Chapter 22
Integrated Management of Fruit Flies – Case Studies from Uganda

Brian E. Isabirye, Caroline K. Nankinga, Alex Mayamba, Anne M. Akol, and Ivan Rwomushana

Abstract Fruit flies (Diptera: Tephritidae) pose a threat to commercialisation of the horticulture industry in Uganda. They impair the quality and quantity of fruits produced, and limit access to lucrative regional and global markets. Here we explore past and present efforts, and future plans for research and management, of fruit flies in Uganda. Early research geared towards collection and identification of fruit flies recognised the pest status of many species and highlighted the need for establishing sustainable management strategies. Subsequently large-scale research initiatives have substantially increased knowledge on the biology and ecology of fruit flies in Uganda. Based on these studies, integrated pest management (IPM) options for fruit flies have been designed and piloted. Amongst the most promising options are the Male Annihilation Technique (MAT) in combination with the Bait Annihilation Technique (BAT) or Protein Food Bait (PFB) and Orchard Sanitation (OS). Fruit bagging is also receiving attention. It is now recommended that IPM options are combined and scaled up in an area-wide approach. The government of Uganda has demonstrated genuine commitment to eradication of fruit flies through three key project initiatives: (i) Gaining insight into the ecological and physiological factors influencing fruit fly populations and infestation rates in mango-growing regions of Uganda (NARO-MSI); (ii) Equipping key technical personnel at local and district levels with knowledge on identification and management of key fruit fly pest species (NAADS); (iii) Promotion and adoption of IPM practices for fruit fly management (NARO-ATAAS). These initiatives will ensure the long-term sustainability of management options.

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1 Background

Horticulture is one of the fastest growing agricultural sub-sectors in Uganda, employing many people and with products now listed as strategic exports worth US$35 million per year (Uganda Export Promotions Board 2012). Although the monetary value of fresh fruit and vegetables has been increasing, fruit production is constrained by a multiplicity of pests and diseases, the most serious of which are fruit flies (Diptera: Tephritidae). In Uganda fruit flies cause heavy pre-harvest losses and thus prevent expansion of domestic trade in fruit and vegetables (Nakasinga 2002; Nemeye 2005; Okullokwany 2006; Mayamba et al. 2014; Nankinga et al. 2014a; Akol et al. 2013; Isabirye et al. 2016).

Uganda, like many developing countries, aims to expand its economy through increased export trade in fruits and vegetables using new technologies that can secure market access. Such exports are subjected to the sanitary and phytosanitary restrictions of the World Trade Organization (2016) agreement (www.wto.org)). Here we explore the various efforts to manage fruit flies in Uganda. We describe the research and development activity and various initiatives and approaches targeted at managing fruit flies in Uganda. Furthermore, future research and development needs are discussed.

2 About Uganda

Uganda lies across the Equator, between latitudes 4° 12´ N and 1° 29´ S and longitudes 29° 34´ W and 35° 0´ E. Temperatures range between 15° and 30 ° C. More than two-thirds of the country is represented by a plateau, lying between 1000 and 2500 m above sea level. Precipitation is fairly predictable, varying from 750 mm in Karamoja in the Northeast, to 1500 mm in the high rainfall areas on the shores of Lake Victoria, in the highlands around Mt. Elgon in the east, in the Rwenzori Mountains in the southwest, and some parts of Masindi and Gulu. Its climate is tropical, with a good distribution of rain throughout the year in most parts of the country and with two dry seasons per year (December–February and June–August), except for certain regions in the north of the country that have only one rainy season (April–October) and one dry season (November to March).

Agriculture is the backbone of Uganda's economy; 95 % of the population produces both crops and livestock for food and cash income. Many farms are small (0.5–1.5 acres) but there are also medium sized (5–20 ha) and large farms including ranches (average 1200 ha). Agriculture contributes over 15 % to the Gross Domestic Product (GDP) and over 90 % to the country's foreign exchange earnings (World Bank Report 2013). It also contributes over 60 % of total government revenue in

addition to employing more than 80 % of the total labour force and providing over half of the total income for the bottom three-quarters of the population. There is considerable scope for increased production of fruits and vegetables. The country is able to produce all year round and there is potential for organic production of exotic and off-season fruits and vegetables such as pineapples (*Ananas comosus* L. Merr), apple (*Malus domestica* Borkh.), bananas (*Musa* species) and passion fruit (*Passiflora edulis* Sims).

3 Fruit Fly Management in Uganda: A Historical Perspective

Early exploratory and surveillance projects on fruit flies were led by collectors from national museums in Europe, USA, Canada and Africa who still hold voucher material (Table 22.1). Work was targeted at the collection and identification of fruit flies in Uganda. By 1990, these studies had recognised the pest status of many species and highlighted the need for establishing a management strategy for fruit flies in Uganda (Nakasinga 2002). Following this several national and regional fruit fly initiatives began. In Uganda, key initiatives included: the *icipe*-led African Fruit Fly Programme (AFFP) which began in 1999; the Food and Agricultural Organization of the United Nations initiative (2005 to present); the Citrus Research International (CRI) initiative (2009–2010); the National Agricultural Advisory Services (NAADS) initiative (2009–2011); the Millennium Science Initiative (MSI-NARL-Uganda) (2010–2014); and the Agricultural Technology and Agribusiness Advisory Services (ATAAS) initiative (2011–2016).

These initiatives have resulted in an extensive pool of resources for surveillance, identification, field management, quality assurance, monitoring and suppression of fruit flies. Significant advances in the generation and use of knowledge on the biology and ecology of fruit flies in Uganda have been made (Nankinga et al. 2014a; Mayamba et al. 2014). Using this information, options for integrated pest management (IPM) of fruit flies have been designed and piloted in selected regions. The most common IPM options piloted have evolved around the use of: the Male Annihilation Technique (MAT) based on methyl eugenol which attracts mainly males; the Bait Annihilation Technique (BAT) based on waste brewer's yeast, mazoferm and GF-120 which attract female flies of all species; Orchard Sanitation (OS) which involves burying infested fruits and other good agronomic practices; and fruit bagging (FB) which involves the wrapping of fruits in paper bags 1 month after fruit set to prevent the female fruit flies depositing eggs in the immature fruit.

Table 22.1 Fruit fly species recorded in Uganda since 1909, and the respective Museums and Collection centres[a] where samples and information are held

Species	Museum
Bactrocera dorsalis (Hendel)	ANON, FSCA, IITAB, QDP, MRAC
Bactrocera munroi White	BMNH
Bistrispinaria atlas Munro	BMNH, CNC
Bistrispinaria fortis Speiser	BMNH
Bistrispinaria magniceps Bezzi	BMNH, CNC
Capparimyia bipustulata Bezzi	ANON, TAU, SANC, USNM
Capparimyia melanaspis Bezzi	TAU
Carpophthoromyia interrupta De Meyer	CNC
Carpophthoromyia pseudotritea Bezzi	BMNH, SANC
Ceratitis aliena Bezzi	BMNH
Ceratitis anonae Graham	TAU, USNM, BMNH, CNC, ICIPE, MRAC
Ceratitis argenteobrunnea Munro	BMNH, ICIPE, SANC
Ceratitis bremii Guarin-Maneville	CNC, FSCA, SANC
Ceratitis brucei Munro	BMNH
Ceratitis capitata Wiedemann	ANON, BMNH, MRAC, USNM
Ceratitis connexa Bezzi	SANC
Ceratitis cosyra Walker	ANON, ICIPE, MRAC, SANC
Ceratitis cuthbertsoni Munro	ANON
Ceratitis ditissima Munro	BMNH, CNC, ICIPE, TAU, USNM
Ceratitis edwardsi Munro	BMNH, CNC, SANC
Ceratitis fasciventris Bezzi	BMNH, CNC, ICIPE, MRAC, SANC, TAU
Ceratitis flexuosa Walker	USNM, BMNH, CNC, ICIPE, MRAC, SANC
Ceratitis hamata De Meyer	BMNH
Ceratitis marriotti Munro	BMNH
Ceratitis pedestris Bezzi	MRAC
Ceratitis pinnatifemur Enderlein	CNC
Ceratitis pinnatifemur Enderlein	MRAC, SANC
Ceratitis punctata Wiedemann	USNM, CNC, ICIPE, MRAC, SANC, TAU,
Ceratitis querita Munro	CNC
Ceratitis roubaudi Bezzi	CNC, MRAC
Ceratitis rubivora Coquillett	BMNH, FSCA, SANC
Ceratitis stipula De Meyer & Freidberg	CNC, MRAC, USNM
Ceratitis striatella Munro	BMNH, SANC, TAU
Ceratitis turneri Munro	BMNH
Ceratitis venusta Munro	BMNH, USNM
Ceratitoides nigromaculatus Hendel	CNC, DEI
Clinotaenia camerunica Hancock	BMNH
Dacus apiculatus White	CNC, FSCA
Dacus apostata Hering	TAU
Dacus armatus Fabricius	BMNH, MRAC, SANC
Dacus aspilus Bezzi	BMNH, SANC

(continued)

Table 22.1 (continued)

Species	Museum
Dacus bivittatus Bigot	CNC, FSCA, NMBZ, MRAC, USNM, NMKE
Dacus brevis Coquillett	CNC
Dacus ceropegiae Munro	TAU
Dacus chapini Curran	BMNH
Dacus ciliatus Loew	ANON, BMNH, SANC, MCSNM
Dacus croceus Munro	BMNH, CNC, SANC
Dacus disjunctus Bezzi	BMNH, CNC
Dacus elegans Munro	TAU
Dacus externellus Munro	CNC, SANC
Dacus fasciolatus Collart	ANON, SANC
Dacus freidbergi Munro	SANC
Dacus hamatus Bezzi	NMKE
Dacus hargreavesi Munro	BMNH, SANC
Dacus humeralis Bezzi	FSCA, MRAC
Dacus inflatus Munro	CNC
Dacus inornatus Bezzi	BMNH, SANC
Dacus katonae Bezzi	BMNH
Dacus langi Curran	MRAC
Dacus limbipennis Macquart	BMNH, CNC, MRAC, SANC, TAU, FSCA
Dacus linearis Collart	CNC, TAU
Dacus longistylus Wiedemann	BMNH
Dacus macer Bezzi	BMNH, CNC, MRAC, SANC, TAU, USNM
Dacus masaicus Munro	CNC, TAU, FSCA
Dacus maynei Bezzi	ANON, CNC, MRAC, SANC, TAU, USNM
Dacus mediovittatus White	MRAC
Dacus nigriscutatus White	TAU
Dacus notalaxus Munro	SANC
Dacus parvimaculatus White	CNC
Dacus phimis Munro	SANC
Dacus punctatifrons Karsch	ANON, BMNH, CNC, FSCA, MRAC, SANC
Dacus rufoscutellatus Hering	TAU
Dacus schoutedeni Collart	BMNH, CNC
Dacus siliqualactis Munro	ANON, BMNH, SANC, MRAC
Dacus sphaeristicus Speiser	TAU
Dacus spissus Munro	BMNH
Dacus telfaireae Bezzi	FSCA, MRAC
Dacus tenebricus Munro	ANON, SANC, USNM
Dacus theophrastus Hering	CNC
Dacus triater Munro	CNC, TAU
Dacus yangambinus Munro	CNC
Leucotaeniella guttipennis Bezzi	BMNH
Perilampsis formosula Austen	BMNH, SANC, TAU

(continued)

Table 22.1 (continued)

Species	Museum
Perilampsis pulchella Austen	BMNH, MRAC, SANC, TAU, USNM, ICIPE
Trirhithrum albomaculatum Rader	TAU
Trirhithrum brachypterum Munro	BMNH
Trirhithrum coffeae Bezzi	BMNH, CNC, MRAC, SANC, TAU, USNM
Trirhithrum demeyeri White & Hancock	BMNH
Trirhithrum fraternum Munro	BMNH, CNC
Trirhithrum homogeneum Bezzi	ANON, BMNH, SANC
Trirhithrum inscriptum Graham	CNC
Trirhithrum meladiscum Munro	BMNH
Trirhithrum micans Munro	BMNH, PPHZ, SANC, TAU
Trirhithrum nigerrimum Bezzi	ANON
Trirhithrum nigrum Graham	NMW
Trirhithrum notandum Munro	BMNH, CNC, SANC, TAU
Trirhithrum occipitale Bezzi	BMNH, CNC, TAU, USNM
Trirhithrum overlaeti Munro	BMNH
Trirhithrum quadrimaculatum White	BMNH
Trirhithrum transiens Munro	BMNH
Trirhithrum validum Bezzi	BMNH, TAU
Zeugodacus cucurbitae Coquillett	FSCA, MRAC

Nakasinga (2002), Ekesi and Billah (2006), Mayamba et al. (2014), Isabirye (2015)
[a]*ANON* Non Specified Collection; *BMNH* Natural History Museum, London, UK; *CNC* Canadian National Collections, Ottawa, Canada; *DEI* Deutsches Entomologisches Institut, Eberswalde, Germany; *FSCA* Florida State Collection of Arthropods, Gainesville, USA; *ICIPE* International Centre of Insect Physiology and Ecology, Nairobi, Kenya; *IRSNB* Koninklijk Belgisch Instituut voor Natuurwetenschappen, Brussel, Belgium; *IITAB* International Institute for Tropical Agriculture, Cotonou, Benin; *MCSNM* Museo Civico di Storia Naturale, Milan, Italy; *MRAC* Koninklijk Museum voor Midden Afrika, Tervuren, Belgium; *PPHZ* Plant Protection Research Institute, Harare, Zimbabwe; *QDPI* Queensland Department of Primary Industries, Brisbane, Australia; *NMW* Naturhistorisches Museum Wien, Austria; *NMBZ* Natural History Museum of Zimbabwe, Bulawayo, Zimbabwe; *NMKE* National Museums of Kenya, Nairobi, Kenya; *SANC* Plant Protection Research Institute, Pretoria, South Africa; *TAU* Tel Aviv University, Tel Aviv, Israel; *USNM* United States National Museum of Natural History, Washington D.C., USA

4 Milestones and Achievements in Management of Fruit Flies in Uganda

4.1 Status of Knowledge on Fruit Flies in Uganda

4.1.1 Diversity and Distribution

Uganda has a rich diversity of fruit flies; to date 102 species from ten genera have been reported (Nakasinga 2002; Nemeye 2005; Okullokwany 2006; Ekesi et al. 2006; Isabirye et al. 2015a; Table 22.1). Amongst the most diverse genera are

Dacus, Ceratitis and *Trirhithrum*, while the least diverse are *Ceratitoides, Clinotaenia, Leucotaeniella* and *Perilampsis*, each with only one species. Species in the genera *Bactrocera, Ceratitis, Trirhithrum* and *Dacus* are the most economically important. Overall, the oriental fruit fly, *Bactrocera dorsalis* (Hendel), is the most important pest species accounting for 99 % of all fruit flies collected in three of the main fruit growing zones in Uganda (Mayamba et al. 2014; Isabirye et al. 2015a). Intraspecific diversity (allopatric and host-associated) is prevalent amongst some species of fruit flies in Uganda (Isabirye et al. 2012, 2014a). Significant differences in allometry and developmental instability (fluctuating asymmetry) amongst host plants has also been reported (Akol et al. 2013). Such geographic and host-associated fluctuating asymmetry or adaptations may affect the efficiency of common control methods.

Fruit flies are widely distributed across Uganda and in most of the major agro-ecological zones. However, they are marginal in Karamoja, Bushenyi, the Kabale-Rukungiri highlands and the Kisoro-Kibale highland zones (Isabirye et al. 2015b). Isabirye et al. (2014b) predicted that future fruit fly ranges are likely to have declined by approximately 25.4 % by the year 2050. Species richness was predicted to decrease differently across zones. Future niches are predicted to shift northwards to more humid regions (Isabirye et al. 2014b).

Seasonality in population abundance has been recorded for *B. dorsalis* and *Ceratitis* species (Fig. 22.1a, b). Populations of adult *B. dorsalis* increase from April and peak during the July fruit season. They then decline from August when the fruit season has finished. Populations of *Ceratitis* species are generally extremely low; the largest trap catches are observed in May but they fluctuate widely over the trapping period (Mayamba et al. 2014). These seasonal patterns have been attributed to climate (precipitation and temperature) and biophysical (e.g. host availability) variables (Mayamba et al. 2014; Akol et al. 2013).

4.1.2 Host Utilization

The major fruit fly pest species in Uganda have been reported from a wide range of host plants. For example, *B. dorsalis*; the Mediterranean fruit fly (medfly), *Ceratitis capitata* (Weidemann); the Natal fruit fly, *Ceratitis rosa* Karsch; and the melon fly, *Zeugodacus cucurbitae* (Coquillett) all with a wide range of host plants (Table 22.2). Damage attributed to fruit fly infestation on mango, *Mangifera indica* L., ranged from 33 to 83 % (Nankinga et al. 2014a). In a study by Isabirye et al. (2016), 1,812 fruits from 38 fruit species, 30 genera and 18 plant families were sampled in three agro ecological zones: Lake Victoria Crescents (LVC), Western Highlands (WH), Northern Highlands (NH) and 35 % of the samples were positive for fruit fly infestation. *Bactrocera dorsalis* was the predominant species found, being recorded from 29 of the 38 plant species and 76.3 % of the infested fruits (Isabirye et al. 2016). Excluding *B. dorsalis*, the proportion of fruit infested by a given fruit fly species ranged from 7.9 % for infestation by the coffee fruit fly, *Trirhithrum coffeae* Bezzi, to 65.8 % for infestation by *C. rosa*. The most heavily infested fruits came from

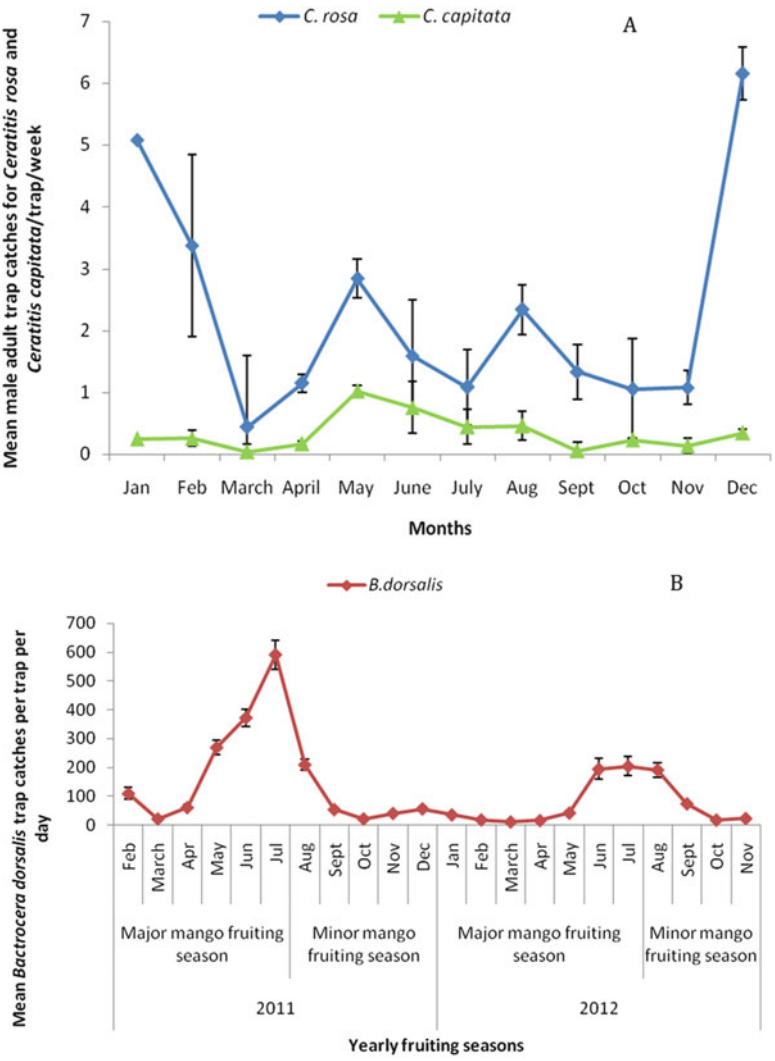

Fig. 22.1 Seasonal population fluctuation (Mean ± standard errors) of *C. rosa* and *C. capitata* (**a**) *B. dorsalis* (**b**) in mango orchards in the Lake Victoria Crescents zone, Uganda (Mayamba et al. 2014)

plants in the family Combretaceae, followed by Anacardiaceae and Myrtaceae, while plants in the Verbenaceae, Rutaceae and Euphorbiaceae were least infested. Tropical almond (*Terminalia catappa* L.) was the preferred host of *B. dorsalis*, followed by guava (*Psidium guajava* L.), mango, avocado (*Persea americana* Mill.) and oranges (*Citrus sinensis* L.)/ other *Citrus* species. Amongst mango varieties, significant differences in infestation levels were common both within and across ecological zones in Uganda (Agum 2014; Mayamba et al. 2014; Nankinga et al.

Table 22.2 Host plants of the major fruit fly pest species in Uganda

Species	Host plant
Bactrocera dorsalis (Hendel)	*Anacardium occidentale* L., *Mangifera indica* L., *Sclerocarya birrea* (A. Rich) Hochst, *A. muricata, A. senegalensis, A. squamosa, C. papaya, Terminalia catappa* L., *C. melo, Cucurbita* spp., *P. americana, Antiaris toxicaria* Lesch., *Ficus* sp., *Musa* sp., *Acca sellowiana* (O. Berg) Burret, *Eugenia uniflora* L., *P. guajava, Cydonia oblonga* Mill., *Prunus* spp., *Coffea arabica* L., *Citrus limon* (L.) Burm.f., *Citrus reticulata* Blanco, *Citrus sinensis* (L.) Osbeck, *Citrus* spp., *Manilkara zapota* (L.) P. Royen, *C. annuum, Solanum lycopersicon* L., *Solanum* spp., *Theobroma cacao* L.
Bistrispinaria fortis (Speiser)	*Sorghum vulgare*
Bistrispinaria magniceps (Bezzi)	*Panicum maximum* Jacq.
Capparimyia bipustulata (Bezzi)	*Capparis erythrocarpus*
	Capparis sp.
Capparimyia melanaspis (Bezzi)	*Maerua* sp.
Ceratitis anonae (Graham)	*Myrianthus arboreus* Beauv.
	Artocarpus sp.
	Syzygium jambos L. (Alston)
	M. indica, *A. muricata*, *T. catappa*, *P. americana*, *A. toxicaria*, *Artocarpus* sp., *E. uniflora*, *P. guajava*, *C. arabica*, *Citrus* spp., *Solanum* spp., *T. cacao*
Ceratitis capitata (Wiedemann)	*Coffea canephora* Pierre ex A Froehner, *C. oblonga, Ficus* sp., *M. indica, M. zapota*, *Prunus persica* L. (Batsch), *A. occidentale, Annona cherimola* Mill., *A. muricata*, *A. reticulata*, *A. squamosal*, *C. papaya*, *T. catappa*, *Cucurbita* spp., *P. americana* Mill., *Ficus* sp., *P. guajava*, *Prunus* spp., *C. arabica*, *C. sinensis*, *Citrus* spp., *C. annuum, S. lycopersicon*, *Solanum* spp., *Vitis vinifera* L.
Ceratitis cosyra (Walker)	*M. indica, Sclerocarya birrea* (A. Rich) Hochst, *A. cherimola, A. senegalensis, P. guajava, Citrus* spp.
Ceratitis ditissima (Munro)	*Chrysophyllum albidum* G. Don, *Citrus paradisi* Macfad.
Ceratitis edwardsi (Munro)	*Voacanga* sp., *Voacanga thouarsii* Roem. & Schult.
Ceratitis fasciventris (Bezzi)	*M. arboreus*, *C. arabica*, *M. indica*, *Pancovia turbinate* Radlk., *P. guajava, Syzygium jambos* L. (Alston), *P. americana, C. limon, Solanum* spp.
Ceratitis flexuosa (Walker)	*M. indica*
Ceratitis punctata (Wiedemann)	*C. albidum*, *Ficus* sp., *M. indica*
	T. cacao, *S. birrea*

(continued)

Table 22.2 (continued)

Species	Host plant
Ceratitis rosa	*A. occidentale*, *M. indica, A. muricata, A. reticulata, A. senegalensis*, *A. squamosa*, *Cananga odorata* (Lam.) Hook & Thomson, *C. papaya*, *T. catappa, Cucurbita* spp., *Drypetes* natalensis (Harv.) Hutch., *P. americana, Ficus* sp., *A. sellowiana, P. guajava, Prunus* spp., *C. arabica, C. reticulata, C. sinensis, C. albidum, M. zapota*, *S. lycopersicon*, *Solanum* spp., *T. cacao*, *V. vinifera*
Ceratitis stipula De Meyer & Freidberg	*M. arboreus*
Ceratitis striatella (Munro)	*Pycnanthus* sp.
Ceratitis venusta (Munro)	*Solanum naumannii* Engl.
Dacus armatus (Fabricius)	*M. indica*
Dacus bivittatus (Bigot)	*Cucurbita* spp., *Momordica charantia* L., *Vitex* spp., *C. melo*, *S. lycopersicon*, *M. indica*
Dacus ciliatus (Loew)	*M. charantia*, *S. birrea*, *C. papaya, C. melo*, *P. guajava, Citrus* spp., *C. annuum, S. lycopersicon*
Dacus humeralis (Bezzi)	*M. indica*
Dacus langi (Curran)	*M. indica*
Dacus limbipennis (Macquart)	*M. charantia, Momordica* sp.
Dacus mediovittatus (White)	*M. indica*
Dacus punctatifrons (Karsch)	*Gloriosa* sp., *M. indica, Melothria* sp.
Dacus siliqualactis (Munro)	*Gomphocarpus semilunatus* A. Rich
Dacus telfaireae (Bezzi)	*M. indica*
Dacus tenebricus (Munro)	*G. semilunatus*
Perilampsis formosula (Austen)	*Ficus* sp.
Perilampsis pulchella (Austen)	*Ficus* sp., *Loranthus* sp.
Trirhithrum coffeae (Bezzi)	*C. arabica*, *C. canephora*, *Citrus* spp. *C. annuum*
Zeugodacus cucurbitae (Coquillett)	*Annona muricata* L., *Annona reticulata* L., *Annona senegalensis* Pers., *Annona squamosa* L., *Carica papaya* L., *Cucumis melo* Ser., *Persea americana* Mill., *Psidium guajava* L., *Citrus* spp., *Capsicum annuum* L., *Solanum* spp.

Nakasinga (2002), Ekesi and Billah (2006), Mayamba et al. (2014), Isabirye (2015)

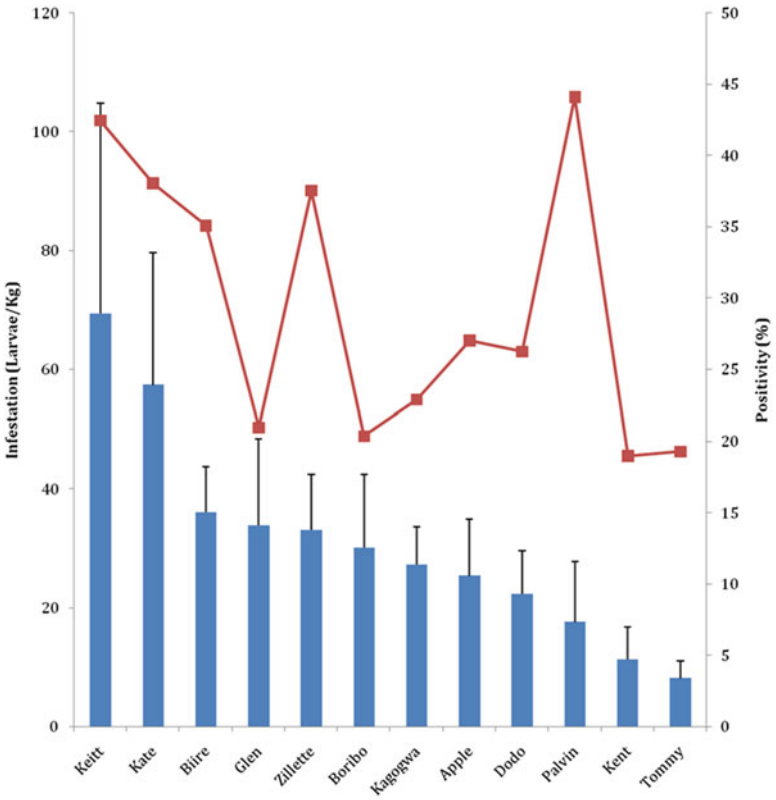

Fig. 22.2 Mean variability in infestation of different mango cultivars from three major fruit growing zones in Uganda (Nankinga et al. 2014a). Positivity = the proportion of samples that are positive for fruit fly infestation

2014a; Isabirye et al. 2016). Overall, the varieties Tommy, Atkin and Kent were the least likely to be infested, while the varieties Keitt, Kate and Biire were the most likely to be infested (Nankinga et al. 2014a; Fig. 22.2). There was also a significant interaction between zones and variety in the degree of infestation (larvae per kg). For instance, the varieties Glen and Boribo had significantly higher levels of infestation in the LVC zone than in the NMH zone, while the varieties Kate and Keitt had significantly higher levels of infestation in the NMH zone than in the LVC zone (Isabirye et al. 2016). Early maturing varieties seemed to be more susceptible to infestation than mid-season varieties (Isabirye et al. 2016). The differences in degree of infestation have been attributed to variability in physical, chemical and post-alighting cues produced by the host plant (Agum 2014; Akol et al. 2013). Also, as the mango season progresses from fruit set to ripening the availability of mature fruits increases as does the population of fruit flies and the level of fruit damage (Mayamba et al. 2014; Isabirye 2015). It has been demonstrated that female *B. dorsalis* have evolved to oviposit on host plant species on which their offspring are

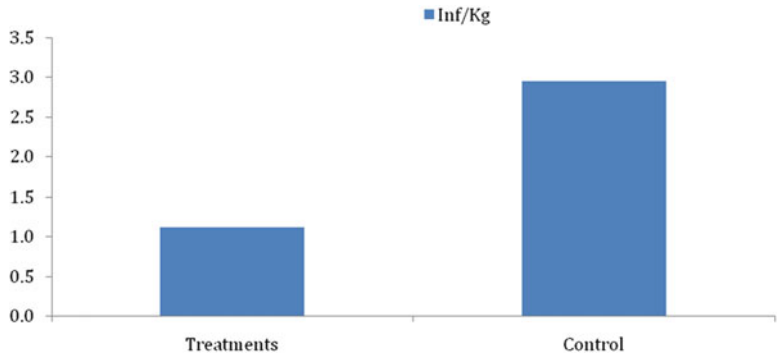

Fig. 22.3 Effect of treatment (BAT + MAT + OS) on infestation of citrus by fruit flies in eastern Uganda (NARL Annual Report 2011)

likely to fare best, in support for the Preference Performance Hypothesis (PPH) (Akol et al. 2013). However, the PPH is not very evident amongst different cultivars of the same host plant species, with the trends more closely supporting the Optimal Foraging Theory (OFT) (Akol et al. 2013). However, this still implies that female *B. dorsalis* use information from host fruits to determine host fruit quality and optimize offspring growth and survival.

4.2 Farm Level Fruit Fly Management Initiatives in Uganda

There have been several initiatives aimed at the management of fruit flies in Uganda. Amongst these are:

4.2.1 Citrus Research International (CRI) Initiative

In 2010, CRI in collaboration with the National Agricultural Research Organisation (NARO) of Uganda supported trials on the management of *B. dorsalis* on smallholder citrus orchards in Eastern and Central Uganda. Treatment farms used a combination of MAT (specifically for *B. dorsalis*); BAT (hydrolyzed protein-Mazoferm) and bio lures (for all species); and OS (specifically burying fruits). Control farms (standard farm practice) undertook irregular weeding and seldom applied conventional pesticides such as cypermethrin and malathion. Fewer fruit fly emergences were recorded from fruits sampled from farms employing the three treatment components (MAT + BAT + OS) compared with control farms (Fig. 22.3). In another similar trial where the treatment components were separated, the BAT + MAT and MAT alone treatments significantly reduced the diversity of fruit fly pests in citrus orchards compared with control treatments (standard farm practice) (Fig. 22.4). The BAT alone treatment was less effective in reducing the diversity of fruit flies

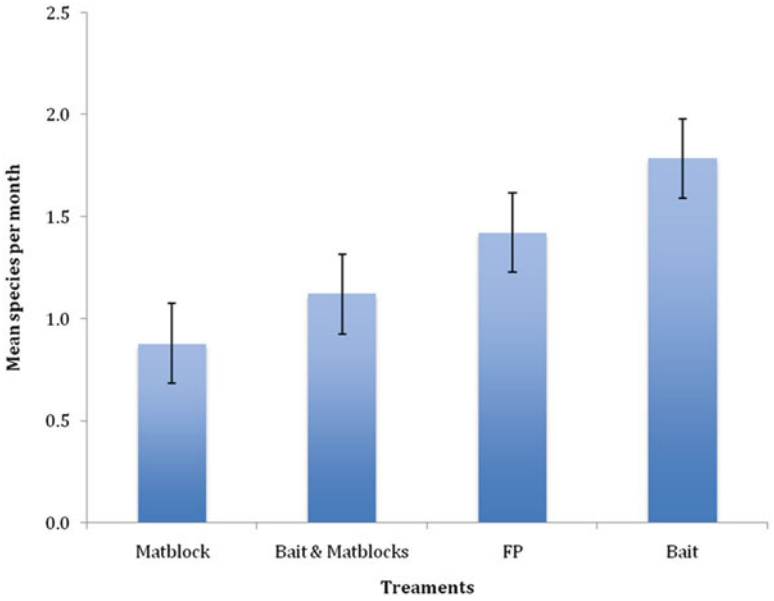

Fig. 22.4 Effect of different treatments on the diversity of fruit flies in citrus orchards in Eastern Uganda (NARL Annual Report 2011)

compared with the control, although the difference between the two was not statistically significant (Nankinga et al. 2014b).

4.2.2 Millennium Science Initiative (MSI-NARL-Uganda) Initiative

This project aimed to gain insight into the physical, ecological and biochemical factors influencing fruit fly infestation of mango in Uganda. Three students (one PhD and two MScs) were trained and a knowledge base established for evaluating IPM options for fruit fly control in Uganda. In initial surveys, MSI fruit fly project found that most commercial farmers were applying conventional insecticides and local botanical mixtures as standard farm practice to control fruit flies. The initiative validated and promoted IPM options based on combinations of MAT, BAT and OS (Nankinga et al. 2014a; Fig. 22.5). Results further confirmed that a combination of MAT + BAT + OS were effective in reducing fruit fly damage, compared with the common practice of using only MAT or standard farm practice (Nankinga et al. 2014b, c). In particular, deep burying of infested fruit (OS) killed larvae, preventing them from developing and emerging as adult flies and returning to the crop (Millennium Science Initiative 2013).

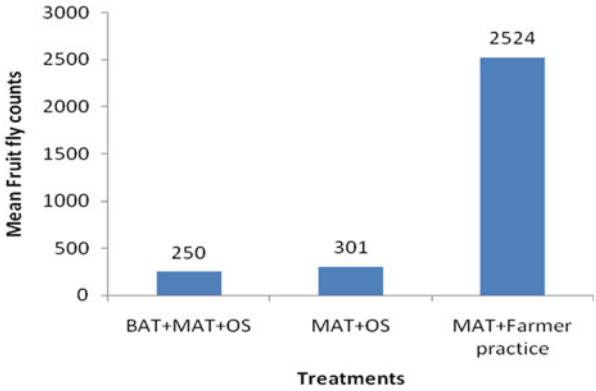

Fig. 22.5 Effect of three main treatments on abundance of fruit fly pests in Uganda (Millenium Science Initiative 2013)

4.2.3 National Agricultural Advisory Services (NAADS) Initiative

In response to countrywide outcry about the severe effects of fruit flies, particularly *B. dorsalis*, NAADS conducted several awareness and capacity building initiatives between 2009 and 2011, to underpin the development of fruit fly control strategies. NAADS also provided farmers across the major fruit growing regions in Uganda, with tools and materials, such as traps, attractants and pesticides. The initiative also attempted to establish a countrywide extension network to monitor fruit fly populations in different regions.

4.2.4 *icipe*'s African Fruit Fly Programme (AFFP), Previously Called the African Fruit Fly Initiative (AFFI)

AFFP was established in response to requests from African fruit growers, national authorities and regional commodity and quarantine bodies and began in 1999. In Uganda, AFFP assisted with assessing the impact of fruit fly infestation on key crops with: development and testing of affordable fruit fly management methods; exploring and releasing natural enemies of fruit flies; establishing parameters for post-harvest treatment; producing and disseminating tools, distribution maps and pest identification keys for strengthening fruit fly quarantine; and with training personnel. Through *icipe*-led monitoring efforts, at least eight new fruit fly species were recorded in Uganda with voucher specimens stored in the *icipe* museum facility (records from *ICIPE* on Table 22.1). Control and monitoring methods based on commercially available (food bait-waste brewer's yeast, entomopathogenic fungi, and other attractants) were evaluated on-farm. Given the similarity of agro-ecological zones across East Africa, it is possible that *icipe*-released (in Kenya) *Fopius arisanus* (Sonan) parasitoids; (targeting *B. dorsalis*) have spread into Uganda (Ekesi and Billah 2006).

4.2.5 Food and Agricultural Organization of the United Nations (FAO) Initiative

FAO has supported various horticultural initiatives in Uganda. They funded the first major programme on surveillance and management of *B. dorsalis* in Uganda (Nemeye 2005). This initiative was part of the emergency response activities of the governments of Kenya, Tanzania and Uganda following the first detection of *B. dorsalis* in Kenya. Since then, FAO has continued to support local government in Uganda with capacity building and provision of farm inputs such as seedlings of high-yielding fruit varieties, lures and other fruit fly control tools. FAO have trained over 650 farmers from 21 agricultural functional groups and four farmer associations.

4.2.6 The Agricultural Technology and Agribusiness Advisory Services (ATAAS) Initiative

ATAAS is a government of Uganda 5-year project that started in 2011 and is administered by the Ministry of Agricultural Animal Industry and Fisheries (MAAIF). ATAAS seeks to address the weak linkage between the different participants involved in agricultural research and development in Uganda. The initial fruit fly control strategies that were planned, tested and promoted under MSI (i.e. combinations of MAT + BAT + OS) are being scaled up for area-wide fruit fly management in selected fruit growing zones in Uganda, as part of the ATAAS initiative. In addition, under ATAAS, NARO is evaluating the bagging of fruit prior to maturity as a management option for fruit flies. Preliminary results are finding fewer fruit fly infestations in fruit that have been bagged compared with unbagged fruit. These results were consistent in all three districts where the experiment was done (Nankinga et al. 2014b, c); Fig. 22.6).

4.3 Future Plans and Ways Forward on Fruit Fly Management in Uganda

Despite the economic importance of tephritid fruit flies to horticultural production and exports for Uganda, there is currently no coordinated national management plan for fruit flies in the country. The various government agencies have no specific budgetary support for fruit flies; instead, interest in these pests is vested in the professional interests of individual scientists. A management plan is essential to identify and offer information on the risk levels of key fruit fly pests in the country, their biology and ecology, diagnostic protocols and response plans, preparedness and prevention measures, surveillance and detection strategies, and management information.

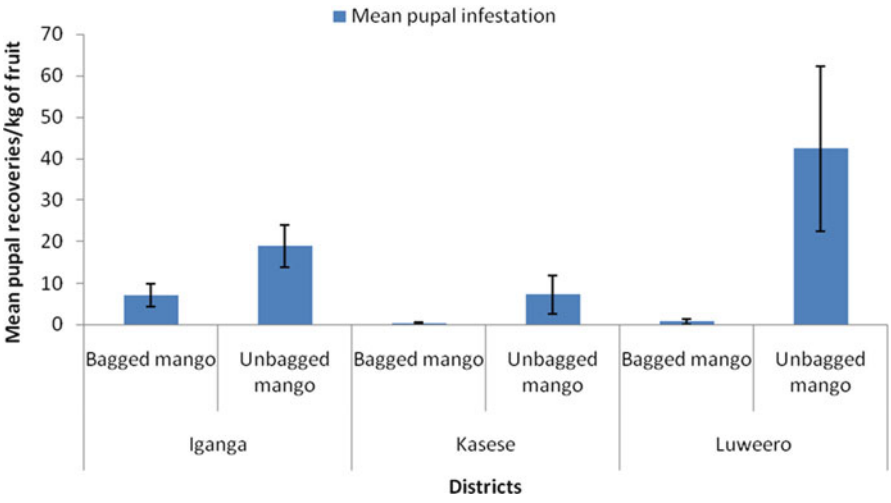

Fig. 22.6 Mean recovery of pupal (±) SE from bagged and un-bagged fruits sampled in four mango growing districts in Uganda, 2013 (NARL Quarterly Report 2014)

In support of a national fruit fly management plan there is a need to collect, collate and archive species-specific data sets on the key fruit fly pest species. Out of the MSI-supported initiative on ecology and management of fruit flies in Uganda, a small collection of tephritid fruit flies was collated and is archived in the Zoology department of Makerere University. Existing data sheets should be regularly updated, the information stored in a single accessible portal, and its utilization promoted widely. The information accessible through this portal should include diagnostic protocols, treatment schedules, pest data sets, national standards and information on premium markets and phytosanitary requirements. This would help to identify knowledge gaps and assist in the development of a national research priority list (including a capacity gap analysis of the production supply chain) to inform research providers. Establishing an accessible and regularly updated knowledge hub that provides all relevant fruit fly information would represent a valuable network for communication and collaboration that could ultimately improve the effectiveness of the various ongoing fruit fly management initiatives.

An effective knowledge hub is only possible if the information on it is accurate and there are mechanisms in place for the information to be validated and continuously improved and updated. For example, a nationally agreed standard for fruit fly diagnosis and surveillance is required. This would include a national diagnostics network of all relevant national and international experts, laboratories and centres of expertise, essential equipment and reference collections, thereby providing a tool to promote communication and collaboration. These standards should meet market access requirements of local, regional and international markets. Furthermore, the current technologies, innovations, and management practices for fruit flies in Uganda need to be validated and agreed. Standard guidelines for site-specific

implementation of the different control packages need to be developed and include the potential for scaling up. This would support current activities focused on implementing the various management options and the documentation of realistic pathways for their increased adoption.

Finally, efforts to raise awareness concerning the impact of fruit flies should be increased to encourage a change in attitudes and behavior in relation to the management options adopted. This should include the development of a national communication strategy that could analyze current awareness activities, identify possible synergies amongst participants, and propose and implement an innovative communication strategy for fruit fly management in Uganda.

References

Agum WO (2014) Fruit physical and physiological factors influencing mango fruit infestation by fruit flies in the Lake Victoria Crescent agro ecological zone ff Uganda. MSc thesis, Gulu University, Uganda

Akol AM, Masembe C, Isabirye BE, Kukiriza CN, Rwomushana I (2013) Oviposition preference and offspring performance in *Bactrocera invadens* (Diptera: Tephritidae). Int Res J Hort 1:1–14

Ekesi S, Billah MK (eds) (2006) A field guide to the management of economically important Tephritid fruit flies in Africa. ICIPE Science Press Nairobi, Kenya, 106 pp

Ekesi S, Nderitu PW, Rwomushana I (2006) Field infestation, life history and demographic parameters of *Bactrocera invadens* Drew, Tsuruta and White, a new invasive fruit fly species in Africa. Bull Entomol Res 96:379–386

Isabirye BE (2015) Diversity, host utilization and ecological niche of fruit flies (Diptera: Tephritidae) in Uganda. Ph.D thesis, Makerere University, Uganda

Isabirye BE, Nankinga CK, Muyinza H, Masembe C, Akol AM (2012) Effect of three host species on infestation levels, offspring survivorship, sex ratio and body weight of *Bactrocera invadens* (Diptera: Tephritidae). In: Proceedings of the 2nd international symposium of Tephritid Workers of Europe, Africa & The Middle East (TEAM)

Isabirye BE, Masembe C, Nankinga C, Muyinza H, Akol AM (2014a) Geometric morphometrics of geographic and host-associated population variations of *Bactrocera invadens* in Uganda. In: Proceedings of the 9th International Symposium on Fruit Flies of Economic Importance (ISFFEI), p 155

Isabirye BE, Masembe C, Nankinga CK, Rwomushana I, Muyinza H, Akol AM (2014b) Projections of climate-induced future range shifts among fruit fly species in Uganda. In: Proceedings of the 9th International Symposium on Fruit Flies of Economic Importance (ISFFEI), p 134

Isabirye BE, Akol AM, Nankinga CK, Masembe C, Rwomushana I (2015a) Species composition and community structure of fruit flies (Diptera: Tephritidae) across major mango-growing regions in Uganda. Int J Trop Ins Sci:1–12

Isabirye BE, Masembe C, Akol AM, Muyinza H, Rwomushana I, Nankinga CK (2015a) Modeling the potential geographical distribution and ecological niche of selected fruit fly (Diptera: Tephritidae) species in Uganda. J Plant Pest Sci 2:18–33

Isabirye BE, Akol AM, Muyinza H, Masembe C, Rwomushana I, Nankinga CK (2016) Fruit fly (Diptera: Tephritidae) host status and relative infestation of selected mango cultivars in three agro ecological zones in Uganda. Int J Fruit Sci 16(1):23–41

Mayamba A, Nankinga CK, Isabirye BE, Akol AM (2014) Seasonal population fluctuations of *Bactrocera invadens* (Diptera: Tephritidae) in relation to mango phenology in the Lake Victoria Crescent, Uganda. Fruits 69:473–480

Millenium Science Initiative (2013) Gaining insight into the physical, ecological and biochemical factors influencing fruit fly infestation of mango in Uganda. End of Project Report, NARL, Kawanda

Nakasinga JK (2002) Studies on fruit fly species occurrence, distribution and composition on mango in Uganda. MSc thesis 91 pp

Nankinga CK, Isabirye BE, Muyinza H, Rwomushana I, Stevenson PC, Mayamba A, Aool W, Akol AM (2014a) Fruit fly infestation in mango: a threat to the Horticultural Sector in Uganda. Uganda J Agric Sci 15:1–4

Nankinga CK, Mayamba. A, Nampeera. F, Wasswa. W, and Isabirye. BE (2014b) A bronchure of mango fruit fly management in Uganda. Second Edition June 2014

Nankinga C, Isabirye BE, Mayamba A, Muyinza H, Aool W, Rwomushana I, Stevenson P, Akol A (2014c) Status of fruit fly infestation of mango and other fruits in Uganda. In: Proceedings of the 9th International Symposium on Fruit Flies of Economic Importance (ISFFEI), p 202

NARL Annual Report (2011) National Agricultural Research Laboratories Annual Review and Planning Report, Biotechnology and Biodiversity Program, 23 pp

NARL Quarterly Report (2014) National Agricultural Research Laboratories Quarterly (May–August) Report, Biotechnology and Biodiversity Program, 37 pp

Nemeye P (2005) Surveillance and management of *Bactrocera invadens* in East Africa. Progress report No. 2. 20 pp

Okullokwany FS (2006) Report on surveillance and management of *Bactrocera invadens* in East Africa-Phase II (Uganda). Ministry of Agriculture Animal Industry and Fisheries, 8 pp

Uganda Export Promotions Board (2012) www.ugandaexportsonline.com

World Bank Report (2013) Uganda Economic Update, 2013 Summary. http://www.worldbank.org

World Trade Organisation (2016) www.wto.org

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