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Assessment of Fruit Fly Damage and Implications for the Dissemination of Management Practices for Mango Production in the Upper West Region of Ghana

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Ghana's mango (*Mangifera indica*) industry is facing potentially serious problems with fruit flies (Diptera: Tephritidae), which endanger the industry's contribution to the national economy. Asian fruit flies in the genus *Bactrocera* are destructive pests of fruits and vegetables worldwide, but little is known about their prevalence in Ghana since the first detection of *Bactrocera invadens* in 2005. This paper reports the results of a study of the occurrence of *B. invadens* in Ghana's Upper West Region and assesses the pest's distribution, the damage it causes, and potential management options. Despite limited collections of *B. invadens* in 2007 (the first formal survey of this pest), the results of weekly trapping provide a good preliminary understanding of its presence in the region. Systematic trapping and host fruits surveys confirmed its presence in all eight districts and at three experimental stations. The highest density (10.8 flies per trap per day) was recorded in Nadawli district and the lowest (1.6 flies per trap per day) in Lawra district. In total, 10,349 flies were captured during the study period which lasted for 6 months. The counts were highest in August, when the flies attack developed fruits. Late-maturing cultivars (mostly exotics) were more severely attacked than early (local) cultivars, and *B. invadens* also attacked cashew (*Anacardium occidentale*) and shea tree (*Vitellaria paradoxa*) in the study area.

Mango farmers were interviewed to obtain information about the pest. Sixty percent reported that the fruit fly, although a recent pest on mangoes in the study area, had decreased fruit production. Mealybugs (*Rastrococcus invadens*) accounted for 13% of the pests in mango fields, but ants (*Oecophylla longinoda*) and termites (*Microtermes* spp.) were also important pests that negatively affected mango production. Fruit fly control is still at an experimental stage in Ghana. Therefore, control should focus on integrated pest management to protect important crops. Training of agricultural extension officers, mango farmers, and other stakeholders, and international cooperation, will be imperative to ensure effective management of this invasive pest.

Key words: *Bactrocera invadens,* invasive species, mango, methyl eugenol, Ghana

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1. Introduction

1.1 Background

Asian fruit flies in the genus *Bactrocera* Macquart (Diptera: Tephritidae) are regarded as some of the most destructive pests of fruits and vegetables worldwide (White and Elson-Harris, 1992). Losses result from direct feeding damage, decay by opportunistic pathogens, and the loss of export market opportunities through quarantine restrictions imposed by importing countries to avoid entry and establishment of these pests. *Bactrocera* species are well-documented invaders, and rank high on quarantine lists worldwide (Clarke *et al.,* 2005). *Bactrocera invadens* Drew, Tsuruta and White (Diptera: Tephritidae), an invasive species, belongs to the *Bactrocera dorsalis* (Hendel) complex of tropical fruit flies (French, 2005). This group includes about 80 described species (and possibly with some undescribed specimens remaining in col-

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lections (Lawson *et al.,* 2003). They are native to a region that extends between tropical Asia and northern Australia (Drew and Hancock 1994). The group is arguably one of the most important pest species complexes in world agriculture (Clarke *et al.,* 2005; Drew *et al.,* 2005).

Preliminary results from host range studies show that species of the *B. dorsalis* complex attack both cultivated and wild hosts, including mango *Mangifera indica* (Anacardiaceae), lemon orange *Citrus limon* Burman (Rutaceae), tomato *Lycopersicon esculentum* (Solanaceae), banana *Musa* spp (Musaceae), guava *Psidium guajava* (Myrtaceae), marula *Sclerocarya birrea* (Anacardiaceae), custard apple *Annona muricata* (Annonaceae), avocado *Persea americana* (Lauraceae) and Indian almond (*Terminalia catappa* (Combretaceae) (Ekesi and Billah, 2006; Rwomushana *et al.,* 2008).

The latest arrival in Africa of a member of the *B. dorsalis* complex is *B. invadens,* a highly prolific and phytophagous species that is particularly invasive. Work done by ICIPE scientists (M.K. Billah, African Fruit Fly Programme, ICIPE, Kenya - pers. Comm.) in comparing field collections of fruit flies over the period between 2001 and 2007 seem to point to a gradual displacement of the previously prevalent mango fruit fly (*Ceratitis cosyra*). *B. invadens* is thought to have invaded Africa from the Indian subcontinent, and it was discovered in Sri Lanka after it was first reported from Africa (Drew *et al.,* 2005). It was reported in Ghana in 2005 (Drew *et al.,* 2005; Billah *et al.,* 2006). The route or means by which it entered Kenya is still unclear. However, it is thought that the intense movement of commodities and humans within Africa, coupled with frequent exchanges with Asia, the Middle East, and Europe, is a likely source of the introduction (Lux *et al.,* 2003; Billah *et al.,* 2006).

The pest has been detected in a number of east African countries (Mwatawala *et al.,* 2004 as well as north of Sudan, and has since spread to western and central Africa (Drew *et al.,* 2005). There is little information available about prevalence of the pest in Ghana since its initial detection in 2005 (Billah *et al.,* 2006). The data resolution upon which pest management decisions rely cannot be attained without an explicit knowledge of the biology of the pest and the damage it causes. Moreover, studies of field infestation rates in orchards are important for establishing the pest status of *B. invadens* and for formulating control strategies. The objectives of the present study were thus to confirm the identification of the fruit fly, define its distribution and the extent of damage it causes, and use this knowledge to explore possibilities for managing it. This paper reports the results of surveys for the fruit fly and interviews with mango farmers in the Upper West Region of Ghana in 2007.

The results of this study will guide strategies to enhance the food security and income generation capacity of mango farmers in the region, where the mango crop accounted for an average of more than 40% of the total household farm income. Other important goals of the study were to perform a region-wide delimiting survey that could help determine appropriate methods for the control or management of the pest; to provide a basis for training the various stakeholders in the mango production subsector to identify and manage the fruit fly and other mango-related pests and diseases; and to explore the possibility of using an integrated pest management (IPM) approach to protect mangoes in the study area.

1.2 Importance of Agriculture in the Ghanaian Economy

Ghana, a relatively small country with a total population of 18.4 million and an area of 238,533 km^2, lies in the center of the West African coastline (Ghana Statistical Service, 2000). It is a tropical country that consists of three broad ecological zones: forest, forest-savanna transition, and savanna. These broad categories are further divided into coastal savanna, rainforest, semi-deciduous forest, forest-savanna transition, Guinea savanna, and Sudan savanna.

The forest zone covers about one-third of the country (8.2 million ha), and supports two-thirds of the country's population (World Bank, 1988). Most of the country's economic activities are also located in this zone, including activities associated with the production of cocoa, minerals, oil palm products, rubber, and timber. The zone has a bimodal rainfall pattern (with the majority of the rain falling in July and September, with annual precipitation ranging from 1,300 to 2,100 mm. Ghana's northern savanna zone covers about 67%

(15.7 million ha) of the country's total area. The zone has a unimodal rainfall pattern, with erratic and usually unpredictable precipitation that occurs primarily in August and that ranges between 900 and 1,200 mm annually. Industrial crops such as cotton and shea nuts and food crops such as rice, maize, sorghum, millet and yam are predominant.

Ghana's major farming systems are largely defined by the agro-ecological zones. They include (1) rotational bush-fallow systems, (2) permanent tree crop systems (such as mango farming in the north), (3) compound farming systems, (4) mixed farming systems (such as the maize-yam system). Agriculture is the dominant sector of the Ghanaian economy. It employs about 60% of the workforce and contributes about 40% of the GDP. The major agricultural exports include cocoa, timber and wood products, and horticultural crops (e.g., pineapple, papaya, mango, vegetables), which account for more than 57% of total foreign exchange earnings. The non-cocoa subsector includes cereals (e. g., maize, rice, sorghum, millet), legumes and pulses (e.g., cowpea, groundnut, beans), roots and tubers (e.g., cassava, yam, cocoyam, sweet potato), industrial crops (e.g., cotton, oil palm, rubber, coconut, shea nut, cola nut), horticultural crops (e.g., pineapple, mango, papaya, avocado, citrus, pepper, tomatoes, cashew, watermelon, eggplant, okra, onion, cabbage, lettuce), and other crops (e.g., plantain, banana, ginger).

1.3 Mango Production in Ghana

Ghana has ideal sites for the production of mangoes in the north and in parts of the south, as the crop develops well under conditions ranging from semi-humid to semi-arid (Billah, 2007). The mango industry is divided into the southern and northern sectors. The coastal and transitional zones form the southern sector, and the savanna zone forms the northern sector. In the southern zone, large businesses with huge acreages operate as both producers and exporters. Small farmers are mostly organized into associations, as it is very difficult to enter the business individually (because of its capital-intensive nature). In the northern zone, the Integrated Tamale Fruit Company (ITFC), a nongovernmental organization, has created a scheme that allows participating farmers to grow 0.4 ha-1 of mangoes with input support provided on credit and technical advice. Owing to ITFC's involvement in the mango sector, small farmers are able to grow mangoes in addition to performing their other farming activities. On average, yields are estimated to be about 2.4 ha-1. Ghana's temperature averages 24℃, but ranges from 21 to 34℃ in the southern zone and from 18 to 40℃ in the northern zone. The lowest temperatures occur between December and mid-February in the northern zone. About 85% of the mangoes produced in Ghana are the 'Keitt' cultivar, and the remaining 15% are 'Kent', 'Tommy Atkins', 'Julie', 'Palmer', 'Zill', 'Irwin', 'Haden', 'Springfield', and 'Jaffna', plus a range of local cultivars.

Ghana is one of the few countries in the world with two mango seasons, and with the right cultural practices, both seasons can yield fruits for the international mango market. The major season in the northern sector starts in November-December. Fruits normally mature 3 to 3½ months after flowering, and take 4 to 6 weeks to ripen sufficiently for harvesting. In the minor season, flower initiation starts in late July or early August and mature in October. Improved cultivars are grown primarily for export, but production difficulties, inadequate management skills, and pest and disease problems have made that aim difficult to achieve. Losses due to fruit flies in Ghana are estimated at between 60% and 85% of the crop, depending on the cultivar and season (Billah *et al.,* 2006). This deprives communities of an important source of nutrition (particularly vitamin A) and leads to the loss of highly valuable market share. Apart from pineapples, most horticultural products are susceptible to fruit fly attack. Fruit flies can also trigger a quarantine in many countries, and their detection in exports leads to complete banning of a crop by importing nations. Ghana began exporting mangoes to the EU in 2004, with a total export of 177 t, making mangoes one of the country's largest exports of fresh produce to the EU. However, in 2005, a ban was placed on Ghanaian mangoes to South Africa (it remains in force) for fear of potential invasion by *B. invadens.*

1.4 Life Cycle of Fruit Flies (Diptera: Tephritidae)

Adult fruit flies mature sexually between 4 and 10 days after emergence, and begin to mate almost immediately. Soon after mating, the female uses her sharp ovipositor to lay her eggs in fruit by piercing it to a depth of 2 to 5 mm before ovipositing. The banana-shaped eggs are deposited in batches of 3 to 8, depending on the species. The eggs hatch into tiny white maggots (larvae) within 3 to 12 days, depending on the temperature conditions. Inside the fruit, the maggots molt twice. When fully grown, the maggots leave the fruit and bury themselves in the soil, where they pupate in hard cases called puparia. The duration of the pupal stage ranges from 10 to 20 days, depending on climatic conditions. In different countries, depending on the climatic conditions and abundance of host fruits, fruit flies may complete more than a dozen generations in a year.

1.5 Damage Symptoms

Direct damage begins when the female fly punctures the fruit skin and lays eggs underneath it. Damage symptoms subsequently vary from fruit to fruit, but invasion by various pathogens is common. When the eggs hatch, the rotten fruit tissue caused by these pathogens makes it easier for the larvae to feed. The puncture and feeding galleries made by the developing larvae provide access for pathogens to develop and increase the extent of the decay. Generally, the fruit falls to the ground as the maggots pupate, or just before. Attacked fruits often have puncture marks made by the entry of the female's ovipositor. Sometimes there may be some tissue decay around these wounds, and some fruits with a very high sugar content exude globules of sugar that can attract other pests.

1.6 Current Status of *B. invadens* in Africa

The fruit fly, first reported in Kenya in 2003 (Lux *et al.,* 2003) and then in Tanzania (Mwatawala *et al.,* 2004), has now been formally named. Drew *et al.* (2005) have described the species as *B. invadens* Drew, Tsuruta and White in reference to its rapid invasion of Africa. The description is based on specimens from several African countries and from Sri Lanka. *Bactrocera invadens* is morphologically very similar to *B. dorsalis* from Southeast Asia, to *Bactrocera kandiensis* (Drew and Hancock) from Sri Lanka, and to *Bactrocera rubigina* Wang and Zhao from China. *Bactrocera invadens* belongs to the *B. dorsalis* complex and according to Drew *et al.* (2005), the origin and identity of the invading species was originally unknown, although it was recognized as belonging to an Asian species complex. The species appears to have invaded Africa from the Indian subcontinent, and was only discovered in Sri Lanka after it was found in Africa, when large numbers of specimens were identified from a collection of tribe Dacini made in Sri Lanka by K. Tsuruta, now head of the Insect Identification & Diagnostics Lab, Japan thereby confirming its provenance.

The fruit fly is of great economic significance in Africa (Mwatawala *et al.,* 2004), where its rapid spread across tropical Africa and growing numbers of reports in fruit crops strongly indicate its potentially devastating pest status. *Bactrocera invadens* may initially have been overlooked in some areas, and thus its original discovery should not be assumed to indicate its point of invasion into Africa, but rather should demonstrate the vigilance of the African Fruit Fly Program (AFFP) at the International Centre of Insect Physiology and Ecology (ICIPE) in Nairobi, Kenya. The species was first found soon after the completion of an extensive programme of monthly fruit and baiting collections carried out from February 1999 to January 2003 by the AFFP (Copeland *et al.,* 2004). The first detections were made by M. K. Billah (AFFP Taxonomist, Nairobi) from mango fruits from the Hawkers' Market in Nairobi. This was followed by the first field collection at Tiwi, in the coastal province of Kenya, by A. Manrakhan (ICIPE) from a McPhail trap baited with NuLure protein (Miller Chemical and Fertilizer Corporation, Hanover, USA), during a routine survey and the first reared specimens from the field by Copeland from fruits of *Strychnos mellodora* from the Shimba Hills of Kenya. The species was subsequently found to be a serious pest of mangoes, and the first specimens from Tanzania were obtained from mangoes collected from a market place in Matombo on 25 July 2003 (Mwatawala *et al.,* 2004).

The species has already spread rapidly across Africa and, according to Drew *et al.,* (2005), has now been recorded from Kenya (February 2003, reared from fruit), Tanzania (December 2003, fruit), Sudan (May 2004, fruit), Benin (June 2004, methyl eugenol trap), Uganda (July 2004, methyl eugenol), Cameroon (August 2004, fruit), Togo (October 2004, methyl eugenol), Senegal (October 2004, torula liquid trap), Ghana (January 2005, methyl eugenol) and Nigeria (January 2005, methyl eugenol). It is also known to have been observed in the Democratic Republic of Congo (uncertain date and source of collection) and in Sri Lanka (Tsuruta *et al.,* 1997, Tsuruta and White, 2001; M.K. Billah, unpublished data).

One characteristic of *B. invadens* is that it is strongly attracted to methyl eugenol, which contrasts with African Dacini species, including *Bactrocera cucurbitae* which are attracted by the Cue Lure (White, 2006). Although methyl eugenol had not been widely used, it was deployed at sites in Kenya and other African countries (including Tanzania) in 1999 and 2002 by ICIPE's African Fruit Fly Program. Samples from the programme examined by M. K. Billah (of ICIPE) and confirmed by Dr. I.M. White (of the Natural History Museum, UK, and a leading authority on dacine fruit flies) did not contain the species, suggesting that it was not yet established in 2002, or that it was present in very low numbers. The rapid increase in collections of the pest between 2003 and the present is a further indication of the rapidity of its invasion of Africa. The host plant list is also growing at a rapid rate; *B. invadens* has now been recorded on guava, citrus, papaya, tomatoes, and especially mango, as well as on a number of wild hosts, including *Strychnos* spp. See most current list from Rwomushana *et al.,* 2008.

This new species is of high phytosanitary risk, especially to the countries of southern Africa (where it is not yet present) (M.K. Billah — pers. comm.) and ultimately to trading partners, including the USA. Countries such as South Africa, Botswana, Namibia, Lesotho, Swaziland, Mozambique, Malawi, Zambia, Zimbabwe, Angola, and their trading partners should consequently institute immediate measures to prevent the introduction of *B. invadens* from infested countries. Because of fear of introduction of the pest to the Republic of South Africa, mango imports from Ghana were banned in 2005 (M.K. Billah, pers. comm.).The species should also be of great concern in the context of plant protection and quarantine measures and pest risk analyses being developed for vulnerable fruits in affected countries, both of which should be reassessed. This is especially important because there is currently no scientific basis to assume that the fruit fly will be susceptible to the normal cold treatment procedures used to eliminate pests. Cold treatment experiments are also strongly recommended until the pest's temperature tolerance can be determined.

2. Materials and Methodology

2.1 The Study Area

The Upper West Region (UWR) of Ghana was created in 1981 from what was then the Upper Region, and covers a geographical area of approximately 18,478 km^2 (7.7%) of the total area of Ghana. The region is divided into eight administrative districts: Wa Municipal, Wa West, Wa East, Jirapa Lambussie, Nadawli Lawra, Sissala East, and Sissala West (Fig. 1). It has an approximate population of 600,000 people (Ghana Statistical Service, 2000), of whom about 89% derive their income from agriculture and related activities. The region is situated in the Guinea savanna ecological zone, which is bordered to the north by the Republic of Burkina Faso, to the east by Ghana's Upper East Region, to the south by Ghana's Northern Region, and to the west by Côte d'Ivoire. The

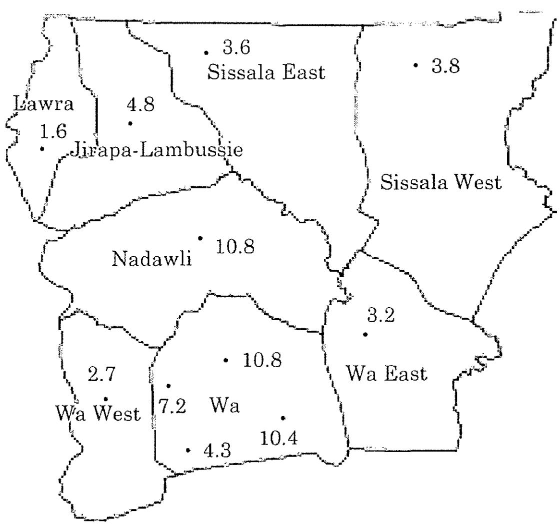

Fig. 1. Map of the Upper West Region (UWR) of Ghana, showing the catches of *Bactrocera invadens* per trap per day, and the locations where the survey was undertaken in 2007.
(Source: http://www.maplibrary.org/stacks/Africa/Ghana/Upper%20West/index.php)

vegetation of this zone is characterized by grasses, shrubs, and stunted trees. The major staple foods grown in the region are sorghum, millet, maize, rice, cowpea, groundnut, and yam. The cash crops include soybean, cotton, and cashews. The shea tree, which grows in the wild, is one of the major cash crops for rural farmers. Other crops include bambara groundnut, Kersting's groundnut, and sweet potato.

Wa is the capital of the region and its only urban center. No all-weather roads connect the major towns, and electricity can be sporadic even in the capital. Mobile phone networks have recently linked some of the districts, but a substantial investment will be needed to bring the UWR's infrastructure up to the standard of the rest of Ghana. The poor transport networks have important consequences for farmers, since crops that must be sold shortly after harvesting, such as tomatoes, are difficult to market compared with the situation in the Upper East Region, which has asphalt roads that link it with southern markets. The typical landscape is a gently undulating plain with hills and small mountains rising up to 350 m above the surrounding plains. The Black Volta river, the only perennial water system, runs from north to south across the region. The floodplain soils vary from brown sandy clays to silty clay loams (FAO, 1967). The highly weathered soils, derived primarily from granites, are easily waterlogged and eroded. Geologically, these rocks are characterized as the upper and lower Birrimian series; the upper can be seen in flat plains cut by granite outcrops, whereas the lower can be seen as outcrops of red laterite that mostly lies just below the surface. This patchy geology may well explain why farming systems are so diverse across the region.

2.2 Vegetation

The UWR is covered by Guinea savanna, with relatively high density of certain typical tree species (Chipp, 1922). Broadly speaking, the low human population densities in this area have permitted remarkable conservation of the savanna vegetation, quite unlike much of the remainder of northern Ghana. Typical indigenous species are the dawadawa (*Parkia biglobosa*), shea (*V. paradoxa*), mahogany (*Khaya senegalensis*), and silk-cotton (*Ceiba pentandra*). Baobabs (*Adansonia digitata*) are characteristic of areas of former human settlement. Of the introduced trees, the neem (*Azadirachta indica*) and mango (*M. indica*) are common in villages and increasingly common as escapes in uncultivated areas.

2.3 Rainfall and Climate

The climatic regime of the UWR is semi-arid, with annual rainfall of 900 to 1200 mm. The 29-year mean for three local weather stations was 989 mm. The rain mostly falls in a 5-month season from May to September. Temperature is considerably less variable than rainfall, and ranges from 30℃ in August to 38℃ in February.

2.4 Insect Collections (Traps and Lures)

The Lynfield trap was used during present study monitoring survey. The trap was locally made from a recyclable cylindrical plastic container with four holes (each 2.7 cm in diameter) evenly spaced around the upper half of the trap. The lure was methyl eugenol (AgriSense, London) mixed 4: 1 with malathion (EC 50% a.i.). Methyl eugenol attracts male *Bactrocera* species (e.g. *B. invadens, B. zonata* and *B. dorsalis*). It also attracts a few *Dacus* species. Methyl eugenol can be chemically described as benzene, 1, 2-dimethoxy-4-(2-propenyl). It is also a naturally occurring compound reported from 10 different plant families. Traps were suspended on mango, cashew, and shea trees at a height of approximately 2 m and were checked to determine fly catches 30 min after setting, and were then rechecked at weekly intervals. The effectiveness of the lure was about six weeks and was refreshed after that interval.

2.5 Data Collection and Sampling

To determine the extent of spread of the flies, in the UWR, the survey covered all the eight districts. Towns where the traps were installed were chosen randomly. Three experimental fields of the Ministry of Food and Agriculture, all located in Wa Municipal District, were also surveyed. Overall, we used a total of 11 sample locations which were chosen by random sampling of identifying mango plantations within each district. At each location, a methyl eugenol trap was installed on a mango, cashew, and shea tree 2 m above the ground, and fruit fly catches were recorded weekly for 6 months. To determine the effects of the flies on fruit production and the current damage caused by fruit flies and other related pests of mangoes, 190 farmers were interviewed using a semi-structured questionnaire to obtain first-hand knowledge about the pests. Field observations and focus group discussions were also conducted. Information obtained in the interviews covered the host plants, the pests and their social effects, the control efforts, and the damage caused by the pests.

3. Results and Discussion

3.1 Identification of the Fruit Fly in the Upper West Region

It is clear that good knowledge of the biology and behavior of the species responsible for the crop damage is required to successfully establish and perfect integrated pest control methods. This necessitated the identification of the actual fruit fly species responsible for mango damage in the UWR. Morphological examination of the fruit fly species captured from the study area confirmed that *B. invadens* was present (Drew *et al.,* 2005; Fig. 2).

3.2 Distribution of *B. invadens* in the Upper West Region

Table 1 and Figures 3 and 4 show the total *B. invadens* catches and variation in catches among months and districts during the present monitoring survey. The relationship between average monthly rainfall and monthly catches of *B. invadens* is shown in Figure 5. The highest pest density (10.8 specimens per trap per day) was recorded in Nadawli District where a total of 1994 *B. invadens* were captured (Table 2). In contrast, Lawra district recorded the lowest density: 295 specimens, which amount to 1.6 specimens per trap per day. A total of 10,349 flies were captured from the eight districts and three experimental fields during the study period (Table 2) . The severity of the infestation appears to be higher in the districts that share a border with neighboring countries that have high levels of mango production, where the pest has also been identified. The number of catches or counts reached the highest level in August, which was also the primary time when the flies to attack the developed fruits (Fig. 5). Vayssières *et al.* (2005) reported that increases in the population of *B. invadens* appear to be directly linked to the ripening of different mango cultivars. Temperatures in July, August and September (an average of 30.8℃) were warmer for the development of *B. invadens.* Figure 5 shows a strong increase in the *B. invadens* population as the season progressed from July to October. The pest is believed to thrive well in moist weather and at high temperatures (Rwomushana *et al.,* 2006). Figure 5 shows that the highest incidence of *B. invadens* concentration occurred at the peak of the rainfall season in the study region. The fly's abundance also remained higher in most of the districts during the rainy season (Table 2). This confirms the suggestion of Amice and Sales (1997) that climatic variables such as rainfall and temperature play a role in the abundance of *B. invadens.*

Fig. 2. Photograph of a male *Bactrocera invadens.*

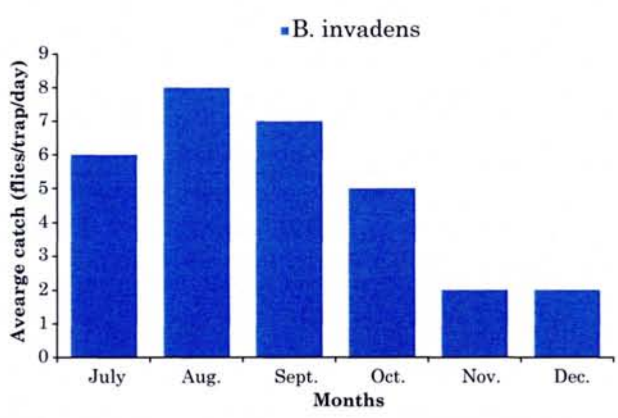

Fig. 3. Trends in *Bactrocera invadens* capture (number per trap per day) in the Upper West Region of Ghana from July to December 2007.

Table 1. Catches of *Bactrocera invadens* and its distribution in the Upper West Region of Ghana in 2007

District	Type of crop	Area (ha)	Total No. of insects	Total No. of trees	Flies caught per trap per day*	No. of traps
Nadawli	Mango	0.4	1994	40	10.8	1
Wa West	Mango	0.17	503	17	2.7	1
Lawra	Mango	0.4	295	40	1.6	1
Wa Municpal	Mango	0.4	1925	25	10.4	1
Municipal						
Wa East	Mango and shea	0.15	600	10	3.2	1
Sissala West	Mango	0.15	700	9	3.8	1
Sissala East	Mango and cashew	0.04	657	6	3.6	1
Jirapa-Lambussie	Mango	0.12	890	11	4.8	1
MOFA Exp. Field (1)	Cashew	1.0	795	150	4.3	1
MOFA Exp. Field (2)	Mango	0.8	1325	80	7.2	1
MOFA Exp. Field (3)	Shea	0.4	665	20	3.6	1
Total		**4.03**	**10349**	**408**	**5.1**	**11**

Source: Field monitoring report, 2007, MOFA (Ministry of Food and Agriculture). *Number of flies caught per trap per day was calculated as follows (IAEA, 2003): Flies per trap per day $=F/(T \times D)$ Where $F=$total number of flies, $T=$number of serviced traps per station (1), $D=$average number of days traps were exposed in the field (July to December, 184 days).

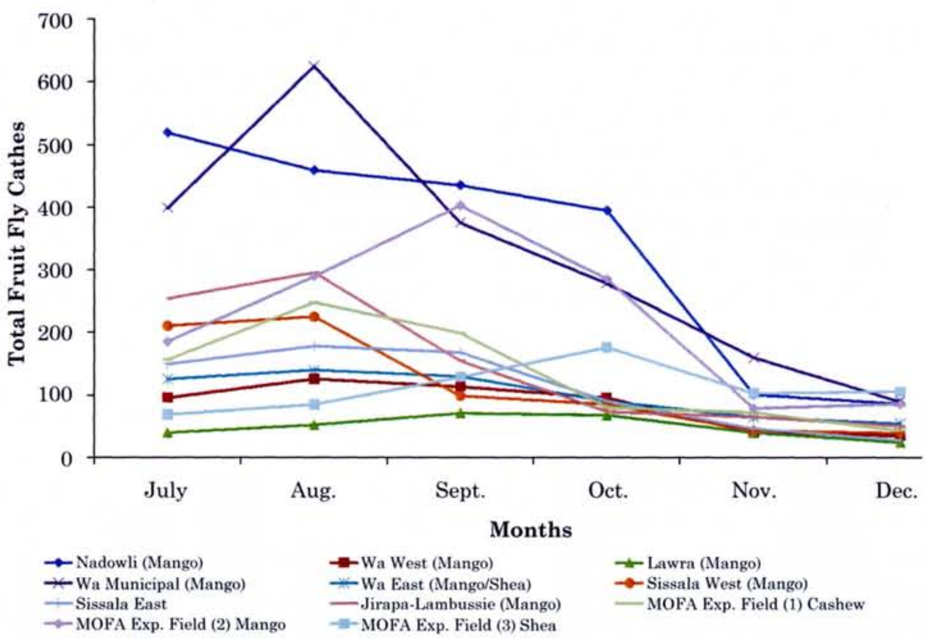

Fig. 4. *Bactrocera invadens* catches in methyl eugenol traps in the eight districts and three Ministry of Food and Agriculture (MOFA) experimental fields during the survey from July to December 2007.

The monitoring data revealed that males could be trapped throughout the mango season (Fig. 5). This suggests that in regions with the potential to grow two mango crops per year, the flies may remain abundant throughout the year. This is confirmed by the report of White and Elson-Harris (1992) that *Bactrocera* species are multivoltine and that they can attack fruits belonging to several

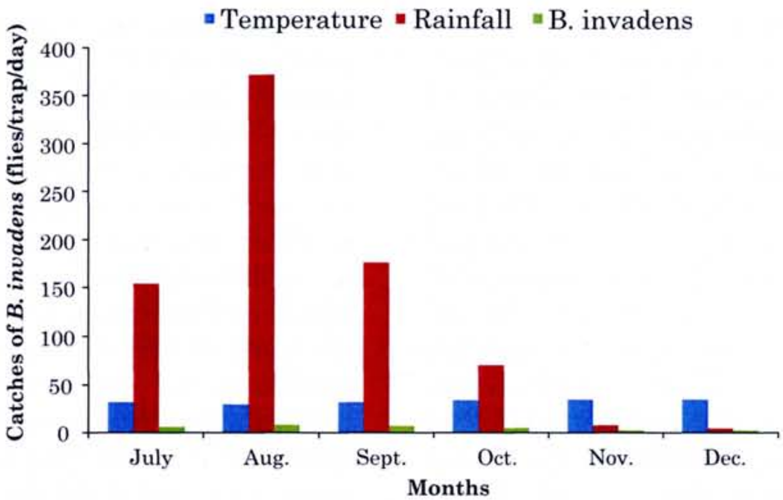

Fig. 5. Relationship between average monthly rainfall, temperature and catches of *Bactrocera invadens* in the Upper West Region of Ghana in 2007.

Table 2. Catches of *Bactrocera invadens* from July to December 2007 in the Upper West Region of Ghana

District	July	August	September	October	November	December	Total
Nadawli	519	459	435	395	100	86	1994
Wa West	95	125	113	95	40	35	503
Lawra	40	52	71	68	40	24	295
Wa Municipal	399	625	375	278	159	89	1925
Wa East	125	139	129	89	64	54	600
Sissala West	210	225	98	85	43	39	700
Sissala East	149	178	168	89	46	27	657
Jirapa-Lambussie	253	295	154	73	65	50	890
MOFA exp. field 1	156	247	198	79	72	43	795
MOFA exp. field 2	185	289	403	285	78	85	1325
MOFA exp. field 3	69	85	128	176	102	105	665
Total	**2200**	**2719**	**2272**	**1712**	**809**	**637**	**10349**
Flies caught per trap per day	6.5	8.0	6.8	5.0	2.3	1.9	

unrelated families of plants. This further complicates any potential control measure because of the possibility of reinvasion of a region if the control measures only target cultivated crops or a subset of the available host species.

The successful use of methyl eugenol traps demonstrated the value of this non-hazardous method of monitoring fruit fly populations and its possible use as a control method (Control methods are discussed in section 3.4). Parapheromone lure traps thus allow fast, inexpensive monitoring of insect populations, and are potentially useful both for general population monitoring in a region and for on-farm monitoring to determine when control measures should be deployed. However, it is difficult to calibrate traps to determine the threshold levels that would lead to control activities (Stonehouse *et al.,* 1998). The only reliable technique for arriving at such estimates appears to be the mark-release-recapture technique (Ito and Koyama, 1982). This technique, if made easily available, could have a profoundly positive impact for mango farmers in the UWR, because thus far, no effective control measures have been found for

B. invadens.

As is the case for many crop pests, the population of *B. invadens* varies between months, as does the severity of the associated attacks. In such cases, the application of a threshold rule may provide economically optimal control (Mumford and Norton, 1984). However, threshold-based control strategies are uneconomical if the return on the investment in controls is less than the cost, which is often the case when the pest density is low. Thus, it is important to determine whether these returns are positive in months with light levels of attack; if so, control can be applied routinely and prophylactically. If not, then a threshold-based program of supervised control measures may be a better course. For example, control measures against *Anastrepha* spp. in mangoes in Peru begin when McPhail trap catches average two adults per trap per week (Herrera and Vias, 1977).

The survey in the present study further revealed that *Bactrocera* species attack plants such as cashew and shea tree in the UWR (Table 1, Fig. 4). This shows that the pest is capable of reproducing in these plantations in the wild, and that there is a sufficiently large population of alternative hosts for the species to thrive even outside the main mango season. Host availability has been shown to have an important impact on the seasonal abundance of fruit flies in orchards (Tora Vueti *et al.,* 1997). Aluja *et al.* (1989) support the theory that since fruit flies attack different crops in the same area, their management must be based not only on a single crop such as mango, but also on control measures in wild hosts and other commercially grown host plants. Thus, to improve efficiency of fruit fly management, the phenology of all potential host plants in a region must be elucidated.

3.3 Extent of Economic Losses

3.3.1 Importance of mangoes in the Upper West Region

Mangoes are large trees that can reach 30 m in height. They are very popular in the UWR for their fruit and for the shade they provide. Mangoes can be produced in plantations, with a typical density of 100 trees/ha, or scattered in villages, towns, and fields. Yields vary between 50 and 200 kg of fruit per tree (i.e., 5 to 20 t/ha). Export of mangoes in Ghana began in 2004 with a total of 177 tonnes, making mangoes one of the country's largest fresh produce to the EU. Of the estimated 4,860 MT produced annually, only 125–407 MT (2.6–8.4%) are exported (GEPC, 2006; R.N. Attatsi, President, Pineapple and mango producers and exporters association of Ghana (Pampeag, 2007; unpublished data).The UWR contributed only about 5% of this total. However, these statistics seem to include only plantations, not the scattered trees that are found all over the country. In addition, the statistics do not include the fact that each household has at least two trees of local cultivars, with a production of around 20 kg per tree. However, the survey performed in the present study determined that farmers in the region have started to create large plantations and that the average mango production is expected to rise sharply.

3.3.2 Mango trees as a component of the Upper West Region's Farming System

Mango farms vary considerably in size, and are seldom grouped into uniform production blocks in the UWR. They are scattered among areas that contain both wild and abandoned fruit trees that act as reservoirs for a range of pests. Different mango cultivars were recorded in the present study, but only two categories were retained in the analysis: local cultivars with small, fibrous fruits and grafted (exotic) cultivars with large fruits that lack fibers. Of all the farmers that were interviewed, 75% preferred the local cultivars because of the free availability of their seedlings, the long survival of trees from the local varieties, and the value of the fruit on the local market. Other reasons included the resistance of the local cultivars to insect pests, diseases, and climatic stress, and subjective factors such as taste preferences.

Among all the producers, 5% preferred exotic cultivars because of the good quality of the fruits and their high commercial value for distant markets. Other advantages of the exotics that the producers reported were the small size of the trees and the fact that they begin to produce fruit at a young age. An additional 20% planted both local and exotic cultivars. Large-scale cultivation of the exotic cultivars has started in the region owing to the high demand for their fruit in both local and international markets. A fruit processing factory has also been established in the region to take advantage of the availability of these fruits.

Mango production in the UWR generally involves few special cultural practices. The mango trees are found scattered around houses, towns, and fields, whereas plantations are found in marginal land that cannot support other crops, and in lowlands, where they play a major role in soil erosion control. Inputs such as fertilizer and pesticides are rarely used, and none of the farmers interviewed irrigated. Almost 81% of the respondents used no chemical control measures in their mango fields. Some of the reasons for this were inadequate knowledge of the pests and a lack of access to appropriate chemicals. The major technology adopted by these farmers is the increased use of exotic cultivars.

The educational level of mango farmers in the UWR is low, and training facilities are both rare and of low quality, which creates a significant barrier to adopting and using the available technologies. In the UWR, men (especially those older than 40 years) are responsible for cultivation and management of the trees, whereas women take part in the marketing. Most fruits are usually sold in local markets. A traditional belief in the UWR, which says that you will die when you plant a tree and eat its fruit or sit under its shade, has scared many youth away from planting mangoes. In some ethnic groups, only nephews and very old people with a short lifespan are allowed to plant the trees for food and shade. However, this taboo is gradually fading away owing to educational campaigns.

3.3.3 Objectives of mango cultivation

The major purpose of planting mango trees is to produce fruit for domestic consumption. The fruit is high in sugar and vitamins, especially in vitamin A. In towns, it is a valuable dessert fruit, and in rural areas, it can serve as a whole meal during working days in the field. Almost all the mango producers that were interviewed said that they ate mangoes, and 97% declared that they had planted mango trees for fruit production and as a cash crop. Mangoes are also considered valuable for their esthetic value (shade) by 3% of the producers. Various community activities are held under the trees, such as formal and informal meetings, games, and commercial activities. Because of the size of the trees and the density of their foliage, mangoes are often planted in schoolyards, near administrative buildings, along avenues, and in parks, where social and commercial activities take place. Various parts of the mango tree are used to prepare medicinal mixtures to combat a range of diseases. Additional uses such as protection of the soil against soil erosion, the creation of windbreaks, and rootstock production for nurseries were also mentioned. When the tree is trimmed, the leaves are used to feed livestock and the wood is used for fuel.

3.3.4 Impact of *B. invadens* and other pests on mangoes

The main problems mentioned by mango producers throughout the survey were the infestation of mango trees by fruit flies (i.e., *B. invadens, Ceratitis*

(a) **(b)**

Fig. 6. Mango fruits (a) attacked by *Bactrocera invadens* and (b) that dropped prematurely as a result of *B. invadens* attack.

cosyra, Ceratitis capitata and mealybugs (*Rastrococcus invadens*) (Fig. 6a). Most of the producers had some knowledge of the mango mealybug, which has been present in the region for longer than the fruit fly. One of the descriptions given for a mealybug infestation was "a white worm with black powder that produces a honey-like oil". Some producers described the more recently introduced fruit fly as responsible for premature dropping of mango fruits, and described maggots found in the sliced fruit (Fig. 6b) Most producers (60%) agreed that the fruit fly was a serious pest and that it decreased fruit production. Mealybugs accounted for 13% of the pests found in mango fields, and were being controlled by biological means (by *Gyranusoidea tebygi*) (Hymenoptera: Encyrtidae). The reappearance of this pest in some areas in two years back may have resulted from indiscriminate use of chemical pesticides in cotton production. In most cases, the incidence of pests was reported to be higher at the beginning of the rainy season. Other farmers (27%) cited the red ant *Oecophyllya longinoda* (Hymenoptera: Formicidae) as another constraint, and others reported problems with termite (*Microtermes* spp). Many of these pests cause damage at subeconomic levels and become serious pests only locally, as a result of changes in cultural practices or indiscriminate use of pesticides.

3.4 Possibilities for Managing the Fruit Fly Problem: A General Overview

Current pest management practices are affected not only by the domestic and export fruit markets, but also by consumer attitudes toward health concerns and the cosmetic appearance of the fruit. In general, mango pest management depends strongly on the use of pesticides (Galan-Sauco, 1990; Nachiappan and Baskaran, 1986; Peña, 1993). However, control of pests of mango fruit by chemicals alone has been complicated by the development of resistance and a resurgence of minor pests that have been elevated to major pest status (Cunningham, 1984). The costs of pest control have also escalated, and in some cases, increasing amounts of pesticides are required to keep the large number of pest species under control.

In addition, most mango pests also attack other fruit crops. Fruit flies, scales, mites, thrips, lepidopteran flower feeders, weevils, and beetles are mostly generalists, and management schemes for these pests must therefore account for the other host crops used by these species. Aluja *et al.* (1997) suggested that in the case of fruit flies, an assessment of vegetation adjacent to the infested mango orchard is crucial. In the tropics and subtropics where mango is grown, the management of key pests (e.g., fruit flies, seed weevils) must become mandatory in order to have a significant effect within a large region. The use of measures such as quarantine must be practiced by neighboring producing areas in order to have a positive effect on sanitation for a particular crop. In areas where maximizing yields and the proportion of unblemished fruit are not priorities, the emphasis should be placed on biological control. Fruit fly control in sub-Saharan Africa is still in an experimental stage (Ekesi and Billah, 2006). Therefore, fruit fly control should focus on an IPM approach to ensure effective protection of the crop. Some management strategies that could be adapted for use in Ghana are described below.

3.4.1 Selective pesticides

Pesticides that are used in IPM programmes must have selective toxicity so that they do not affect non-target organisms. The current trend is the development of insect growth regulators that are highly effective for a limited group of insects. For example, Diaz *et al.* (1996) suggested the use of cyromazine to reduce the fertility of *Anastrepha obliqua* (Diptera: Tephritidae). Cunningham (1984) suggested that oils (e.g., petroleum and olive oil) could be used to control scales on mango. However, most of the recommendations from other countries are based on highly toxic or illegal, unregistered, persistent chemicals (Singh, 1991). Thus, there is a great need to research safe, pest-specific, effective chemicals that could be used in Ghana.

3.4.2 Biological control

Biological control has great potential for regulating pest populations in IPM programmes in mango orchards. However, it may be difficult for biological control alone to reduce a fruit pest from an economic problem to nuisance status. A combination of releases of parasitoids to augment their populations a and the release of sterile insects has been considered, at least in theory, to be more effective for fruit flies than either method applied alone (Barclay, 1987).

In Africa, several parasitoids are being tried to combat *B. invadens,* and *Fopius arisanus* (Hymenoptera: Braconidae) seems to be promising for controlling the species (Dr. M.K. Billah, 2008, pers. comm.). *Fopius arisanus* only attacks the fruit fly's eggs, and is currently reported to be the dominant fruit fly parasitoid in Hawaii (Purcell *et al.,* 1998; Wong and Ramadan, 1987), partly owing to its intrinsic competitive superiority against all larval fruit parasitoids (Wang and Messing, 2003). It was also reported as the most abundant parasitoid in Sri Lanka during the exploratory mission to that country in search of natural enemies for possible use in classical biological control against *B. invadens* in Africa (M.K. Billah, unpublished data). The government of Ghana must therefore invest in trials of this method, as was done in the past to control mealybugs on mangoes, (Moore, 2004) since it would be difficult for any individual or group of farmers to afford the cost of this technology.

3.4.3 Host plant resistance

Mango is tolerant to *Noorda* spp. and *Idioscopus* spp. (Bagle and Prasad, 1984; Cunningham, 1984) and resistant to *Sternochetus mangiferae* (Coleoptera: Curculionidae) Hansen (1993). Carvalho *et al.* (1996) have also demonstrated different degrees of susceptibility of mango cultivars to *A. obliqua.* Angeles (1991) reported that *Mangifera altissima* does not seem to be affected by mango pests such as leafhoppers, tip borers, and seed borers in the Philippines. There is little doubt that wild mangoes have potential value in breeding that has not yet been documented in relation to fruit flies. The tolerance or insect resistance of mango cultivars and related species should be determined in natural stands or in established germplasm collections. Therefore, tests for mango resistance to fruit flies should include provisions for exposure to the insects under varying conditions whenever possible, and researchers in the UWR should work towards achieving this goal.

3.4.4 Mechanical fruit protection (bagging or wrapping)

Fruit wrapping has been found to be effective in controlling fruit flies after their population has been reduced by baiting and trapping devices. Protective coverings such as newspaper, plastic and paper bags are effective in preventing fruit flies from laying eggs (Ekesi and Billah, 2006). Despite the cost of this approach, protective coverings are still being used to a certain extent by producers of high-value fruits for export and by home gardeners. For this approach to be effective, the fruits should be wrapped or bagged before the period when fruit flies are mostly likely to begin oviposition. If this method is shown to be practical in the UWR, mango farmers may be able to easily adopt this method to reduce fruit fly damage in the region.

3.4.5 Cultural controls

Two principal cultural methods can be used to control fruit flies: field sanitation and the use of trap crops. Field sanitation is particularly important. The method focuses on the destruction of all unmarketable and infested fruits and the disposal of crop residues immediately after harvesting. This is a laborious exercise, but can be effective if the fruits are collected twice a week and destroyed throughout the entire growing season. Infested fruits should be buried at least 3 feet under the soil surface. The addition of lime can help to kill emerging larvae. The fruits can also be chopped up and soaked to prepare bio-fertilizer or to feed livestock. The use of trap crops around the perimeter of a plantation can intercept pests during their migration, regardless of the direction of attack. This approach then concentrates the pest populations in the trap crops, where they can be controlled (e.g., by sanitation), thus preserving natural enemies in the main crop (Aluja *et al.,* 1997). Because many insect pests act as vectors of important crop diseases, reducing pest populations on the main crop may also reduce losses to these diseases. Early harvesting could also be done to reduce infestations, particularly for crops that will be exported (i.e., where the fruit will ripen in transit).

3.4.6 Release of sterile insects

The release of sterile insects is an environmentally friendly, species-specific method of insect control that has been described as "birth control for insects" (Knipling, 1992). It involves mass breeding of huge quantities of target insects in a "factory" and sterilizing the males. These sterile males are then released in the air over infested areas, where they mate with wild females, thereby reducing the number of viable eggs. The Sterile Insect Technique depends on the ability to mass rear millions of sterile flies for release at the appropriate time (when the pest population has not reached its peak) in order to overwhelm the pest population, and over very wide areas (Tan, 2000). This leads to a decrease in the reproductive potential of the resident pest population and ultimately to its eradication. For example, almost 1.5 billion flies were released in 1991 against *C. capitata* in the Kauai Coffee Plantation in Hawaii, resulting in a population suppression of 56% compared with a control of no release (Vargas *et al.,* 1994). These features make the SIT approach complex and expensive, and its efficacy may be compromised in situations where the population density of the pest flies are very high (Knipling, 1992). For example, eradicating the melon fly (*B. cucurbitae*) from southwestern Japan using this method cost more than 5 billion Japanese Yen (about US- million) and 200,000 worker-days (FAO, 1986). Such an approach also requires cooperation from neighboring countries to be effective and sustainable.

3.4.7 Male-annihilation technique

The male-annihilation technique involves the use of a high density of bait stations consisting of a male lure combined with an insecticide (usually malathion, and more recently fipronyl) to reduce the population of male fruit flies to such a low level that mating does not occur. This approach has been used successfully to control several *Bactrocera* species, such as *B. dorsalis* in Rota Island (Steiner *et al.,* 1965) and Japan (Ushio *et al.,* 1982). For example, coconut husk blocks impregnated with methyl eugenol and malathion could be used in Ghana. Findings from Ibrahim *et al.* (1979) and Qureshi *et al.* (1976, 1981), demonstrated that increasing the number of traps baited with methyl eugenol significantly decreased damage caused by Dacus fruit flies. As indicated by Lux *et al.* (2003), the new pest responds strongly to methyl eugenol, and it is technically possible to suppress it using the male-annihilation technique, as has been achieved in other tropical regions (Tan, 2000). This method could be easily applied in the UWR if mango farmers are introduced to it because of its ease of application, provided the materials are made affordable. But there are serious considerations and pre-requisites in the technical application of this strategy. According to Billah *et al.* (2006), this, however, requires that such actions are undertaken within hours after first detection or shortly after its introduction. They also require rigorous operational standards and are expensive, since resources have to be mobilized for large operations at very short notices. However, given the scarcity of the resources and the virtually non existent regular fruit fly monitoring programs, the design of any management strategy in this regard must be pragmatic and realistic.

3.4.8 Protein bait sprays

In this approach, the protein baits acts as a food attractant and its effectiveness relies on the fact that immature females need to consume protein (Ekesi and Billah, 2006) before they can produce mature eggs. The fly suppression is mainly based on use of food baits (hydrolyzed protein or their ammonium mimics) combined with a killing agent such as pesticide and applied in localized spots. These sprays are less harmful to beneficial insects, making them suitable for use in IPM programmes. Costs are considerably lower than in broadcast-spraying because less material is used per tree or per hectare. This method could easily be used by mango farmers in the UWR if they are taught how to apply the method and if the sprays are affordable.

3.4.9 Post-harvest fruit treatment

Without post-harvest treatment to provide quarantine security, the export of fruits and vegetables to lucrative markets is limited by quarantine restrictions. In fruit fly control, some of the available quarantine treatment technologies may include the following:

(i) heat treatment to increase the temperature of the host fruit above the insect's thermal limit
(ii) cold treatment to decrease the temperature of host fruit below the insect's thermal limit
(iii) the use of radiation to kill the insects

These approaches could be implemented by plant quarantine units and other experts at ports and border posts to ensure that only pest-free products are allowed to move between regions or countries. However, these treatments must not be detrimental to the fruits and vegetables, and therefore require trained expert users.

3.5 Strategic Plans to Manage the Fruit Fly Problem in the UWR

Based on the various interventions being adapted by various countries, I propose the following approach to manage the fruit fly problem in the UWR.

3.5.1 Enhance the knowledge of agricultural extension officers about appropriate methods for managing fruit fly damage to mangoes

(i) Organize training for agricultural extension officers on the identification and management of mango pests and diseases.

3.5.2 Teach mango farmers the knowledge and skills they need to identify mango pests and diseases and to control them

(i) Organize meetings with farmers in mango-growing communities to create awareness of mango pests and diseases.
(ii) Organize radio talk shows to educate farmers about the management of mango pests and diseases.
(ii) Facilitate the formation of mango farmer groups.
(iv) Organize training for mango farmer groups on how to identify and manage mango pests and diseases.

3.5.3 Give development partners access to information on mango pests and their management at the regional plant protection office

Establish an inventory programme to monitor fruit flies and other pests that are responsible for damage to mangoes in the target area.

(i) Develop and produce publications (e.g., control manuals and handbooks) on mango pests and diseases for stakeholders who need this information. For those who are not sufficiently literate to use these publications, provide training sessions based on these materials.

3.5.4 Monitor and supervise

(i) Monitor the fruit fly situation and report to the national Plant Protection and Regulatory Services Directorate (PPRSD).

4. Conclusion and Recommendations

4.1 Conclusion

Detection of economically important fruit flies is critical to the sustainability of agriculture. Survey data can reveal changes in the relative abundance of the fly population over time and indicate when populations have built up to dangerous levels in an area. This information can be used to define the measures that must be taken to reduce local populations of the insect pest in a target area. The preliminary knowledge of the *B. invadens* distribution pattern in the UWR provided by the present study should serve as baseline data from which further investigations could be carried out, starting with a district-wide delimiting survey that would help to determine appropriate methods for the detection, control, and management of the pest. As indicated by Lux *et al.* (2003), the new pest responds strongly to methyl eugenol, and it is technically possible to suppress it using the male-annihilation technique, as has been achieved in other tropical regions (Tan, 2000). This approach, however, requires that such actions be undertaken within hours after the first detection of a problem (i.e., before most of the males have a chance to breed) or shortly after the introduction of an insect into an area. Such programs also require rigorous operational standards and are expensive, since resources must be mobilized to conduct large operations at very short notice.

Given the scarcity of resources and the lack of regular fruit fly monitoring programmes in the UWR, the design of any fruit fly management strategy must adopt a more pragmatic and realistic approach that relies on educating all stakeholders and getting them involved in developing and implementing solutions. Since there has been a recent upsurge of fruit growing and export in Ghana, treating the fruit fly with a sense of urgency will go a long way toward improving the entire horticulture industry: solutions learned and implemented from controlling fruit flies can be extended to other pests.

4.2 Recommendations

Since *B. invadens* is of great quarantine concern and because it is capable of devastating Ghana's agricultural industry (especially mango production), the results of the present survey should be immediately communicated to the relevant quarantine authorities in Ghana: the district office of the Ministry of Food and Agriculture in the districts where the pests have been captured, the Savannah Agricultural Research Institute (SARI), and the PPRSD Head Office in Pokuase. The following recommendations should be implemented as soon as feasible to reduce the spread of the pest:

- Trapping and survey programs by the Ministry of Food and Agriculture in the UWR to provide up-to-date data that can be used to support decision-making.

Implementation and enforcement of phytosanitary measures to control the movement of materials that can host fruit flies. Fruit disinfection and the operation of roadblocks to prevent the movement of infested fruits between areas should be implemented, especially with cooperation from neighboring countries.

4.3 Issues for Future Study

Many of the techniques discussed in section 3 of this paper, such as the development of species-specific control methods, require detailed investigation to determine whether they will be effective in the UWR and how they can be adopted most effectively and economically. Further studies on the use of geographic information systems and Global Positioning System technologies to monitor the locations and dispersal of fruit flies and to allow prediction of outbreaks and spread of the insect would be helpful. Such studies can help managers to locate infestations, assess their condition, and detect trends and patterns (e.g., the relationship between infestations and rainfall patterns). Both tools can be very effective ways to manage trap locations and analyze capture data.

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