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Review

Review of the pest status, economic impact and management of fruit-infesting flies (Diptera: Tephritidae) in Africa

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Fruit flies are a major threat to the horticulture industry in Africa owing to their damage incidence and economic losses to fruit and vegetable crops, and their quarantine implications. Numerous studies with different research interests have been conducted on fruit flies throughout the African continent. Despite these studies, there is little knowledge among stakeholders about fruit fly pests in terms of the economically important species, their pest status, economic impact and control strategies. These parameters are prerequisites in designing management tools for addressing the fruit fly problem in the continent. This paper reviews the status of the fruit fly menace in Africa by reporting some of the findings of previous researchers while laying emphasis on what needs to be done.

Key words: Tephritid fruit flies, pest status, economic losses, management, Africa.

INTRODUCTION

Fruit and vegetable production is one of the fastest growing sectors of the horticulture industry in Africa (Weinberger and Lumpkin, 2007). The sector contributes to poverty alleviation by promoting food security while helping to increase total export earnings for African countries. It has been integral to any thinking of economic growth and development. A strengthened horticultural sector can have a positive impact on the Millennium Development Goals (MDGs) of Sub-Saharan Africa (SSA) (World Bank, 2008). Throughout Africa, several fruit and vegetable crops are grown for both domestic and export markets. The major ones include mango, citrus, pineapple, papaya, avocado, banana, tomatoes, peppers, okra, garden eggs and the cucurbits. More than 900,000 t of fruit and vegetables are exported annually while an unestimated volume is comsumed domestically (Weinberger and Lumpkin, 2007). For example, in 2007, the horticulture industry generated over US$ 16 billion in foreign exchange from exported commodities and over US$ 6,500 million domestically to the continent; directly and indirectly employing over 40 million people (World Bank, 2008). More than 50% of the production volume is affected by fruit fly infestation (USDA-APHIS, 2008). Several constraints however, hinder the sector from realizing its full potentials. Among them include: insufficient investments, inadequate basic and applied

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research, poor extension of existing innovations and methods of dissemination, porous quarantine borders and economic treaties, limited knowledge of the incidence and management of key pests and diseases (Norman, 2003). Currently, the key insect pest constraint for the increased and sustainable production of fruit and vegetable crops in Africa is infestation by fruit flies (Jaeger, 2008). Tephritid fruit flies have been recognized as one of the most economically important group of insects which pose serious threat to the horticultural industry in Sub-Saharan Africa (SSA) (White and Elson-Harris, 1992; Ekesi and Billah, 2006; De Meyer et al., 2012).

Fruit fly infestation has led to heavy losses in yield and quality of fresh fruits, and restrictions to quarantine-sensitive markets throughout Africa. Fruit fly research and management is yet to be fully optimized in most parts of Africa. There is limited knowledge and awareness among stakeholders along the fruit value chain in terms of the species concerned, their economic impact and management strategies (STDF, 2009). It is necessary to collate existing research information which is prerequisite for developing action plans and formulating management decisions for addressing the menace posed by these problem pests in the region. This paper presents a review of the economically important fruit fly species in Africa, the damage and losses they cause, their economic impact on the horticultural sector of SSA and available management options.

PEST SPECIES OF FRUIT FLIES

According to White and Elson-Harris (1992), Sub-Saharan Africa (SSA) is a reservoir of 915 fruit fly species from 148 genera, with over 299 species developing in both wild and cultivated fruits. Most species of fruit fly which attack commercially grown fruit and vegetable crops belong to two genera; *Ceratitis* and *Dacus* (White and Goodger, 2009). A few species belong to other genera such as the coffee fruit flies (*Trirhithrum* species*)* which are close relatives of *Ceratitis,* or the genus *Bactrocera,* which are close relatives of *Dacus* (White and Elson-Harris, 1992)*.* 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 1).

Indigenous fruit fly pest species in SSA

Sub-Saharan Africa is the 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 as *Ceratitis cosyra* (Walker), *C. quinaria* (Bezzi), *C. fasciventris* (Bezzi), *C. rosa* (Karsch), *C. anonae* (Graham) and *C. capitata* (Wiedemann). Traditionally, yield loss on mango due to native fruit flies can range between 30% and 70% depending on the locality, season and variety (Lux et al., 2003). Other important native *Ceratitis* species in the region include *C. rubivora* (Coquillet)*, C. puntata* (Wiedemann)*, C. discussa* (Munro), *C. ditissima* (Munro) and *C. pedestris* (Bezzi) that attack a variety of important fruits and vegetables. Several native *Dacus* species (e.g. *D. bivittatus* (Bogot) *D. lounsburyii* (Coquillet) *D. ciliatus* (Loew), *D. puntatifrons* (Wiedemman), *D. frontalis* (Becker), *D. vertebratus* (Bezzi) etc) also inflict considerable losses on vegetable crops especially the cucurbits (White and Elson-Harris, 1992; De Meyer et al., 2012; Ekesi and Billah, 2006).

Exotic fruit fly pest species in SSA

Although Africa is known to be the place 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 (De Meyer et al., 2012). In 2003, *B. invadens* was detected and described for the first time in Africa as a junior synonym of *B. dorsalis* (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., 2009). Although damages caused by *B. latifrons* are currently centered on local solanum species such as *Solanum aethiopicum* and *S. macrocarpon* (Mwatawala et al., 2009); damage to tomato (*Lycopersicon esculentum*) seems to be the largest (De Meyer et al., 2012). The melon fly *B. cucurbitae* has also been in Africa for years without a clear date of introduction (White and Elson-Harris, 1992).

Among all the native and exotic fruit fly species, one specie, *B. invadens,* that is commonly referred to as the African invader fly, is thought to be responsible for causing extensive economic losses to horticultural crops throughout Africa since its first detection in 2003 (Lux et al., 2003). The rapid spread and devastating impact of *B. invadens* in SSA has been a matter of serious concern to the horticulture industry (De Meyer et al., 2012).

DAMAGES CAUSED BY FRUIT FLIES

Because of their polyphagous habit, fruit flies inflict serious damages on a wide range of fruit and vegetable crops. Direct damage begins with female fly puncturing the fruit skin and ovipositing 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

Table 1. Economically important fruit fly species in Sub-Saharan Africa.

Genera	Species	Notes on pest status
Ceratitis	*Ceratitis 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.
	Ceratitis 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.
	Ceratitis 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. 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.
	Ceratitis 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.
	Ceratitis 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
	Ceratitis 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	*Dacus bivitattus* (Bigot)	Commonly called the pumpkin fruit fly. Occurs in eastern and West Africa. Mainly pest of cucurbits.
	Dacus 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.
	Dacus frontalis (Becker)	Occurs mainly in East and Southern Africa. Pest of cucurbits principally on cucumber, pumpkin and watermelon.
	Dacus vertebratus (Bezzi)	Commonly called the jointed pumpkin fly. Occurs in East, West and Southern Africa. Pest of cucurbits with special preference for watermelon.
	Dacus lounsburyii (Coquillet)	Occurs in East and Southern Africa. Recorded mainly on sweet melons, watermelons and pumpkins.
Trirhithrum	*Trirhithrum 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 1. Contd.

	Trirhithrum 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	*Bactrocera cucurbitae* (Coquillet)	Commonly called the melon fly. Reported from East and West Africa since1930s. Primary pest of both cultivated and wild cucurbits.
	Bactrocera 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)
	Bactrocera zonata (Saunders)	Commonly called the peach fruit fly. Pest in Egypt, Libya and Indian Ocean Island of Mauritius. It has 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.
	Bactrocera 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).

are introduced into the fruit. These bacteria reproduce and cause the tissues surrounding the egg to rot (Vayssières et al., 2009). 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 entry points for pathogens to infect, develop and increase the fruit decay. From a quantitative point of view, the damage is caused by larvae at the second and especially third instar stages, by the removal of the significant proportion of the pulp which consequently 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 and Billah, 2006).

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. Invasive species can alter succession 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 (Lyon and Miller, 2000).

ECONOMIC LOSSES AND IMPACT OF FRUIT FLIES

Fruit producing communities in Africa have experienced heavy losses due to fruit fly infestation. This occupies a large proportion of the profitable fruit crop production in the region (Lux et al., 2003). Annual damage to fruit and vegetable crops caused by fruit flies is worth millions of dollars (NRC, 1992). Prior to the invasion of Africa of *B*. *invadens*, the major fruit fly pests in Africa were the *Ceratitis* species, whose average damage was estimated at about 20-30% on mango and citrus (Lux et al., 2003). In South Africa, *C*. *rosa* ranked second in importance to *C*. *capitata* (CDFA, 2007). In many West African countries, *C*. *cosyra* featured prominently on mango (Lux et al., 2003). In recent years however, *C. cosyra* and other related species has continuously suffered competitive displacement by the invasive *Bactrocera* species (Ekesi and Billah, 2006). For example, the African invader fly, *B. invadens* is believed to be native to Sri Lanka and currently deported from 28 African countries including the Comoros Island and Cape Verde (Drew et al., 2005). 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 (Ekesi et al., 2009). Currently, *B*. *invadens* is found in almost all countries in sub-Saharan Africa. It is thought to be responsible for causing production losses to horticultural crops throughout Africa since its first report in 2003.

The export of potential host species of *B. invadens* such as mango, citrus, 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 the US banning importation of several cultivated fruits and vegetables from African countries where *B. invadens* has been reported. In the case of avocado, Kenya lost US$ 1.9 million in 2008 due to *B. invadens* quarantine restriction imposed by South Africa (USDA-APHIS, 2008). The current export volume for Mozambique is estimated at 35,000 t per year with a foreign exchange value of US$ 17.5 million, but South Africa, its major trading partner has closed its markets to fresh fruits from the northern part of the country due to the presence of *B. invadens*. At the Vanduzi Company in the Central province of Manica, about US$ 1.5 million has been lost due to the presence of *B. invadens* and quarantine restrictions on the export of various fresh fruits and vegetables (Cugala et al., 2009). The direct damage caused by *B. invadens* and other tephritid pests seriously threatens the income, food security and livelihood of millions of families that produce and sell fresh fruit and vegetables across Africa.

Bactrocera invadens is an overabundant, highly polyphagous species attacking 40 host fruit and vegetable crops in 22 families. Yield loss due to fruit fly damage may exceed 70% on mango and 40% on citrus (COLEACP-CIRAD, 2009). An assessment of damage of *B*. *invadens* on mango in Benin showed yield loss averages varying from 10 to 57% between the months of April and June (Vayssières et al., 2009).

In Senegal, fruit growers reported an average yield loss of about 40% all year round (Video Senegal, 2007). Production losses due to *B*. *invadens* in Ghana have been estimated to over 40% (UDSA-APHIS, 2008). The Phytosanitary Council of the African Union has described *B. invadens* 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 continent (Ekesi et al., 2009). Several countries in Africa continue to suffer significant loss in revenue due to lost export markets associated with the presence of *B*. *invadens*. A concerted effort is required by the fruit fly research communities to provide better understanding and technologies, build capacity and create awareness on the significance of this economically important pest to improve horticultural production in Africa and beyond.

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 (STDF, 2009). The effect of these pests has led to barriers to trade in fresh fruit commodities, costly surveys, control and eradication programmes throughout the world and thus, imposing limits on the export market (Ekesi and Billah, 2006). The introduction of uniform and strict maximum residue levels across Europe exacerbates the problem and further jeopardizes export of fruits and vegetables. Of greater concern, is the fact that even in countries where fruit fly management methods are undertaken, rejection by European markets is increasingly largely because with global trade and passenger travelling, they are easily translocated and the risk of majority of African fruit flies as key and potential quarantine pests is becoming increasingly realized (Ole-Moi Yoi 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 disinfestation treatments against fruit flies (White and Elson-Harris, 1992).

Since 2007, the African continent has experienced several interceptions of fresh mangoes imported to the European Union (EU) (Table 2). Though the updated data is currently unavailable, results should be regarded as a fluctuation rather than a reduction of the fruit fly problem. The rapid spread and devastating impact of *B. invadens* in SSA has been a matter of serious concern to the horticulture industry. Trade of several fruit and vegetable crops between Africa and the US has been severely hampered due to the Federal Order by US banning importation of several fruits from African countries where *B. invadens* has been reported (USDA-APHIS, 2008). These restrictions seriously threaten the income, food security and livelihood of millions of families that produce and sell fresh fruits and vegetables across Africa. With increasing emphasis on quality of fruit and vegetable produce, and the possibility of expansion of

Table 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).

trade in horticultural commodities, importing and exporting countries are giving increasing attention to fruit fly management at pre-harvest and post-harvest levels (Drew et al., 2005).

MANAGEMENT STRATEGIES FOR FRUIT FLIES

Fruit fly management generally involves two basic approaches: the eradication approach and the IPM approach (Lux et al., 2003; Ekesi and Billah, 2006).

The eradication approach

This approach usually involves an area-wide action to eliminate the target fruit fly population in order 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). It has been 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 fertile 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 wild females. It also has the advantage of being compatible with other control methods and has increased efficiency with decreased target population density (IAEA, 2003).

Although SIT for the African continent are currently unavailable, many attempts have been made worldwide in controlling these pests 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 possibility to produce sterile, viable and competitive males of *B*. *invadens* in Ghana and Africa as a whole.

The IPM approach

Previous experience with exotic and native fruit fly species in Africa has shown that management of fruit fly pests in general is unlikely to be successful if based on a single management technique (Allwood and Drew, 1997; Lux et al., 2003). 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 (Allwood and Drew, 1997). 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 two or more of the available tactics as discussed below:

Monitoring with attractants

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 and Billah, 2006). The estimate of pest abundance or a change in numbers provides an essential measure by which control decisions can be made. According to Manrakhan (2006), 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.

Tools used in monitoring fruit flies consist of attractants, traps and insecticides (used in traps as killing agents). The two main types of attractants used in fruit fly monitoring include parapheromones (male lures) and food baits (Lux et al., 2003).

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. 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 low levels such that mating does not occur or are reduced to low levels. Parapheromones are available in both liquid form and polymeric plugs (in the form of a controlled-release formulation). 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 (Ekesi and Billah, 2006; COLEACP-CIRAD, 2009). The traps and trapping procedures for monitoring fruit flies are dependent on the attractant and the nature of the area (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. 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). They are available in both liquid and dry synthetic forms. Available food baits include liquid proten hydrolysates, yeast products, ammonium salts, and the threecomponent lure (consisting of putrescine, ammonium acetate and trimethylamine) (Lux et al., 2003; IAEA, 2003; Ekesi and Billah, 2006). A number of commercial baits are now available in the market, such as GF-120 (Success® Apart), Nulure, Buminal and SolBait that are premixed with insecticides like spinosad for direct application (Ekesi et al., 2009; Vayssières et al., 2009). The bait system is 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. However, a major problem in the use of baits in Africa is that they are quite expensive and inaccessible to a large number of fruit and vegetable growers.

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 occurring 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). The soil can also be inoculated with neem cake and other botanical formulations to kill pupating larvae (Ekesi and Billah, 2006).

In recent studies, several potent isolates have been identified against *B. invadens* both for soil inoculation targeting pupariating larvae and adult using auto dissemination devices (Ekesi et al., 2009; 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. 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. This technique of fruit fly control is expected to be environmentally friendly and easily adoptable by farmers, and can be used as a supportive measure to the bait sprays. Further research on formulation of the fungus is underway and the product would be available for use in the near future.

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). Currently, there is no known published research on the use of post-harvest fruit treatment methods against tephritid pests in Africa, but once developed, these treatments should increase the export potential of tropical fruit and vegetable crops in the region (Ekesi and Billah, 2006).

CULTURAL CONTROL

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 developmental 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. Fruit destruction is achieved by crushing the infested fruit in a grinding machine or burying them deep (at least >50 cm) under the soil surface with addition of sufficient time to kill the developing larvae. This can contribute significantly to reduction in fruit fly populations on 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 is being strongly advocated among fruit and vegetable growers across Africa.

Cultural control for fruit flies is a laborious exercise but can be quite effective if the fruits are regularly collected and destroyed throughout the season. Collection and destruction of infested fruits is strongly recommended to reduce resident populations of fruit flies in orchards. 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. 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 reservoirs, crop sanitation has been an essential component of fruit fly management programmes in the Integrated Tamale Fruitts Company in 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.

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 infestation. To be effective, the fruits must be wrapped or bagged well before fruit fly attack that is, 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. At present, there is no known published research on the use of mechanical fruit protection methods against tephritid pests in the continent.

Prompt harvesting of fruits

Avoidance of fruit fly infestation is possible by harvesting fruits at the stage of maturity when fruits or vegetables are not very vulnerable to fruit flies. Fruit flies do not attack certain fruits such as papaya, banana and sapodilla when they are 100% green. Only the ripe fruits are susceptible. Bananas, for example, have been exported around the world because they are not susceptible to fruit flies at the mature green stage. An unsuccessful example of using early harvesting to control fruit fly is on mango where species like *B*. *invadens* and *C*. *cosyra* are still capable of infesting even immature or mature green mangoes (Ekesi and Billah, 2006). However, early harvesting to evade fruit fly infestation is an important technique in the production of these fruits.

Biological control

Biological control is the use of parasitoids, 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 flies (Stibick, 2004). A major hazard to natural enemies is the blanket spray of pesticides. 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. Biological control practices are advantageous in that the natural enemies are programmed to search for the target pests. It is also relatively safe, permanent and economical (Ekesi and Billah, 2006).

Among the parasitoid species the Opines, which are koinobionts, are the most abundant parasitoid group most frequently used in IPM and biocontrol programmes. 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 (Stibick, 2004). *Fopius* (*Opius*) *longicaudatus* var. *maliaensis* Fullaway, *Fopius* (*Opius*) *vandendoschi* Fullaway, and *Fopius* (*Opius*) *ariasanus* Fullaway, have become established in Hawaii and are primarily effective against the oriental and the Mediterranean fruit flies in cultivated crops. Releases that have taken place in Hawaii and noted that all the benefits are almost entirely due to *F*. *arisanus* (*Opius oophilus*) have been given extensive review. He observed a decreased infestation of about 80% in guava as a result of reduction in *B*. *dorsalis* populations through the effects of parasitism. Use of parasitic hymenoptera to control tephritid fly populations can be dated back to the 20th Century when natural enemies were 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 been conducted to the development of mass rearing systems for some species (Stibick, 2004), 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, oblique* and Caribbean fruit fly, *A . suspensa.* A recent study conducted in Benin on the use of predator ants to manage fruit flies revealed that *Oecophylla longinoda* significantly reduced the number of fruits damaged by deterring fruit flies. 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. Also, birds and rodents have been reported to cause a high level of larval mortality by consuming infested fruit (Drew et al., 2005). 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.

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*. 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 agro ecosystems, which can contribute to the suppression of fruit flies. Efforts to conserve these natural enemies through efficient management 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 effort.

Chemical control

Tephritid fruit flies have been controlled since the beginning of the 20th Century by combining baits 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 on 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 (Ekesi and Billah, 2006; Mwatawala et al., 2009; COLEACP-CIRAD, 2008). This technique consists of spreading wooden blocks impregnated with Methyl Eugenol and Malathion that massively attract male *Bactrocera* 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.

CONCLUSION

Despite extensive research, fruit flies still remain a major threat to fruit and vegetable production in Africa. The damage and economic impact of fruit flies should be of great concern to all stakeholders along the fruit value chain. Smallholder farmers in the African continent could be suffering from higher losses due to fruit fly infestation. The export potential of fresh fruits and vegetables from Africa could also be more threatened by these quarantine pests. A concerted effort is required by the fruit fly research communities to provide technologies, build capacity and create awareness on the importance of these pests for improving the horticulture industry in Africa. More research information is needed to document the species inventory, host plant diversity economic status and population dynamics of fruit flies in all ecological zones of Africa. There is the need to establish national committees in all member countries to help increase stakeholder awareness, and to develop and disseminate more adaptive and sustainable management strategies for addressing the fruit fly menace in Africa.

Conflict of Interest

The authors declare that they have no conflict of interest.

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