) noted that the growing acknowledgment of the importance of biological control of fruit flies is related to three events: (1) the improvement in mass rearing techniques for exotic and native parasitoids that allow the development of new control strategies involving the inundative releases of these natural enemies; (2) the growing world-wide concern of the use of agrochemicals in fruit orchards owing to their negative effects on the environment and human health; and (3) the present drive towards biodiversity conservation in agro-ecosystems, through ecologically acceptable tactics such as habitat manipulation in combination with the use of natural enemies.

The main focus of many biological control programmes for fruit flies has been the use of parasitic Hymenoptera (Wharton, 1989; Sivinski *et al.* 2000; Bokonon-Ganta and Messing, 2008). Staphylinid predators have been used only rarely (Clausen *et al.*, 1965; Van Mele *et al.*, 2007), probably owing to their relatively low efficacy as fruit fly suppression agents (Vargas *et* *al*., 2007). Numerous studies have highlighted various aspects of the role of parasitic Hymenoptera in the biological control of tephritid pests (Clausen, 1978; Gilstrap and Hart, 1987; Wharton, 1989; Waterhouse, 1993; Knipling, 1992; Headrick and Goeden, 1996; Purcell, 1998) and thus, demonstrating the possibility of these agents for use in fruit fly suppression efforts (Sivinski *et al.* 2000; Vargas *et al.* 2007). Hence, parasitoids from Africa, including several species of *Psyttalia* and *Fopius*, have attracted much interest as biological control agents against fruit flies (Wharton *et al.* 2000; Billah *et al.* 2008a, b; Rousse and Quilici 2009). *Psyttalia concolor* (Szpligeti) has been widely released throughout the Mediterranean region through various augmentative biocontrol programmes (Raspi, 1995). Experiments in ICIPE, Kenya indicated a high parasitism rate on *B. invadens* by *F. caudatus* (Mohammed *et al.*, 2010). Indeed, the African continent has been the focus of several biological control programs, with a particular attention to parasitoid surveys and collections for export to other regions to control pests such as the Mediterranean fruit fly, *C. capitata* (Wiedemann) (Wharton *et al.*, 2000; Wang *et al.*, 2009) and the olive fly, *B. oleae* (Rossi) (Neuenschwander, 1982; Mkize *et al.*, 2008). Among such examples of parasitoid surveys are the research conducted to determine the parasitoids associated with fruit flies in Mali (Vayssières *et al.* 2002*)*, Benin (Vayssières *et al.* 2011b) and Senegal (Vayssières *et al.*, 2012).

Although some other previous surveys have included other African countries (Silvestri 1914; Steck *et al.*, 1986; Wharton et al., 2000; Vayssières *et al.* 2002), several available plant species were not included among the host fruits sampled (Vayssières *et al.* 2011b). And throughout Sub-Saharan Africa, there has been little effort to date to survey natural enemies attacking tephritid pests of both cultivated and wild fruit species in many parts of the continent. Presently, there is limited published information on the natural enemies attacking tephritid pests of fruit crops in

Ghana (Utomi, 2006) and none in the northern savanna ecosystems of the country. Recent area-wide monitoring in wild and cultivated fruits reveals high tephritid populations and the threat they pose to fruit and vegetable production in the area (B. K. Badii Unpubl. data). These fruit fly populations are also alternatively hosted by wild fruits that are present all year round in and around fruit orchards. Thus, these populations may constitute suitable reservoirs for indigenous parasitoid species which, if known, can serve as potential biocontrol agents for these damaging pests. This study sought to document the parasitoid fauna associated with fruit-infesting flies in the northern savanna ecology of Ghana. Specifically, this is a 2-year area-wide survey to provide preliminary information on (i) inventory of the fruit fly parasitoids in the area and (ii) their overall parasitism levels and pest control potentials. This will help to provide baseline data for future biological control efforts in the country.

8.2.0 MATERIALS AND METHODS

8.2.1 Fruit sampling and processing

To determine the parasitoid species associated with major tephritid pests in the area, samples of host fruit were collected from multiple sites in the savanna ecology of Ghana, between October, 2011 and September, 2013. Mature and ripe fruits from selected plants were randomly collected from farmlands, backyard gardens, roadsides, woodlands and forest habitats. Fruit species included in the sampling programme were mango (*Mangifera indica* L. Anacardiaceae), marula plum (*Sclerocarya birrea* A. Rich. Anacardiaceae), cashew (*Anacardium occidentale* L. Anacardiaceae), soursop (*Annona senegalensis* Pers. Annonaceae), saba nut (*Saba senegalensis* A. DC. Pichon Apocynaceae), tropical almond (*Terminalia catapa* L. Combretaceae), syncomore fig (*Ficus syncomosus* L. Moraceae), water melon (*Citrilus lunatus* L. Cucurbitaceae), luffa

(*Luffa cylindrica* L. Cucurbitaceae), persimmon (*Diospyros mespiliformis* A. DC. Ebenaceae), jujube (*Ziziphus mucronata* Willd. Rhamnaceae), African peach (*Sarcocepholus latifolium* S. Bruce Rubiaceae), shea (*Vitellaria paradoxa* C.F. Gaertn. Sapotaceae), green pepper (*Capsicum anuum* L. Solanaceae), tomato (*Lycopercicon esculentum* Miller Solanaceae), icacina (*Icacina senegalensis* Juss. Icacinaceae) and albarillo (*Ximenia americana* L. Olacaceae). These fruit species were selected because of their high infestation rates for the tephritid pests and/or relative prevalence in the ecology based on previous records in the area (B. K. Badii, Unpubl. data). Collections were made during sampling trips to the study localities during seasons when the target host fruits were available for sampling. Fruit samples were transported to the laboratory where incubation and collection of puparia were done according to procedures described by Copeland (2006), Mwatawala *et al*. (2009) and Vayssieres *et al*. (2011b). Details of the fruit collection, processing and insect monitoring procedures are described in Chapter six.

8.2.2 Parasitoid identification

All parasitic wasps recovered from fruit fly puparia were killed by freezing and preserved in 80% ethanol. Parasitoid species were identified using taxonomic keys from published literature (Wharton and Marsh, 1978; Wharton and Gilstrap, 1983; Wharton, 1999; Wharton *et al.*, 1999. Nomenclature used followed the standard index given by Ronquist (1995), Wharton (1997) and Wharton *et al.*, (1998). For parasitoid species whose identities were uncertain, confirmations were made by M. K. Billah, Department of Animal Biology and Conservation Sciences (DABCS), University of Ghana, Legon. Voucher specimens of wasps were deposited at the Entomology Laboratory of the Department of Crop Science, University of Ghana.

8.2.3 Data analysis

The fruit fly and parasitic wasp species from each sample were recorded for each host fruit species. Parasitoid diversity was measured by first calculating the Shannon-Weaver Index (Southwood and Henderson, 2000) for each fruit species. Percent parasitism (P%) was then calculated as P% = a/(a + b) x 100, where a = number of recovered parasitoids; and b = number of emerged adult flies in each sample (Steck *et al*,. 1986). Infestation level was calculated as the number of fruit fly pupae per kg fruit. The relative frequency of fruit fly and parasitoid species was determined as number of samples of a given species collected divided by total number of collected species multiplied by 100. Host/parasitoid associations were based on assumptions that parasitoids reared from a fruit sample were attacking only hosts that were also reared as adults from that sample, with attack rate on different hosts based on percent of hosts in the sample. Log10 (x + 1) transformation was used on percentage data to stabilize the variance and normalize the data. Analysis of variance was performed using the generalized linear model procedure and mean separations were done using the lest significant difference (LSD) test (SAS, 2003).

8.3 RESULTS

8.3.1 Parasitoid diversity and abundance

The parasitoid species recorded during the survey are shown in Plate 8.1. The results showed that four larva-pupal parasitoid species belonging to the family of Braconidae, Hymenoptera, were reared from 14 out of the 17 fruit species incubated. The parasitoid species were *Fopius caudatus* (Szépligeti), *Psyttalia cosyrae* (Wilkinson), *Psyttalia concolor* (Szépligeti) and *Diachasmimorpha fullawayi* (Silvestri). Parasitoid diversity as measured by the Shanon-Weaner

Diversity index (SDI) showed that parasitoid diversity was lowest (1.2) in green pepper and highest (1.9) in African peach. Other fruit species that haboured maximum number of parasitoids included sour sop, sheanut, mango and icacina (Figure 8.1). Based on total samples studied, the most abundant parasitoid species was *F. caudatus* (61.0%) followed by *Psyttalia* spp (31.3) (with *P. cosyrae* 19.3% and *P. concolor* 12.0%), with *D. fullawayi* being the least abundant (7.7%) (Table 8.1, 8.3).

Psyttalia cosyrae (Wilkinson)

Psyttalia concolor (Szépligeti)

Diachasmimorpha fullawayi (Silvestri)

Fopius caudatus (Szépligeti)

Plate 8.1: Parasitoid species reared from fruit fly puparia recovered from host fruits in northern Ghana.

In the current survey, the parasitoid species seem to exhibit some distinct preferences for the host fruits. For instance, *D. fullawayi* was recovered only from soursop or water melon. Among the cultivated fruit species, only mango produced *Psyttalia* species. Meanwhile, *F. caudatus* emerged from all cultivated fruit species but did not emerge from many of the wild fruit species. It was also observed that some fruit samples that were infested by one species of fruit fly were found to habour more than one parasitoid species. For instance, water melon, icacina and albarillo each yielded two different parasitoid species emanating either from *C. cosyra* or *B. cucurbitae* (Table 8.1)

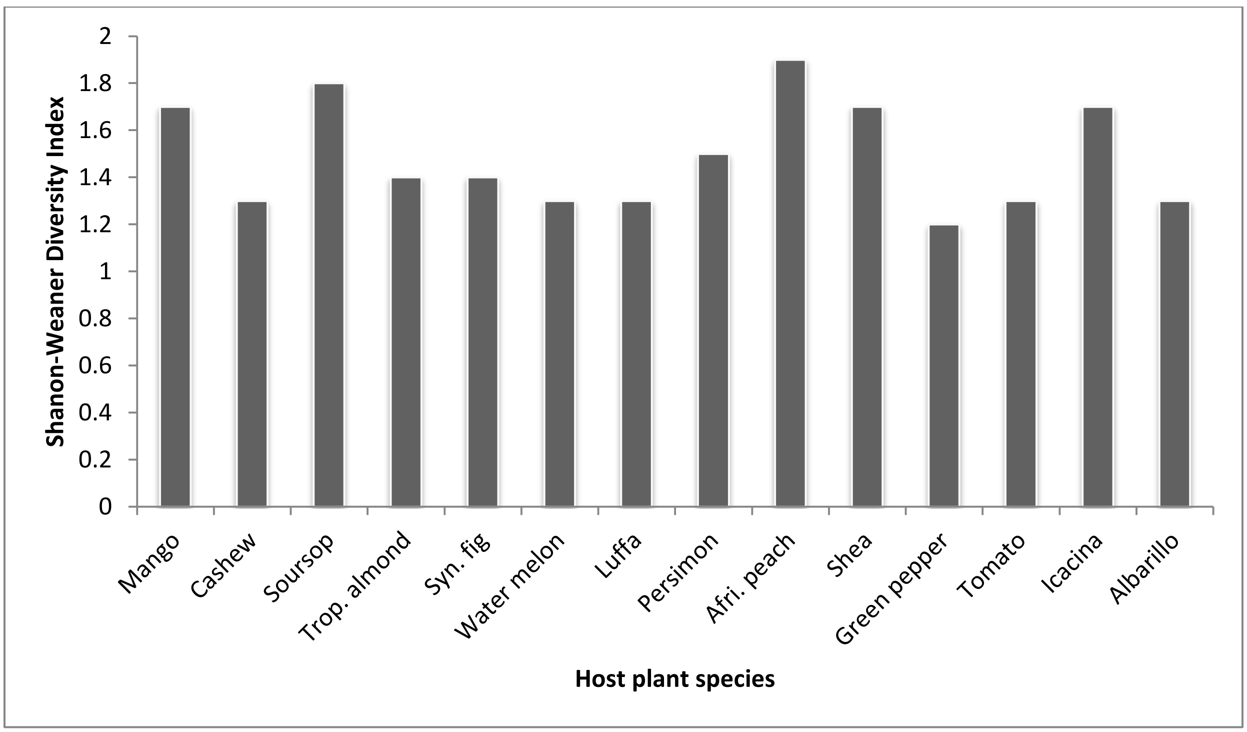

Figure 8.1: Parasitoid diversity as measured by the Shnnon-Weaner Diversity Index in 14 fruit fly host plants collected in northern Ghana.

Parasitoid population density was found to reach its peak during the mid-wet season, but this dropped steadily towards the beginning of the dry season. The highest population of parasitoids was recorded in June while the least was recorded between December and February. With the exception of *F. caudatus* from which two individuals were recorded, no parasitoid species was recorded on December and January (Table 8.2). Among the fruit fly species, *C. cosyra* was found to produce the highest load of parasitoids (59.9%), followed by *B. invadens* (23.0%) while *B. cucurbitae* showed the least reservoir of parasitoids (3.6%). Meanwhile, *C. capitata* produced neither *P. concolor* nor *D. fullawayi.* Also, no *Psyttalia* species emerged from *B. cucurbitae* and no *P. cosyrae* emerged from *B. invadens*. In general however, each of the fruit fly species was found to harbour at least two different parasitoid species in the spirit of co-existence (Table 8.3).

Table 8.1: Fruit flies and associated parasitoid species recovered from host fruits in northern Ghana.

Fruit species	Mean number of pupae/kg fruit	Parasitism level (%)	Fruit fly species recovered	Parasitoid species
Mango	63.2 ± 6.5 d	11.42 ± 1.20 g	*B. invadens, C. cosyra, C. capitata*	*F. caudatus, P. cosyrae, P. concolor*
Cashew	17.2 ± 3.2 a	1.34 ± 0.52 b	*B. invadens, C. cosyra, C. capitata*	*F. caudatus*
Marula plum	70.5 ± 10.1 e	0.00 ± 0.00 a	*B. invadens, C. cosyra*	-
Soursop	52.1 ± 5.1 c	22.90 ± 4.64 i	*B. invadens, C. cosyra*	*F. caudatus, D. fullawayi, P. concolor*
Tropical almond	160.8 ± 16.8 ij	9.12 ± 1.25 f	*B. invadens, C. cosyra, C. capitata*	*P. cosyrae, P. concolor*
Syncomore fig	97.8 ± 11.9 g	4.14 ± 0.64 c	*B. invadens, C. cosyra*	*P. concolor*
Saba nut	21.6 ± 4.9 a	0.00 ± 0.00 a	*B. invadens*	-
Water melon	41.9 ± 6.0 b	3.80 ± 0.09 c	*B. cucurbitae*	*F. caudatus, D. fullawayi*
Luffa	39.1 ± 5.7 b	0.5 ± 0.63 ab	*B. invadens, B. cucurbitae*	*F. caudatus*
Persimon	120.9 ± 13.1 h	4.78 ± 0.59 c	*B. invadens*	*F. caudatus*
Jujube	150.7 ± 15.0 i	0.00 ± 0.00 a	*C. cosyra*	-
African peach	200.4 ± 22.9 l	27.00 ± 2.67 j	*B. invadens, C. cosyra*	*F. caudatus, P. concolor*
Shea nut	180.0 ± 19.2 k	8.53 ± 1.04 ef	*B. invadens, C. cosyra*	*P. cosyrae*
Green pepper	120.2 ± 14.5 h	1.80 ± 0.08 b	*B. invadens*	*F. caudatus*
Tomato	80.6 ± 11.8 ef	6.90 ± 0.71 d	*B. invadens*	*F. caudatus*
Icacina	162.3 ± 22.6 j	14.30 ± 2.37 h	*C. cosyra*	*P. cosyrae, P. concolor*
Albarillo	213.8 ± 25.6 m	4.80 ± 0.34 c	*C. cosyra*	*P. cosyrae, P. concolor*

Means with same latters within columns are not significantly different at p = 0.05.

Table 8.2: Numbers of the parasitoid species in relation to periods of occurrence.

Period (month)	*F. caudatus*	*P. cosyrae*	*P. concolor*	*D. fullawayi*	Total (%)
January	1	-	-	-	1 (0.5)
February	-	1	-	-	1 (0.5)
March	8	2	-	-	10 (5.2)
April	11	7	2	1	21 (10.8)
May	11	1	5	-	17 (9.2)
June	34	10	8	9	61 (31.6)
July	26	7	4	3	40 (20.8)
August	14	4	1	-	19 (9.8)
September	9	3	-	2	14 (7.3)
October	-	2	1	-	3 (1.7)
November	2	-	2	-	4 (2.1)
December	1	-	-	-	1 (0.5)
Total (%)	*117 (61.0)*	*37 (19.3)*	*23 (12.0)*	*15 (7.7)*	*192 (100)*

8.3.2 Infestation and parasitism levels

For the fruit fly/parasitoid samples identified, the fruit fly species most frequently reared from fruit samples that produced parasitoids was *C. cosyra* (ie. 59.9% of all flies reared from fruit samples producing tephritid parasitoids were *C. cosyra*). The least parasitized fruit fly was *B. cucurbitae* (3.6%). *Ceratitis cosyra* and *B. invadens*, the most abundant and damaging fruit fly species in the area were mostly attacked by *F. caudatus* as their principal parasitoid. These fruit flies were also occasionally parasitized by *P. concolor* and to a lesser extent, by *D. fullawayi*. Moreover, *P. cosyrae* also appeared to be a major parasitoid of both *C. cosyra* and *C. capitata* (Tables 8.1 and 8.3).

Table 8.3: Parasotoid species and their relative abundance in tephritid pupae recovered from the host fruits.

Fruit fly species	Parasitoid species*								
	F. caudatus		*P. cosyrae*		*P. concolor*		*D. fullawayi*		All species
	Number	%	Number	%	Number	%	Number	%	Number	%
C. cosyra	71	60.6	28	75.7	13	56.5	3	20.0	115	59.9
C. capitata	17	14.5	9	24.3	0	0.0	0	0.0	26	13.5
B. invadens	24	20.5	0	0.0	10	43.5	10	66.7	44	23.0
B. cucurbitae	5	4.3	0	0.0	0	0.0	2	13.3	7	3.6

*Values are visual counts of total parasitoids recovered from all incubated fruit samples.

Moreover, factors such as the location, habitat (fruit crop species), fruit fly species and fruit seasons determined the occurrence and parasitism rate of the parasitoid species. For instance, fruit species from the Northern Region appeared to record higher infestation and parasitism level compared to those from the other regions though the variation did not indicate significant difference ($p < 0.070$). The lowest level of parasitism was 10.5 % in the Upper East Region which corresponded with the location of lowest fruit infestation (Figure 8.2). Comparing all fruit species included in the study, the cultivated fruit species generally showed significantly ($p < 0.001$) lower parasitism level as compared to the wild fruit species such as peach, soursop and icacina. For instance, parasitism level recorded in green pepper, tomato and water melon was each below 7.5 (irrespective of the region) which was lower than majority of the wild fruit species. However, parasitism level was generally less than 30% in all the fruit species (Figure 8.3). The overall mean parasitism level considering all fruit samples was 7.1 ± 1.3 % with the lowest level of 0.5 ± 0.09 % in *Luffa cylindrica* (Table 8.1).

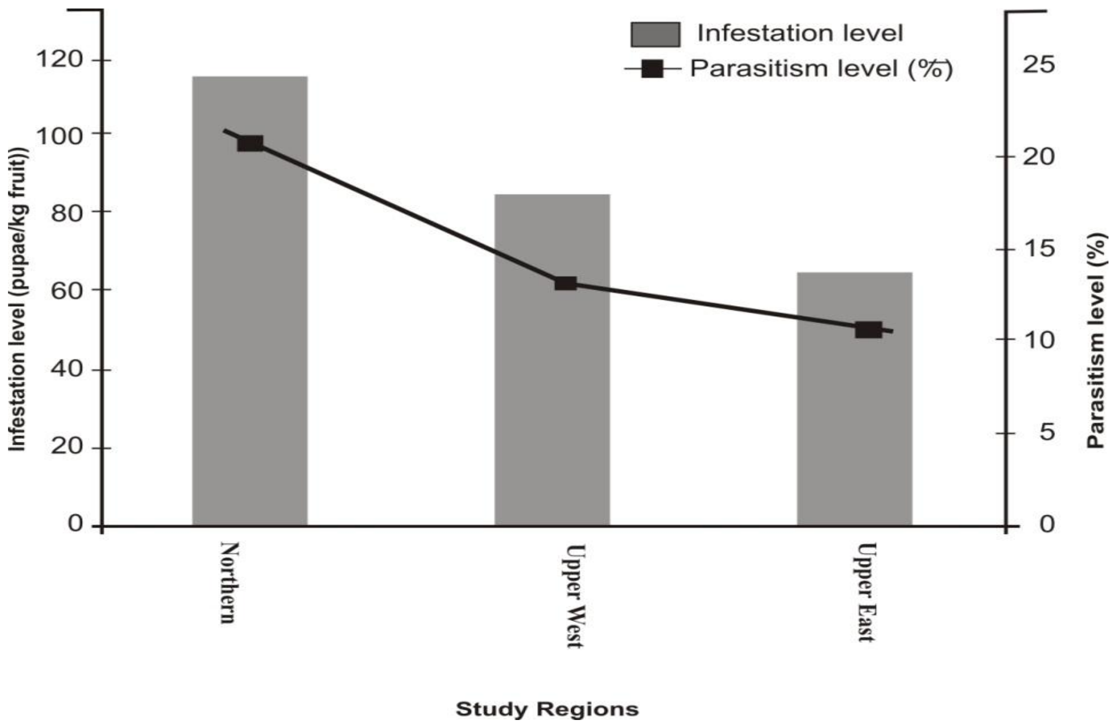

Figure 8.2: Infestation and parasitism levels of fruit fly species in relation to the study regions.

8.4 DISCUSSION

This survey reported four species as first record of parasitic hymenoptera harbored by fruit-infesting flies among cultivated and wild fruits in northern Ghana. These parasitoid species have been reported in previous studies in sub-Saharan Africa. For instance, *F. caudatus, P. concolor, P. cosyra* and *D. fullawayi* were earlier reported from West Africa by Silvestri (1913) and Vayssieres *et al*. (2002), and in other parts of the continent by Wharton (1987). *Diachasmimorpha fullawayi* has been reared from Ceratitidine and Dacine tephritids with nearly all records published under *D. giffardii*, a junior synonym of *D. fullawayi* and *D. carinata* (Wharton 1987; Copeland *et al*., 2009).

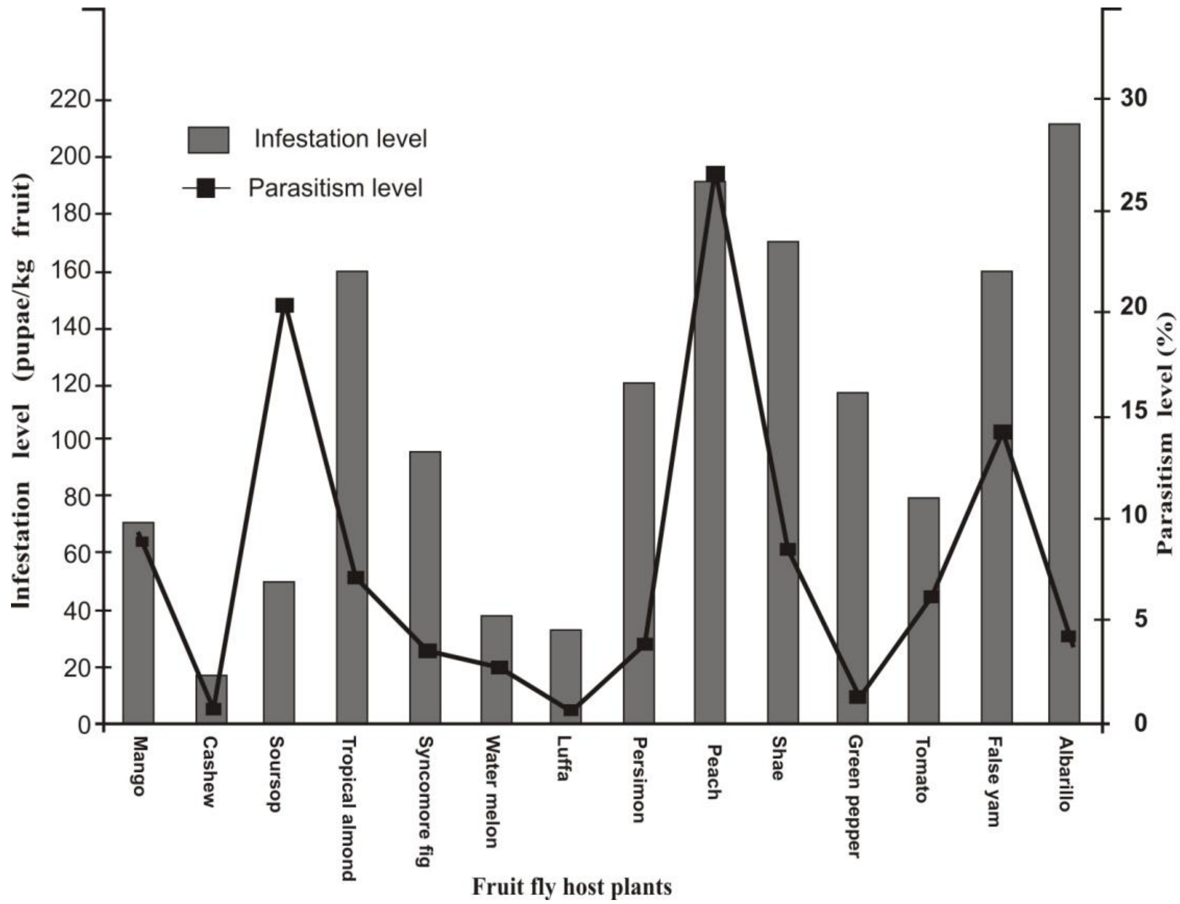

Figure 8.3: Infestation and parasitism level of fruit fly species in relation to host fruit species.

Also, Wharton (1987) reported members of *Fopius* to be very similar to one another, differing primarily in colour. Members of this group of species have been collected from Cameroon and Nigeria, east of Kenya and Tanzania, as well as South Africa and Madagascar, and undoubtedly occur throughout the African sub-region (Wharton, 1987). There are several species of *Psyttalia* in sub-Saharan Africa that are not easily distinguishable mainly due to combination of size, colour and body punctuations (Rugman-Jones *et al.,* 2009; Vayssieres *et al*., 2011b). The species reported in this study included both long-ovipositor forms (identified as *P. cosyra*) and some with relatively short ovipositor which are referred to as *P. concolor*. These species were originally described from infested fruits in Benin (Silvestri, 1913; Vayssieres *et al.*, 2011b), in

Mali (Vayssieres *et al.*, 2002) and more recently, in Senegal (Vayssieres *et al.*, 2012). The present specimens correspond to these previous descriptions. It is however possible that other species of *Psyttalia* were included in the present samples, including either *P. perproxima* (Silvestri) or the nearly identical *P. humilis* (Silvestri) (Vayssieres *et al.* (2011b).

The peak occurrence of the parasitoid species was from June to July, a period which generally coincides with the peak of the rainy season and with the maturity period of most of the surveyed crops, including mango, the major cultivated host of the fruit flies. This information could be of paramount importance for not only could it help avoid intraspecific competition but also when it comes to the introduction of exotic parasitoids which could take this occurrence or favorable period into account for the successful establishment of the parasitoids as biological control agents against fruit-infesting tephritids in mango orchards as well as those of other crops that are generally cultivated during same period of the year (Vayssieres *et al*., 2011b; 2012).

Among the parasitoid species recorded, *F. caudatus* and *P. cosyrae* were most frequently recovered from *C. cosyra* and *B. invadens*. These fruit fly species might thus be the preferred hosts for the parasitoid species. Wharton (1989) observed that fruit fly parasitoids generally develop on several tephritids but many have specific, preferred hosts. This was the case in Hawaii where *F. arisanus* (Sonan) caused substantial reduction of the host populations when released against *B. dorsalis* (Hendel) but became the major parasitoid of the previously introduced *C. capitata* (Wiedmann) (Vargas *et al*., 2007). Laboratory experiments conducted by IITA scientists reported higher parasitism rate of *P. cosyrae* on *B. invadens* compared to *D. fullawayi* (Mohammed *et al*., 2010). Vayssieres *et al.* (2012) however, recorded no parasitoids emerging from *B. invadens* in cultivated and wild fruit crops in Casamance, Senegal. Parasitoid survival and parasitism level can be influenced by abiotic factors such as temperature and relative humidity (Rousse *et al*., 2005). Therefore, samples from different localities or ecologies may yield varying parasitoid guilds. The sampling regions in this study, however, appeared to be of similar climatic conditions which might not be the driving factor for explaining the differences found among the samples in terms of parasitism level. Rather, the phonological pattern and widespread availability of the wild fruit species in each location may be an important factor influencing the occurrence of the parasitoids (Vayssieres *et al.*, 2011b; 2012). Wild fruit species such as soursop, peach and icacina are favorable parasitoid reservoirs with high infestation and parasitism rates.

The overall mean parasitism level was 7.1 ± 1.7 which was above the low level of 6.3 ± 1.9 % and 2.4 ± 1.3 % reported from previous surveys in mango from Benin (Vayssières *et al.*, 2011b) and from Senegal (Vayssières *et al*., 2012), respectively. Previous hypothesis have attributed high rates of parasitism partly to physical ease in locating immature stages of fruit flies in certain fruits (Sivinski *et al.*, 2000), coupled with the poor cultural practices noted in certain orchards. Of the parasitoids reared from the fruits, the dominant parasitoids were mostly recorded from wild fruits such as soursop, African peach and icacina. Cultivated crop species such as mango orchards may constitute unfavourable conditions for parasitoids due to human interventions (cultural practices, insecticide application) that negatively impact parasitoid populations. Hernández-Ortiz *et al.* (2006) made similar observations on parasitoids of *Anastrepha* fruit flies reared from different host fruits in Yucatan, Mexico. These authors attributed the low level of parasitism observed in their study to probable orchard management practices, in which periodic pesticide use could have a negative impact on parasitoid populations. Previous studies carried out in Brazil reported similar species diversity and levels of parasitism (Uchôa-Fernandes *et al.*

2003). In either case, our data are consistent with earlier findings concerning parasitoid abundance in wild and cultivated settings (Sivinski *et al.*, 2000; Hernández-Ortiz *et al.* 2006; Vayssières *et al.* 2011b). This indicates the existence of host habitat preference for the wild fruit habitat for the dominant parasitoid species reported here. Higher infestation levels in wild fruits can serve as a source of infestations in cultivated fruits at least, seasonally. However, these wild plants are also a potential reservoir for the development of parasitoids throughout the year for biocontrol efforts.

There is always a diverse assemblage of native fruit fly parasitoids in any given crop production area (Vayssieres *et al*., 2011b), and the present samples indicate that northern Ghana is not an exception. Yet, the efficacy of this parasitoid assemblage in controlling tephritid pests is low as indicated by the high infestation levels compared to the lower parasitism levels. The most abundant species, *F. caudatus*, generally exhibited high levels of parasitism overall, and was recovered from almost all the fruit fly species including the exotic pest *B. invadens*. This high level of parasitism by native parasitoids may justify the introduction of exotic species such as *F. arisanus,* that is known to be effective in limiting the population of many *Bactrocera* species. (Rousse *et al.*, 2006), including members of the *B. dorsalis* complex. For example in an approach employed by *ICIPE,* Kenya, in 2006, *F. arisanus* was imported from the University of Hawaii, where they were being reared and released for the control of the oriental fruit fly, *B. dorsalis* (a closely related species to *B. invadens*) (Zwaluwenberg, 1947). Basic bioassays pertaining to host preference, acceptability and physiological suitability for the immature development of *B. invadens,* carried out under restrict quarantine condition proved that the egg parasitoid *F. arisanus* is a very promising candidate (>70% parasitism) for management of *B. invadens* (Mohamed *et al*., 2010). *Fopius arisanus* also showed good effectiveness after its introduction to

Tahiti against *B. dorsalis* (Vargas *et al.* 2007). It has also been reported to be able to parasitize 21 tephritid species in the laboratory and to develop, with variable successes, on 18 of them (Rousse *et al.* 2006). Therefore, *F. caudatus*, related parasitoids to *F. arisanus* could represent a promising biocontrol agent against the economically important fruit fly pests in Ghana. It is hoped that this parasitoid when used in a holistic IPM programme in the savanna ecology of Ghana should contribute significantly to the suppression of the ever increasing population of *B. invadens* and other problem tephritids in the country.

CHAPTER NINE

9.0 GENERAL CONCLUSION AND RECOMMENDATIONS

9.1 CONCLUSION

The results of this study have demonstrated that farmer-level training and professional capacity building of frontline extension agents are critical in addressing the fruit fly menace in Ghana. Even though fruit growers were generally aware that fruit flies cause serious damage to their crops with detrimental consequences on their earnings, many growers demonstrated poor knowledge of the economically important fruit fly species, especially the African invader fly, *Bactrocera invadens*. Majority of fruit growers were less conversant with the direct damage symptoms of fruit flies on host fruits. Even though common control practices such as farm sanitation and prompt harvesting of fruits were adopted by a few farmers, nearly 40% growers took no action to control the pests. Recommended control strategies such as pheromone trapping, bait application, soil inoculation and use of natural enemies were virtually unknown or inaccessible to the growers, with majority of growers resorting to the application of unprescribed chemicals with potential environmental and health risks. As regards the competency areas of the pest developed and used for assessing the in-service training needs, Agricultural extension agents (AEAs) demonstrated fair knowledge in six competency aspects of fruit fly pests, but had poor knowledge in five other competencies. The top five competency areas of fruit flies in need for further training of AEAs included knowledge of the economically important species, their economic impact, life cycle, host plant associations and control strategies.

The study further indicated that, majority of the plant species studied were positive to the fruit fly pests. Eleven wild fruit species were reported as new hosts to *B. invadens*, while two fruit fly species were identified as first record in the ecology. *Ceratitis cosyra* and *B. invadens* were the dominant species in terms of abundance, incidence and infestation level. Infestation by *B. invadens* was higher in the commercial fruits while *C. cosyra* dominated in most wild fruit species. Cucurbitaceae were mainly infested by three species of *Dacus*, and *B. cucurbitae*, a specialized cucurbit feeder. Among the commercial fruits, infestation was highest in mango (*Mangefera indica* L), green pepper (*Capsicum anuum* L.) and water melon (*Citrulus lunatus* Thunb.), whereas soursop (*Annona senegalensis* Pers.), tropical almond (*Terminalia catapa* L.), syncomore fig (*Ficus syncomosus* L.), African peach (*Sarcocepholus latifolium* Smith.), sheanut (*Vitellaria paradoxa* C.F. Gaertn.), persimmon (*Diospyros mespiliformis* A. DC.), icacina (*Icacina senegalensis* Juss.) and albarillo (*Ximenia americana* L.) dominated the wild host flora. Fruit fly species of genera *Dacus and Trirhithrum* were of minor importance to the economic fruits in the ecology.

Moreover, twelve main host plants were identified as major reservoirs to *B. invadens* and *C. cosyra* in the ecology. The dynamics of emergence of fly species fluctuated at various levels in response to the availability of these host fruits and the influence of climatic factors, among which precipitation showed the strongest influence on fly populations. The results on parasitoid associations revealed that four species of larva-pupal parasitoids belonging to the family of Baconidae were reared from 14 host fruit species, with *Fopius caudatus* (Szépligetit) being the most abundant and diverse parasitoid species. Parasitism rate was highest in wild fruit habitats such as sour sop, African peach and icacina. *Ceratitis cosyra* and *B. invadens* were the fruit fly hosts harboring *F. caudatus*, and to a lesser extent, *Psyttalia cosyrae* (Wilkinson). These parasitoids generally had their peak occurrence in June and July, a period which coincided with the peak of the rainy season and with the maturity period of many of the surveyed crops.

9.2 RECOMMENDATIONS

Based on the scope of the present study and the key findings obtained, the following recommendations are made:

- It is important to train fruit growers to acquire basic expertise on fruit fly pests and their management through appropriate dissemination strategies such as farmers' field schools aimed at empowering the most receptive farmers to reach a level of independent decision-makers. As farmers adopt multiple efforts to minimize fruit fly infestation in an IPM fashion, there is the need to improve upon these practices so as to enhance their effectiveness in the overall fruit fly suppression programme. This is particularly urgent in view of the increasing prevalence and economic impact of the devastating *B. invadens* on fruit and vegetable crop production in the country.
- Additionally, the professional competence of AEAs needs to be strengthened as a prerequisite to combating the fruit fly menace in the country. Staff capacity development programmes for AEAs should look into how the top five critical educational needs on fruit flies can be addressed in training programmes executed by experts of the national fruit fly management committee. As knowledge and awareness become relevant to technology adoption, and change agents success in securing adoption is related to their credibility, competence of frontline AEAs will serve as vital link in the implementation of IPM systems for fruit fly pests in African countries.
- Future survey also needs to include fruit sellers, exporters and the general public so as to obtain the fruit fly management priority needs of all stakeholders along the fruit value chain.
- The widespread availability of host plants and the diverse fruit fly species in the ecology call for particular attention to their impact on commercial fruits and the development of sustainable management strategies against the economically important tephritid species.

- Programmes aimed at suppression of fruit fly population could focus on the hosts with high infestation rates with respect to particular fruit fly species. However, when it comes to export, fruits with a high incidence become a major concern because of strong quarantine regulations imposed by importing countries. Non-commercial hosts with high infestation rates, and found in the vicinity of orchards, should be removed to minimize reservoir build up in-between crop peaks.
- In addition, any suppression of pest population should be conducted at the start of the growing season since it is more difficult to control fruit flies effectively if the crop season is already underway.
- Control strategies for tephritid pests should imperatively focus on control of the whole production basin (area-wide management), not just on orchard protection. Management strategies also need to optimize ecological mechanisms of control of fruit fly populations (eg. push-pull technologies with mimetic molecules) linked and enhanced with supra-specific host plant diversity.
- Since these results are not intended to be exhaustive, more research needs to be carried out in order to document the entire host range and species composition of tephritid pests in the ecology for incorporation into the overall pest management system.
- Information on the peak activity periods of *B. invadens* and *C. cosyra*, and their seasonal population fluctuations is fundamental for the development of suitable and effective control strategies. These studies provide the key to the precise understanding of the natural abundance of the pests, and assist in development of effective and timely control schedules. Such data could also be used to determine if a forecasting model can be developed to help IPM decision making,

apply sanitary measures, spot treatment with GF-120, male annihilation techniques and setting up bait stations at the best period before the cropping season.

- Finally, the parasitoid species recorded in the study provide critical baseline data for future conservation or introduction of these and related parasitoids for biological control efforts. Further studies should be carried out in other ecologies as these may reveal additional associations and potentially help in understanding the effects of habitat type on fly-parasitoid diversity in the country. This is a preliminary step in the inventory of parasitoid species from cultivated and wild fruits in Ghana. More work remains to be done.

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APPENDICES

Appendix 1: Survey questionnaire to assess the knowledge, perceptions and practices of fruit growers in the management of fruit flies in northern Ghana.

DEPARTMENT OF CROP SCIENCE
UNIVERSITY OF GHANA

RESEARCH AND DEVELOPMENT IN NORTHERN GHANA

SURVEY QUESTIONNAIRE FOR FRUIT PRODUCERS

Dear Respondent,

Thank you for accepting to answer this questionnaire. The researcher is a PhD student from University of Ghana. He is conducting studies to assess ***farmers' knowledge and perceptions and regarding an economically important pest in this area***. The information would be useful in developing sustainable means of addressing the menace in the country. As a partner in the crop value chain, your opinion about the pest, its economic impact and management would be much appreciated.

Questionnaire No…….

Background of Respondent

1. Region……………… …….. **2**. District…………………….. **3**. Community …………..

4. Sex: **a**. Male **b**. Female

5. Age range (yrs) ………………………………..

6. Educational status: **a**. non-formal **b**. basic **c**. secondary **d**. tertiary

7. Which farmer-based association do you belong? ………………………………………

Fruit Production Profile and Pest Constraints

8. Which fruit crop(s) do you grow? ………………………………………………………………….

9. How many years have you been in the fruit production business? ………………..

10. Scale of production (*based on farm size, MoFA criteria*)

a. small scale **b**. medium scale **c**. large scale

11. Type of cropping system practiced?

a. organic monocrop b. organic mixed crop **c**. inorganic monocrop **d**. inorganic mixed crop

Awareness of Fruit Fly Pests

12. Have you heard of fruit fly pests before? **a**. yes **b**. no

13. If yes, from what source did you hear about fruit fly pests?

14. fellow farmers b. fruit traders **c**. agric officers **d**. researchers **e**. radio/TV **d**. others
How would you describe the fruit fly pest problem in your farm?

a. Very serious b. Serious c. No opinion d. Not serious

15. Which of these insects (*show photographs*) is a true fruit fly pest? (select at most 4) ……………

16. Which of them is the new invasive fruit fly pest? ……………………………….

Knowledge of Fruit Fly Damage and Economic impact

17. Indicate your level of agreement or disagreement with these statements regarding the damage and economic impact of fruit fly pests (Scale: 1 = strongly disagree; 2 = disagree; 3 = no opinion; 4 = agree; 5 = strongly agree)

Fruit fly infestation reduces farmers' income
Fruit fly pests are a threat to horticulture
Fruit fly-infested fruits attract poor market

Fruit fly-infested fruits usually contain maggots
Fruit fly damage reduces fruit quality
Fruit rot is the result of fruit fly infestation
Infested fruits may fall prematurely
Fruit fly infestation reduces cost of production
Fruit fly maggots feed on the fruit
The fruit fly menace is a quarantine problem
Adult fruit fly creates punctures on fruits
Adult fruit fly does not feed on the fruit
Fruit fly eggs are laid inside the fruit

Fruit Fly Management Practices

18. What do you normally do to control fruit flies in your farm?
……………………………………….

19. Which of these fruit fly control methods is known to you?

a. Pheromone trapping (MAT) b. Bait application (BAT) c. Soil inoculation d. Orchard sanitation

e. Prompt harvesting f. Biological control g. Wrapping/bagging of fruit h. Heat treatment of fruits i. Chill treatment of fruits j. Irradiation of fruits k. No idea

Way Forward

20. What, in your opinion, is the way forward to addressing the fruit fly problem in your area?

....

End of questionnaire, Thank you!

Appendix 2: Survey questionnaire to assess the in-service training needs of agricultural extension agents in the management of fruit flies in northern Ghana

DEPARTMENT OF CROP SCIENCE
UNIVERSITY OF GHANA

RESEARCH AND DEVELOPMENT IN NORTHERN GHANA

SURVEY QUESTIONNAIRE FOR AGRICULTURAL EXTENSION AGENTS

Dear Respondent,

Thank you for accepting to answer this questionnaire. The researcher is a PhD student from University of Ghana. He is conducting studies to assess ***extension agents' training needs for an economically important pest in this area***. The information would be useful in developing sustainable means of addressing the menace in the country. As a partner in the crop value chain, your opinion about the pest and its management would be much appreciated for the design of training programmes in the future.

Questionnaire No.……

Demographic Information

1. Region:.............	**4**. Age range	4. 51-60	2. Secondary sch. cert.
2. District:.............	1. 20-30	5. Above 60	3. Agric. college cert.
3. Sex: 1. Male	2. 31-40	**5.** Education:	4. Univ. Degree
2. Female	3. 41-50	1. Basic sch. cert.	

6. Number of years in service:
1. 1-10
2. 11-20
3. 21-30
4. 31-40
5. Above

Perceived Level of Knowledge

Please, indicate your perceived level of knowledge of the following aspects regarding fruit fly pests in agriculture. Directly assess your knowledge of by identifying the characteristics or associated skill dimensions of each item. Scale: Poor = 1.00-1.49; Fair = 1.50-2.49; Good = 2.50-3.49; Very good = 3.50-4.49 and Excellent = 4.50-5.00

Competency aspects	Excellent	Very good	Good	Fair	Poor
8.Morphological characteristics					
9.Geographical distributions					
10.Taxonomic classifications					
11. Economically important species					
12. Life cycle					
13. Natural enemies					
14. Host plant associations					
15. Population dynamics					
16. Behavioural ecology					
17. Pest status					
18. Economic impact					
19. Detection and monitoring					
20. Control strategies					
21. National action plan					
22. Directions for future research					

Perceived Level of Importance

Please, indicate your perceived level of importance of the following aspects regarding fruit fly pests in agriculture. Scale: Not important = 1.00-1.49; Of little importance = 1.50-2.49; Somewhat important = 2.50- 3.49; Important = 3.50-4.49 and Very important = 4.50-5.00.

Competency aspects	Very important	Important	Somewhat important	Of little importance	Not important
8.Morphological characteristics					
9.Geographical distributions					
10.Taxonomic classifications					
11. Economically important species					
12. Life cycle					
13. Natural enemies					
14. Host plant associations					

15. Population dynamics					
16. Behavioural ecology					
17. Pest status					
18. Economic impact					
19. Detection and monitoring					
20. Control strategies					
21. National action plan					
22. Directions for future research					

Perceived Level of Competence

Please, indicate your perceived level of competence in the following aspects regarding fruit fly pests in agriculture. Scale: Not competent = 1.00-1.49; Of little competent = 1.50-2.49; Somewhat competent = 2.50-3.49; Competent = 3.50-4.49 and Very competent = 4.50-5.00

Competency aspects	**Very competent**	**Competent**	**Somewhat competent**	**Of little competence**	**Not competent**
23. Morphological characteristics					
24. Geographical distributions					
25. Taxonomic classifications					
26. Economically important species					
27. Life cycle					
28. Natural enemies					
29. Host plant associations					
30. Population dynamics					
31. Behavioural ecology					
32. Pest status					
33. Economic impact					
34. Detection and monitoring					
35. Control strategies					
36. National action plan					
39. Directions for future research					

END OF QUESTIONNAIRE……THANK YOU

Appendix 3: Photographic vouchers of plant species in northern Ghana from which fruit samples were collected for determining the host range, species composition, seasonal phenology and parasitoid fauna of fruit flies.


***Anacardium occidentale*, cashew**


***Ximenia Americana*, yellow plum**


***Mangifera indica*, mango**


***Sclerocarya birrea*, marula**


***Spondias mombin*, tropical plum**


***Harpephyllum caffrum*, wild plum**


Annona senegalensis, sour sop


Annona muricata, custard apple


Annona squamosa, sugar apple


Saba senegalensis, saba nut


Saba comorensis, saba nut


Thevetia peruviana, yellow oleander


Carica papaya, pawpaw


Terminalia catapa, Indian almond


Citrulus lunatus, water melon


Citrulus colocynthis, Egusi


Cucurbita maxima, pumpkin


Cucurbita maxima, pumpkin


Cucurbita pepo, squash gourd


Lagenaria seceraria, bottle gourd


Luffa cylindrical, smooth luffa


Luffa acutangular, angled luffa


Diospyros mespiliformis, persimon


Invingia gabonensis, African wild mango


Ficus platyphylla, flake rubber tree


Ficus syncomosus, Syncomore fig


Ficus asperifolia, sand paper tree


Ficus sur, bush fig


Ficus recemosa, cluster fig


Psidium guajava, common guava


Ziziphus mucronata, jujube


Ziziphus mauritiana, buffalo thorn


Gardenia erubescens, cape jasmine


Vitellaria paradoxa, shea nut


Sarcocepholus latifolium, African peach


Tamarindus indica, tamarind


Blighia sapida, akee apple


Capsicum fructescens, chilli pepper


Capsicum anuum, green pepper


Solanum aethiopicum, African egg plant


Lycopersicon esculentum, tomato


Abelmoschus esculentum, okra


***Solanum melongena*, egg plant**


***Vitex doniana*, black plum**


***Icacina senegalensis*, false yam**


Lannea microcarpa, African grape


Haematostaphis bateri, blood plum


Crescentia cujete, calabash tree


Lannea acida, African grape


Cordia myxa, Sebasten plum


Detarium microcarpum, Tallow tree


Trichilia emetica, Roka tree


Detaruim senegalense, Tallow tree


Parkia biglobosa, Dawadawa


Artocarpus altilis, bread fruit


Averrhoa carambola, star fruit


Eriobotrya japonica, loquat


Feijoa sellowiana, feijoa


Malus domestica, African apple


Flacourtia indica, governor's plum

Pouteria campechiana, egg fruit

Syzigium cumini, jambolan

Carissa grandiflora, natal plum

Vitis vinifera, grape

Strychnos spinosa, monkey ball

Drypetis natalensis, stem fruit

Vepris nobilis, teclea

Lycium campanulatum, boxthorn

Artabotrys monteiroae, marula

Grewia trichocarpa, cross-berry

Bourreria petiolaris

Mimusops bagshawei, red coondoo

Coccinia microphylla, coral vine

Antidesma bunius, lamb's tail

Olea Africana, African olive

Dovyalis caffra, wild apricot

Opilia amentacea, opilia

Scaevola plumier, beach naupaka

Appendix 4: ANOVA for fruit fly species reared from host fruits in northern Ghana

Northern Region

Source of variation	df	ss	ms	vr	Fpr
Fruit fly species	9	3.750276	1.8751	869.84	< 0.001
Residual	10	0.006467	0.00215		
Total	19	3.75674			

Upper West Region

Source of variation	df	ss	ms	vr	Fpr
Fruit fly species	9	14.735306	3.683826	906.54	< 0.001
Residual	10	0.020319	0.004064		
Total	19	14.755624			

Upper East Region

Source of variation	df	ss	ms	vr	Fpr
Fruit fly species	9	17.27305	5.75768	508.17	< 0.001
Residual	10	0.04532	0.01133		
Total	19	17.31837			

Appendix 5: ANOVA for the host plant species infested by fruit flies in northern Ghana

Northern Region

Source of variation	df	ss	ms	vr	Fpr
Plant species	65	627.31	313.57	91.54	< 0.009

Residual	66	505.49	88.68		
Total	131	568.20			

Upper West Region

Source of variation	df	ss	ms	vr	Fpr
Plant species	65	222.24	55.51	81.15	< 0.009
Residual	66	188.05	25.76		
Total	131	210.26			

Upper East Region

Source of variation	df	ss	ms	vr	Fpr
Plant species	65	517.54	258.77	21.67	< 0.001
Residual	66	680.56	11.94		
Total	131	1198.10			

Appendix 6: ANOVA for the infestation indices of the 12 most attacked plant species by the 2 major fruit fly species (*B. invadens and C. cosyra*) in northern Ghana

Northern Region

Source of variation	df	ss	ms	vr	Fpr
Plant species	11	189.00	47.26	45.90	< 0.011
Residual	12	154.50	10.30		
Total	23	343.60			

Upper West Region

Source of variation	df	ss	ms	vr	Fpr
Plant species	11	777.60	194.41	62.19	< 0.001
Residual	12	1684.46	88.69		
Total	23	246.39			

Upper East Region

Source of variation	df	ss	ms	vr	Fpr
Plant species	11	627.13	370.32	21.55	< 0.001
Residual	12	505.49	117.80		
Total	23	243.73			

Appendix 7: ANOVA for parasitoids species recovered from fruit fly puparia in host fruits in northern Ghana

Northern Region

Source of variation	df	ss	ms	vr	Fpr
Plant species	3	8.1601	1.6320	618.20	< 0.001
Residual	4	0.0015	0.0020		
Total	7	8.1617			

Upper West Region

Source of variation	df	ss	ms	vr	Fpr
Plant species	3	1.2106	0.2429	18.907	< 0.001
Residual	4	0.0761	0.0122		
Total	7	1.2877			

Upper East Region

Source of variation	df	ss	ms	vr	Fpr
Plant species	3	5.3599	1.0716	79.85	< 0.001
Residual	4	0.0805	0.0139		
Total	7	5.4407			

Appendix 8: Multiple regression analysis of the effect of climatic factors on the emergence of *C. cosyra* from host fruits in northern Ghana

Variable	Regression coefficient	Standard error	t-value	Prob of t.
Constant	-592	38.6	-153	0.035
X1 Max monthly temperature	-40.9	12.0	-3.40	0.027
X2 Monthly RH (1500hrs)	4.12	2.13	1.94	0.985
X3 Mean monthly precipitation	0.066	0.133	0.49	0.778

Y = 886 – 40.9X1+ 4.12 X2 + 0.066X3

R^2 = 0.6090 = 89.9%   C = 88.6

Appendix 9: Multiple regression analysis of the effect of climatic factors on the emergence of *B. invadens* from host fruits in northern Ghana

Variable	Regression coefficient	Standard error	t-value	Prob of t.
Constant	84.8	23.6	3.59	0.003
X1 Max monthly temperature	1134.0	17.56	0.65	0.553
X2 Monthly RH (1500hrs)	190.0	311.2	0.61	0.574
X3 Mean monthly precipitation	10.90	19.50	0.56	0.605

Y = -66227 + 1134X1+ 190X2 + 10.9X3

R^2 = 0.5870%   C = -6622

Appendix 10: Summary of the Mean monthly air temperature, precipitation and relative humidity (RH) recorded during October, 2011 to September, 2013 at the Meteorological Stations of the Savanna Agricultural Research Institute, Ghana.

	Month	Average air temperature, ^{0}C		Mean precipitation, mm	Mean RH, %
		Max	Min		
Nyankpala					
	January	25.0	24.1	0.0	15.0
	February	36.5	33.2	5.0	19.5
	March	40.8	39.0	10.0	31.5
	April	35.5	34.3	80.0	45.5
	May	34.6	32.5	115.5	55.0
	June	32.0	30.0	130.5	63.5

July	30.4	30.0	150.5	66.5
August	28.4	26.2	210.0	59.5
September	30.5	29.2	240.5	59.0
October	35.5	33.5	100.0	57.0
November	36.7	34.5	5.0	39.5
December	27.8	25.3	0.0	23.0

Wa

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Manga

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