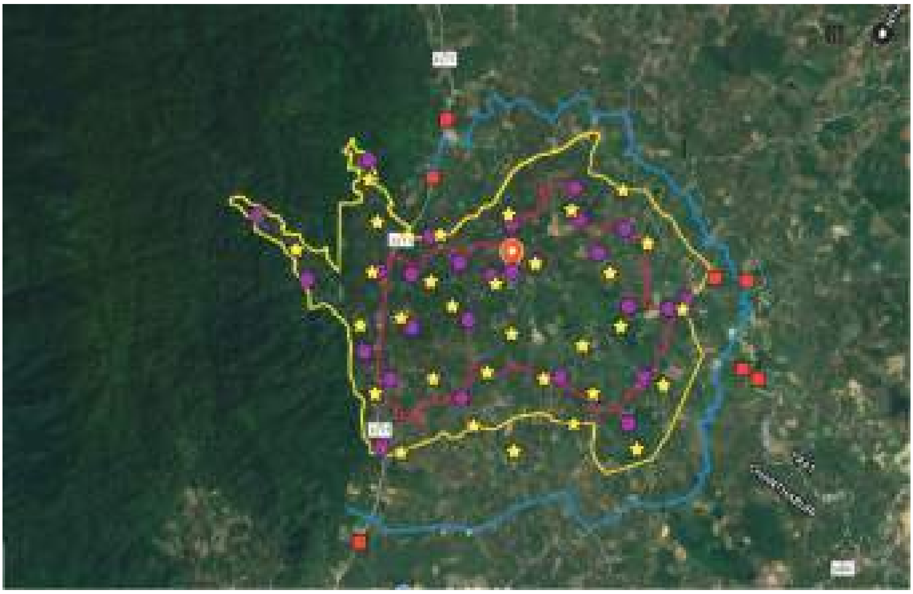

FIGURE 23.2 The new buffer zone of the implemented area, Trok Nong subdistrict. Geographic information system (GIS) was used to re-establish the edge of the buffer zone to a distance of 1 km from the core area as indicated by the blue line.

23.2.2 Integrated Pest Management Program

The SIT AW-IPM program established the diversity and abundance of tephritid fruit flies and host plants. Management options consisting of MAT+BAT+OS+SIT were implemented when alternative and wild-hosts were removed. From the start of the program in 2007, growers were involved along with the SAO and the DOAE's local pest management officers. OS was applied twice per month with a recycle-reuse system, in which damaged or remnant fruits were composted and used as bio-fertilizers. Soil pH was measured to monitor soil status over the period of the implementation. Alternative and wild hosts were removed from the whole area three times per year and were replaced with nonhost plants.

MAT and BAT traps fabricated from local materials were applied prior to SIT releases. MAT traps measuring 5 × 5 cm, made out of fiber blocks or modified recycled water bottles, were dip-soaked in a mixture of methyl eugenol, molasses, and Malathion® and were used for mass trapping at 50-m intervals within the core area during two 3-month cycles. Liquid traps, modified by using recycled water bottles, consisted of 150 cc of total volume. These traps were baited with a mixture of methyl eugenol, protein, and Malathion®, and were placed at 25-m intervals in the buffer area to intercept males and females three times a year.

In 2013, as part of the DOAE's strategies, a community pest management center (CPMC) was formed in the Trok Nong subdistrict. The CPMC consists of a growers' committee and mostly involves the same crop members who manage and make decisions on pest management by themselves. The DOAE and other related organizations support technical knowledge exchange, pest identification, IPM application, parasitoid production, and pest surveillance and monitoring. Fruit fly control activities, including sterile fly releases, were carried out by members of the CPMC in cooperation with the Trok Nong SAO and the DOAE's local officers.

23.2.3 Sterile Male Releases and Surveillance

To safeguard volunteer growers against allergies and environmental pollution caused by pupal fluorescent powder markers in SIT programs (FAO/IAEA/USDA, 2014), the white-striped back strain of *B. dorsalis*, developed by the TINT in 2007 (Boonsirichai et al., 2011), was used. Sterile males were mass produced and released at a rate of 5 million per week in the core area from March to September in each of the 5 years of the project (2008–2012). The white-striped back *B. dorsalis* strain was subjected to quality control measures (FAO/IAEA/USDA, 2014) in a weekly manner. During the same period, the SIT was integrated with other control techniques. In 2013, the same activities were supported by the BACFS and the DOAE.

In 2014, the responsibility of mass production of sterile *B. dorsalis* flies was entrusted to the DOAE. The wild strain of *B. dorsalis* was used due to proprietary issues with the white-striped back strain. Sterile flies were released at the same rate of 5 million per week only from April to August due to budget constraints. Releases were performed at ground level by participating growers (CPMC) and SAO volunteers. Since 2017, releases were adjusted to operate from January to June due to the low population period of wild fruit flies.

A surveillance/monitoring system consisting of a trapping network and fruit sampling was established. Modified Steiner traps distributed as 31 in the core area and 10 in the neighboring area were inspected weekly. Fruit sampling was carried out twice a month for each fruit variety.

Budget and SIT technologies were provided by the TINT during 2007–2012, by the BACFS and the DOAE in 2013, and by the DOAE since 2014 and continuously cooperating with the governor's office and the Trok Nong SAO. Under the IAEA-TC project, the genetic sexing strain (GSS) of *B. dorsalis* has been under a development process, in cooperation with the DOAE, the TINT, and the IAEA, using white pupae selected from the wild strain of the DOAE's mass-rearing facility and the white-striped back strain from the TINT.

23.3 RESULTS AND DISCUSSION

Bractrocera dorsalis is a destructive fly species native to tropical Asia. It has spread around the globe and is one of the most invasive tephritid pest species. In other countries it was synonymized as *Bactrocera invadens* (Schutze et al., 2015), a species with strong quarantine measures that prevent the free movement of fruits between infested countries and even within countries. Such is the case presented here, in Thailand and the Trok Nong subdistrict, with its great production of mangosteen, durian, rambutan, and longong. For this reason, the Thai authorities established a participatory *B. dorsalis* control program engaging national and regional institutions and growers.

23.3.1 *Bractrocera dorsalis* IPM: Host Fruits and Sanitation Practices

Fourteen out of 18 tested fruit species in the Trok Nong subdistrict were potential hosts for *B. dorsalis*; however, guava (*Psidium guajava* (L.) Kunze 1898) was preferred by this species. The preference for guava by *B. dorsalis* was also reported by Goergen et al. (2011). Based on this information, guava, mamiew pomerac, wild banana, java apple, mango, jujube, and star fruit trees, which are alternative hosts of *B. dorsalis*, were eliminated by growers and the CPMC as recommended by the international standards for phytosanitary measures (FAO, 2012).

OS involved the conversion of fallen ripe and damaged fruits into bio-fertilizers that were used to fertilize the soil; this improved the soil quality of 320 ha. These bio-fertilizers raised the pH by approximately one point, which indicated that the soil could maintain its own organic matter mineralization process, and that beneficial bacteria would increase their activity, thus enhancing crop yields.

23.3.2 *Bractrocera dorsalis* AW-IPM Program with a SIT Component

Approximately 200 million *B. dorsalis* sterile flies were released in the target area of the Trok Nong subdistrict (over 25.9 km^2) during 7 months of 2007–2013, and approximately 100–120 million sterile flies were released during 5–6 months from 2014 to 2018. Average S/N sterile-to-wild or sterile-to-native (S/N) ratios and fly per trap per day (FTD) during 2013, 2014, 2015, 2016, 2017, and 2018 compared to those of 2012 are shown in Figures 23.3 and 23.4.

The application of an AW-IPM program using the SIT as a main component resulted in a reduction of longong fruit damage caused by *B. dorsalis*, from 30% in 2005 to 5% in 2013, 0% in 2016, 2% in 2017, and 1% in 2018, along with a reduction of chemical fertilizer costs of about US$406 per ha.

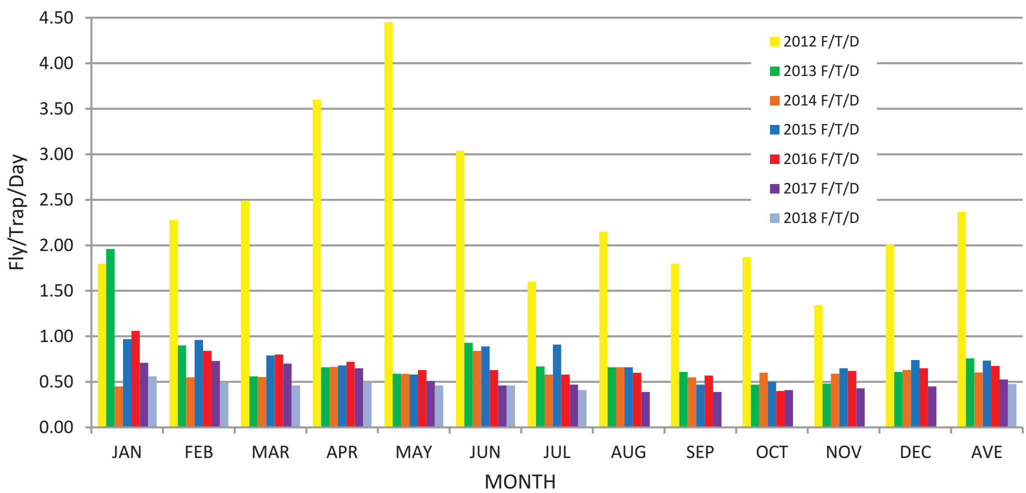

FIGURE 23.3 Average sterile-to-wild or sterile-to-native (S/N) ratios during 2013, 2014, 2015, 2016, 2017, and 2018 compared to those of 2012.

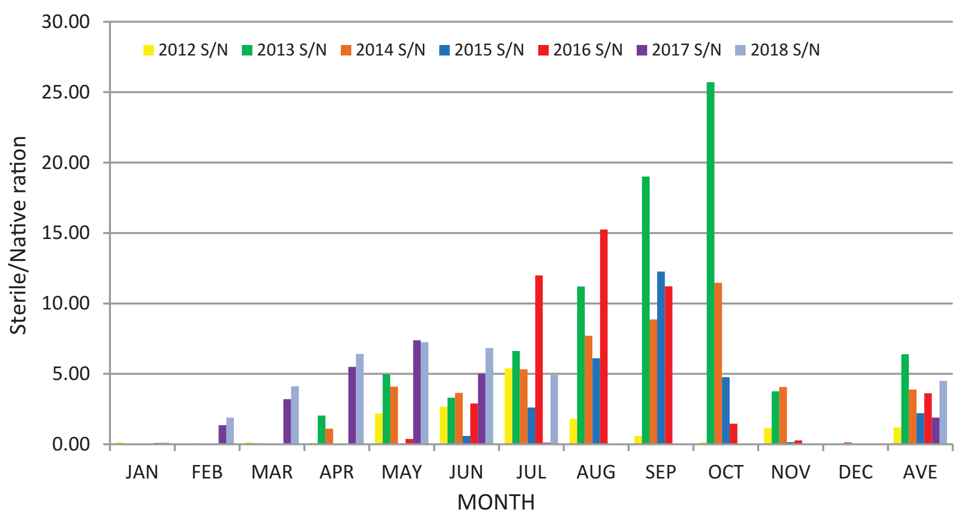

FIGURE 23.4 Average fly per trap per day (FTD) during 2013, 2014, 2015, 2016, 2017, and 2018 compared to those of 2012.

Furthermore, the *B. dorsalis* SIT AW-IPM program resulted in increased market values. The market value of longong was increased to US$83 per ton, and of mangosteen to US$100–167 per ton, or about US$57,500 and US$850,000 per year, respectively. This is a large increase compared to the neighboring control orchards that were not subjected to AW-IPM with SIT under farmer practice.

Similarly to the Mexican AW-IPM program (Salcedo Baca et al., 2010), the Tronk Nong subdistrict SIT project is having a high economic impact as a result of low fruit infestation because of a significantly reduced prevalence of *B. dorsalis* in the region. Fruit prices have increased and hence net income has increased. The orchards under SIT AW-IPM have experienced remarkably lower chemical applications and overall production costs. The treated area has been considered eco-friendly as no pesticides have been applied after the SIT approach. High-quality fruits, especially mangosteen, produced in Trok Nong can be exported in amounts of approximately 4,000 tons each year and have access to markets they could not get into before.

The *B. dorsalis* sterile-to-wild ratio, even if the maximum average was ≈26 for the entirety of the years (the trend indicated in Figure 23.3), showed an increased progression within the sterile fly release period. When the number of released sterile males is constant, the sterile-to-wild ratio starts to increase, which is a direct measure of the reduction of *B. dorsalis* wild populations. Also, sterile males were still trapped at least 1–2 months later, which is an indication of the efficiency of the SIT.

Moreover, the average FTD indicated that wild *B. dorsalis* were controlled at a level of less than 1 in the first year of the SIT approach, and for at least 5 years continuously, even when the SIT was not applied during the whole year. The treated area should be successful in becoming an area of low pest prevalence for fruit flies and could be declared as a low prevalence area for *B. dorsalis* following the ISPM No. 30 (FAO/IPPC, 2008) if it manages to minimize the spread of regulated fruit flies within the area.

The development of a genetic sexing strain (GSS) of *B. dorsalis*, which is under process, for the improvement of the SIT in Thailand is showing positive results. The process is being carried out in cooperation with the DOAE, the TINT, and the IAEA, using white pupae selected from the wild strain of the DOAE's mass-rearing facility and the white-striped back strain from the TINT.

23.4 CONCLUSIONS AND PERSPECTIVES

Our results indicate that environmental-friendly control techniques, orchard sanitation, alternative and wild host removal, mass trapping and interception traps, along with sterile male releases in an AW-IPM approach result in a reduction of *B. dorsalis* wild populations, a reduction of fruit infestation (from 30% to 2%), and an increase in fruit value. Overall, these results indicate a successful implementation of the SIT in AW-IPM and the establishment of a *B. dorsalis* low prevalence area in the Trok Nong subdistrict, with a positive impact in the country. Further research and national plant protection organization (NPPO) involvement are requested to fulfill standard international phytosanitary measures.

This positive result demonstrate that a sterile male release integrated with an AW-IPM approach allows a significant reduction of *B. dorsalis* wild populations in the area year by year. The DOAE implemented the SIT into the AW-IPM program as one of its key phytosanitary measures to control fruit flies, and growers in specific selected areas of 20 provinces joined the AW-IPM program.

As long as growers cooperate with each other and the SIT AW-IPM is effective, the program will continue to be implemented in the Trok Nong subdistrict. Also, as the CPMC grows, it will continue to be an important foundation for the future of the program. Nevertheless, growers will need an easy-to-use system based on consensus for buying irradiated pupae in case that the government stops subsidizing the program at some point.

In the near future, the GSS of *B. dorsalis*, provided by the three organizations of the IAEA, the TINT, and the DOAE, could be more effective in the SIT in AW-IPM for controlling fruit flies in Thailand because only males can be released. Using male-only strains would also provide a sense of confidence to fruit growers. Products from the treated area should also have access to a new niche of markets. However, further efforts should be made following the International Standards for Phytosanitary Measures (FAO/IPPC, 2012) to achieve the status of low prevalence area for *B. dorsalis* under the Thailand NPPO certification.

REFERENCES

Boonsirichai, K., S. Segsarnviriya, W. Limohpasmanee, T. Kongratarpon, T. Thannarin, and K. Sungsinleart. 2011. Genetic variation among the white-striped *Bactrocera dorsalis* (Hendel) in comparison with a Trok Nong-derived population. *12th Conference on Nuclear Science and Technology*, Thailand. In: INIS-TH-326. (https://inis.iaea.org/search/search.aspx?orig_q=RN:43095386).

FAO/IPPC. 2008. International standards for phytosanitary measures. Establishment of areas of low pest prevalence for fruit flies (Tephritidae) ISPM 30. 16 pp. (https://www.ippc.int/static/media/files/publication/en/2016/11/ISPM_30_2008_ALPP_fruit_flies_EN.pdf).

FAO/IPPC. 2012. International standards for phytosanitary measures. Systems approach for pest risk management of fruit flies (Tephritidae) ISPM 35. 10 pp. (http://www.fao.org/docrep/016/k6768e/k6768e.pdf).

FAO/IAEA/USDA. 2014. *Product Quality Control for Sterile Mass-Reared and Released Tephritid Fruit Flies, Version 6.0*. International Atomic Energy Agency, Vienna, Austria. 164 pp. (http://www-naweb.iaea.org/nafa/ipc/public/QualityControl.pdf).

Goergen, G., J. F. Vayssières, D. Gnanvossou, and M. Tindo. 2011. *Bactrocera invadens* (Diptera: Tephritidae), a new invasive fruit fly pest for the Afrotropical Region: Host plant range and distribution in West and Central Africa. *Environmental Entomology* 40: 844–854.

Salcedo Baca, D., J. R. Lomeli Flores, G. H. Terrazas Gonzalez, and W. Wnkerlin. 2010. Economic evaluation of the moscamed regional program in Mexico (1978–2008), pp. 179–188. In: B. Sabater-Muñoz, V. Navarro Llopis, and A. Urbaneja (Eds.), *Proceedings of the 8th International Symposium on Fruit Flies of Economic Importance*. Polytechnic University of Valencia Editorial, Valencia, Spain.

Schutze, M. K., N. Aketarawong, W. Amornsak, K. F. Armstrong, A. A. Augustinos, N. Barr, W. Bo, K. Bourtzis, L. M. Boykin, C. Cáceres et al. 2015. Synonymization of key pest species within the *Bactrocera dorsalis* species complex (Diptera: Tephritidae): Taxonomic changes based on a review of 20 years of integrative morphological, molecular, cytogenetic, behavioural and chemoecological data. *Systematic Entomology* 40: 456–471.

24 Implementation of an *Anastrepha* spp. Risk-Mitigation Protocol for the Mango Export Industry in Cuba

Mirtha Borges-Soto, Maylin Rodríguez Rubial, Evi R. Estévez Terrero, and Beatriz Sabater-Munoz*

CONTENTS

24.1 Introduction 334
24.2 Material and Methods 335
24.3 Results 338
24.3.1 Enterprise Agroindustrial "Victoria de Giron" 338
24.3.2 Enterprise Citricos "Arimao" 338
24.3.3 Enterprise Citricos "Ceiba del Agua" 339
24.3.4 Enterprise Agroindustrial "Ciego de Avila" 339
24.4 Discussion 340
24.5 Conclusions 341
Acknowledgments 341
Note 341
References 341

Abstract Mango (*Mangifera indica* L.) is one of the key products of the Cuban export market. This crop is threatened by a great number of pests and diseases, reaching between 10% and 50% of economic losses worldwide. Tephritid fruit flies are among the key pests of mangoes, deserving specific control programs in many countries. In the 1950s, Cuba established a risk mitigation protocol for *Ceratitis capitata* (Wiedemann) that has been updated regularly, including some other key tephritid species belonging to the genus *Anastrepha*. According to these programs, in late 2008, a study on tephritid invasions demonstrated that only two species of *Anastrepha*, namely *A. suspensa* (Loew) and *A. obliqua* (Macquart) are established in the island of Cuba, threatening the fruit export market. In 2015, the Plant Protection Cuban agency established the basis for the risk mitigation protocol for the mango export industry. This protocol is the objective of the present study. Four mango production areas were selected to survey the application of the Anastrepha *spp. Risk Mitigation Protocol*, following the systems approach indicated as the most appropriate for export. This protocol includes monitoring with a trap grid set at 0.3 McPhail baited traps per hectare, dissection of fruits (mango and guava), establishment of fruit traceability notebooks, training of local personnel, quarantine measures, and selection of orchards, among other measures.

* Corresponding author.

Fruit flies per trap per day (FTD) indexes were determined in each area. Trapping, inter-cropping of fruits and noncrop host fruit surveillance, orchard sanitation, and periodical data registry were set up. Only seven *Anastrepha* spp. were trapped throughout the whole study period (January 2016–June 2017), five *A. suspensa* females and two *A. obliqua* males, which were captured outside the studied commodity. A multicomponent systems approach has been established to reduce the risk of *Anastrepha* spp. in mango varieties destined for international export.

24.1 INTRODUCTION

Tephritid fruit flies are important pests of fruits and vegetables worldwide, with some species declared as threats for the worldwide trade of agricultural fresh products (Aluja and Rull, 2009). The natural distribution (Figure 24.1) of the species is being modified unintentionally by human worldwide trade and expanded due to climate change (Qin et al. 2015). In this sense, almost all fruit-producing countries are under menace of invasive species, especially those countries located in the border of species border boundaries. During the past decade, a number of models and approaches have been developed to determine the invasive risk of Tephritidae species, letting each country decide on the actions to prevent any invasion or establishment as part of the regular activities of their ongoing fruit fly management programs (Godefroid et al. 2015; Qin et al. 2015; David et al. 2017; Dias et al. 2018).

The Republic of Cuba, settled in the middle of the Caribbean sea, is threatened by several tephritid species in two ways: (1) by the risk of invasions from neighboring countries (Bahamas, United States, Mexico, Guatemala, Honduras, Costa Rica, Nicaragua, Panama, Colombia, Venezuela, Puerto Rico, Dominican Republic, and Haiti) during hurricane seasons, and (2) from transoceanic visitors (cruise ships or cargos with fresh fruits from other countries). Cuba has historical records of 30 Tephritidae species distributed in 15 genera, nearly all described from specimens from museum collections (from Cuba universities and research bodies, from the Natural History museum of Washington, DC, or from the Comparative Zoology museum of Harvard University) without a reference to their host plant

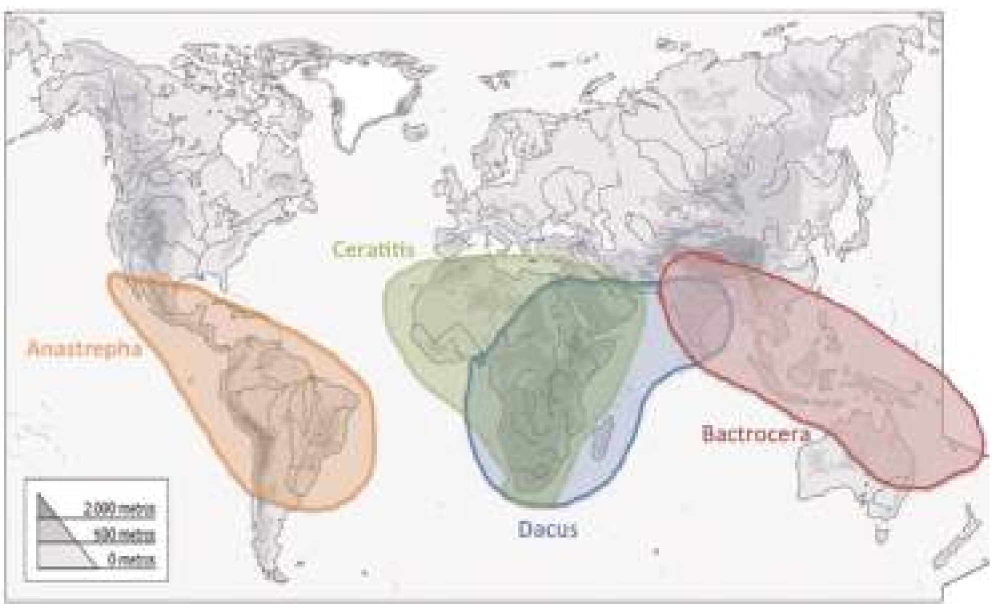

FIGURE 24.1 World atlas with the putative original biogeographical distribution of the four main Tephritidae genera. This distribution map was constructed from data from different papers and from the EPPO (European Plant Protection Organization).

or capture location (Rodríguez Velasquez et al. 2001). Of this Cuban Tephritidae species catalog, only six species belong to the genus *Anastrepha*, namely *Anastrepha suspensa* Loew, *Anastrepha obliqua* Macquart, *Anastrepha soroana* Fernandez y Rodríguez, *Anastrepha ocresia* Walker, *Anastrepha interrupta* Stone, and *Anastrepha insulae* Stone. The last two species have not been recorded in Cuba in the past 30 years, even if during these period some specimens that were caught in monitoring traps were assigned to the genus *Anastrepha*; however, they were not at all assignable to a specific species taxonomical descriptor, and the remaining, with a few specimens, were captured occasionally in minor crops (Borges-Soto et al. 2011, 2015). Only *A. suspensa* and *A. obliqua* were reported regularly with a detailed list of new hosts like pomarrosa (*Syzygium jambos* (L.) Alston, an invasive plant in Cuba), icaco (*Chrysobalanus icaco* [L.] L.) or caimito (*Chrysophyllum cainito* L.), none of which are an economically important crop in Cuba. These two species presented population dynamics in guava with peaks during the guava-maturation months (July–September), affecting up to 15% of guava fruits. Another tephritid species, the papaya fruit fly *Toxotrypana curvicauda* Gerstaecker, is present affecting mainly papaya (*Carica papaya* L.) and rarely affecting the mango production in Cuba. In addition to these species, *Ceratitis capitata* (Wiedemann) was also recorded as present from the specimens stored in the museum but was never found in any of the trapping systems established since early in the last century as part of the Cuba government's plant protection program (Vázquez et al. 1999; Rodríguez Velasquez et al. 2001; FAO, 2003; Drew, 2004; Borges-Soto et al. 2011).

Following the standard guidelines of the International Plant Protection Organization (IPPO n30), Cuba established its own operational procedures to control tephritid species outbreaks, reduce invasions, and determine the presence of these tephritid species in the island (Fernández et al. 1997; Rodríguez Velasquez et al. 2001; Armenteros 2005; Borges-Soto et al. 2011, 2015, 2016).

Mango is cultivated in several tropical and subtropical regions, with 13% of the global production concentrated in Latin America and the Caribbean countries (FAOSTAT 2018). Considered as an exotic rare fruit in Europe and North America, it has expanded its international trade as consumption increased among temperate-zone countries. Only in 2016, global production reached 46 million tons. The cultivars differ in size, shape, appearance, and physiological characteristics, including health-related antioxidant phenolic compounds, but they also differ in their susceptibility to diseases and pests. Tephritid fruit flies are considered key pests of mangoes, with 8 reported species of the genus *Anastrepha*, 30 of *Bactrocera*, 7 of *Ceratitis*, 2 of *Dirioxa,* and 1 of *Toxotrypana* (Yahia, 2011). However, in the Central American and Caribbean countries, only species from the genus *Anastrepha* have been reported to affect mangoes (Birke and Aluja 2011; Aluja et al. 2014). With a production of 420,191 tonnes, encompassing a crop surface of 38,307 ha, Cuba was ranked 17 out of 102 mango-production countries and third in the Central American and Caribbean region in 2016 (FAOSTAT 2018). Such significant position justifies the implementation of an *Anastrepha* spp. risk-mitigation program to protect the Cuban export market.

As previously indicated, surveillance, trapping, monitoring, control, and corrective action implementation procedures were established in several commodities throughout the whole island of Cuba (Rodríguez Velasquez et al. 2001; Borges-Soto et al. 2011, 2015, 2016). After this experience, the Cuba National Fruit Flies Control Program established an *Anastrepha* spp. *Risk Mitigation Program for Mango* following a "systems approach" as described previously for other species in other countries (Follet and Vargas 2009; Moore et al. 2016). Briefly (see Material and Methods for an in-depth description), it includes surveillance, trapping, monitoring, control, corrective actions, and postharvest regulation prior to exportation, all following Cuban national laws 731/98, 50/2008, and 435/94.

In this chapter, we present the results of this risk-mitigation program for mango in four selected areas of Cuba.

24.2 MATERIAL AND METHODS

During the period 2015–2017, 10 mango orchards from four different fruit-production enterprises were selected for the implementation of the risk-mitigation protocol (Table 24.1, Figure 24.2a). Some of these orchards are merged in an Unidad Economica de Base (UEB), the Cuban assignment

TABLE 24.1
Selected Production Areas with Indication of Their Assignment and Captures Obtained

Field ID	Geographical Area	Enterprise Name	Plantation Code	Total Surface (ha)	Traps (n)	Total Number of *Anastrepha* spp. Captured	FTD
1	Jaguey Grande, Matanzas	Agroindustrial "Victoria de Giron"	UEB[a] frutales-granja #4	226.04	62	0	0
2			UEB frutales-granja #5	69	23	1[b]	0[c]
3	Arimao, Cienfuegos	Citricos "Arimao"	UBPC "Breñas"	12	4	1[b]	0[c]
4			UBPC "Seibabo"	12	9	2[b]	0[c]
5			UBPC "La Cuchilla"	10	4	2[b]	0[c]
6	Caimito, Artemisia	Citricos "Ceiba del Agua"	UBPC[a] "24 de Febrero" – finca Ingenio Nuevo	10	4	0	0
7			UBPC "24 de Febrero" – finca Sandoval	12	10	1[b]	0[c]
8	Avila, Ceballos	Agroindustrial "Ciego de Avila"	UEB "Palmarito"	77	24	0	0
9			UEB "Colonia"	92	30	0	0
10			UEB "Nadales"	105	31	0	0

[a] UEB, Unidad Económica de Base; UBPC, Unidad Basica de Producción Cooperativa. Both UEB and UBPC indicate how the orchards are organized in economic units. Descriptions are given in Spanish because each country has a different economical organization of the production units.
[b] Some of the specimens were captured in traps located either at intercrop areas with avocados, guavas, coffee, or citrus, or in backyards, not considered for the fruit flies per trap per day (FTD) determination ([c]).

of crop surface for private economical administration, which will include more than one commodity (fruit fly–susceptible fruit species). Selection was based on the mango cultivars "AG-33 *cv* Tommy Atkins" and *cv* "*Super* Haden," the two varieties selected for this study.

The mango risk-mitigation protocol consisted of:

1. Surveillance of fruit fly populations throughout the year in an established grid across the targeted region;
2. Orchard sanitation (removal of wild noncrop hosts, isolated fruit trees, and ripe-fallen fruits);
3. Establishment of treatments and surveillance registry notebooks at each orchard;
4. Surveillance of any putative tephritid infested fruit by placing in-house designed development cages; and
5. Establishment of a training protocol in each new season.

In addition, postharvest quarantine measures (hot-bath thermal treatment) were also applied following Cuban laws 50/2008, 435/94, and 731/98. These directives allowed working with mango fruits from registered orchards for the export market, creating an "Export passport" that included traceability of origin, surveillance of quarantine species, quarantine postharvest treatment, and packing systems.

The traps used in this project were McPhail traps (IPS, International Pheromone Systems LTD, London, UK or from BIAGRO SL, Valencia, Spain) baited with a mixture of 3% Torula yeast

FIGURE 24.2 Geographical distribution of the areas under study 1: Jagüey Grande, Matanzas county; 2: Arimao, Cienfuego county; 3: Caimito, Artemisia county; and 4: Avila, Ceballos county.

(Fábrica de levadura de Torulas Alfredo Rafael Pérez, Central Azucarero Ciro Redondo, Ciego de Ávila, Cuba; https://www.ecured.cu/Fábrica_de_Levadura_de_Torulas_Alfredo_Rafael_Pérez) and 1%–3% borax (sodium tetraborate decahydrate from Empresa Laboratorios AICA, La Habana, Cuba).

From the geographical map and the plantation scheme (meaning the distribution of each mango tree within the plantation) of each plantation, a trapping grid was established in a one-by-one fashion. This method was adopted because the orchards were not regular and contained the selected mango varieties or mango plantations as well as other fruit fly host plantations, and houses with host plants in the backyards were crossed by service roads, train rails, or other vehicle pathways. Therefore, the trapping grid was composed of: (i) one McPhail trap set every 3 ha following the main diagonal of each mango plantation; (ii) another MacPhail trap was set in each cardinal direction (N, S, W, E) to the target trap per 10 ha of mango crops (as other varieties were established but not studied); (iii) a third trap every 33 ha of remaining mango crops (belonging to the Cuba National Fruit flies control program[1]); (iv) one McPhail trap every 5 ha of other fruit crops (like citrus or stone fruits, established as intercrop areas); (v) one trap per square kilometer in the closest town or inhabited area; and (vi) one trap in each backyard with putative host fruits, if houses were present within the plantation (see Figure 24.2).

At each plantation, a route was established allowing the service of all traps to be made in one inspection. All traps were serviced every 7 days, replacing the attractant solution (as reviewed in Epsky et al. 2014) and storing any trapped insects in 125-mL vials (recovering vials) with the corresponding trap number and collection date. Recovering vials were first evaluated in each enterprise, introducing all the data in their registry notebooks and then were retrieved to the Instituto de Investigaciones en Fruticultura Tropical (IIFT; Cuban Research Institute of Tropical Fruits) laboratory, and specimens belonging to the Tephritidae family were identified to species level under binoculars with the use of the corresponding taxonomic keys.

Infestation level was determined in all orchards as captured flies per trap per day (FTD), as previously determined (Borges-Soto et al. 2011, 2015, 2016).

Two to 5 days before the harvesting period, a sample of mango fruits (25 fruits per orchard, 5 per randomly selected tree) of variable size but nearly at the harvest stage were dissected to determine the presence of developing larvae. This equaled to approximately 13 to 20 kg of fruits per orchard per season.

24.3 RESULTS

The total number of captured *Anastrepha* flies and FTD values for all four study areas from January 2015 to June 2017 are presented in Table 24.1. Only seven *Anastrepha* specimens were trapped, five *A. suspensa* females and two *A. obliqua* males. These specimens were captured mainly in the mango intercrop zones or in inhabited areas where guava or avocado trees were present in backyards (traps from the Cuban National program, which in some cases were placed in nonmango tree species). The captures took place close to the harvesting period of these intercrop commodities, especially for guava.

24.3.1 Enterprise Agroindustrial "Victoria de Giron"

Within this enterprise, the risk-mitigation protocol started with an on-site visit, followed by personnel training. After establishing the trap grid, a new set of registry notebooks were established with the exact trap code and its location (row and plant number) within each orchard. The presence of all traps was verified in a second visit, along with the determination of the presence of development cages with putatively infested fruits (mangoes, guavas, papaya, and avocados). The number of assessed alternative fruits was variable, depending on the year, but mangoes were surveyed each season at the preharvest time, as indicated in the material and methods section, and 25 fruits per orchards were randomly selected from five trees (Figure 24.3). Some of the found isolated guava trees were removed as part of the orchard sanitation and risk-mitigation plan. All trap captures were submitted to the IIFT laboratory or to the Plant Protection national reference laboratory for species identification (see Table 24.1). Only one *Anastrepha* specimen was identified.

24.3.2 Enterprise Citricos "Arimao"

Within this enterprise, the mango-production area also included other fruits (mainly avocado and guava) and mangoes for the internal market. All mango-export orchards included field registry notebooks with all the applied treatments, including all steps performed for orchard sanitation, number and location of all types of traps, *Anastrepha* spp. monitoring, and fruit production. These notebooks also included the on-site visit routes from personnel of IIFT and from personnel of the quarantine department. Due to the presence of small guava orchards (sometimes used as intercropping systems), this area was under special surveillance, with traps also baited with Capilure® or Tridmelure® (Figure 24.4), as a part of the Cuban *C. capitata* management program. The presence of

FIGURE 24.3 Enterprise Agroindustrial "Victoria de Giron." Sample of mangoes inspected for the presence of *Anastrepha* spp. larvae prior to the harvesting period.

FIGURE 24.4 Enterprise Citricos "Arimao." Detail of the young mango plantation (left) and a detail of a Rebell trap (right) set at the limit of guava orchards, with an *Anastrepha* spp. specimen.

three *Anastrepha* specimens (Table 24.1) jeopardized the inclusion of this enterprise in the export-targeted authorized list. To avoid this, the Cuban Plant Protection department has established that the guava orchards in this enterprise should be removed and replaced by others crops, such as citrus or mangoes. This replacement will take place in the near future.

24.3.3 Enterprise Citricos "Ceiba del Agua"

Within this enterprise, two different on-site visit routes were established to verify all the areas for export trade. All orchards within this enterprise included field registry notebooks, trap grids, and results. Some of the development cages were also surveyed in some of the field visits. From the same field visits, IIFT personnel noticed the presence of mango fruits with a great variability in size, probably due to the long-lasting blossom period in this enterprise. In this enterprise, only one *Anastrepha* specimen was reported (Table 24.1) in a trap located in a backyard, which contained one guava and several citrus trees for in-home consumption.

24.3.4 Enterprise Agroindustrial "Ciego de Avila"

Within this enterprise, and more precisely within the three selected UEBs, the mango-production area also included other fruits and mango varieties for the local market. All the mango-export orchards included field registry notebooks with all the applied treatments, including all steps required for orchard sanitation, number and location of all types of traps, *Anastrepha* spp. monitoring, and fruit production, which allowed for the record-keeping and traceability of all production from this enterprise. These notebooks also included the on-site visit routes from personnel of IIFT or the training days received. This enterprise was unable to include the established Torula-based attractant for the surveillance of McPhail traps, thus, the sugar cane molasses (3%) and borax (3%) mixture was kept during all the study period (Figure 24.5). Despite this constrain, this enterprise was the most successful in the application of the *Anastrepha* spp. risk-mitigation protocol in mango for export trade, as all the requirements (except for the type of attractant) were met. No *Anastrepha* specimens were recorded in any of the shriveled traps (Table 24.1).

FIGURE 24.5 Enterprise Agroindustrial “Ciego de Avila.” Detail of blossoming mangoes (left) and a McPhail trap (right).

24.4 DISCUSSION

Due to current global warming and other climate alterations, along with unintentional man-driven dispersion, Tephritid species, irrespectively of their ancestral geographic origin, are becoming a global menace for many tropical fruits and vegetables (Godefroid et al. 2015; Qin et al. 2015; David et al. 2017). In the Caribbean Sea, the most noticeable invasive species belong to the genus *Anastrepha*, along with the worldwide distributed *C. capitata*. In Cuba, after several decades, a management program was established to control *C. capitata*, mainly in citrus species, which was used as a base program to establish the *Anastrepha* spp. phytosanitary surveillance program (reviewed in Borges-Soto et al. 2011, 2015, 2016). With this gained experience, the *Anastrepha* spp. *Risk Mitigation Plan* presented here for mango in Cuba was established with a detailed trapping network, surveillance methods, removal of alternative hosts, establishment of sanitation procedures, inspector on-site visits, in-field traceable fruit origins, and registry on the export-trade authorized orchard list. The results presented here allowed the re-assignation of the selected areas as areas with low prevalence of *Anastrepha*, making them suitable for fruit export to *Anastrepha* spp.-free countries as has occurred in other countries (Aluja and Rull 2009; Follet and Vargas 2009).

Historically, mango commodities were mainly subjected to postharvest quarantine treatments (hot-water baths) to reduce the risk of pest introduction into pest-free areas as part of the bilateral agreements between importing and exporting countries (reviewed in Yahia 2011), and the use of a systems approach to certify the “risk-mitigated status” for this commodity had not been considered. Hot-water postharvest quarantine treatments usually render the commodity with less nutritional value and shorter shelf half-life, thus threatening the mango trade without assuring a total “risk-mitigated status.”

In the past 5–10 years, regulatory officials have embraced the use of *systems approaches*, within which the present work fits, by means of applying joint risk-mitigation processes with pre- and post-harvest quarantine procedures (Follet and Vargas 2009; Shelly 2014; Jang et al. 2015; Moore et al. 2016; reviewed in Dias et al. 2018). In this sense, this work provides for the first time the results of the implementation of the Anastrepha *spp. Risk-Mitigation Protocol for Mango* in Cuba, the third mango producer from the Caribbean countries, showing the cumulatively results of systems activities. These results will help the Cuban export market to grow as the systems approaches in course are mitigating the risk of invasion in the importing country by reducing the amount of putatively infested mango fruits that could contribute to invasive pest movements (Qin et al. 2015; David et al. 2017).

Similarly to what happened in other kinds of “push-and-pull” strategies or systems approaches for pest management (Cook et al. 2007; Aluja et al. 2009; ISPM 35 2012; Meats et al. 2012), the results of this work encourage the removal of intercropping tree plants and other *Anastrepha* spp. host fruits from the vicinity of the export-targeted production orchards. However, the benefits of these intercropping systems in the Anastrepha *spp. Risk Mitigation Plan* for mangoes should still be considered because these alternative hosts will attract fruit flies, which otherwise would forage for oviposition sites in mango plantations and would act as a reservoir for natural enemies (Deguine et al. 2015; David et al. 2017). In all, further research will contribute to improve our understanding on how *Anastrepha* fruit flies develop in this mango ecosystem.

24.5 CONCLUSIONS

In conclusion, Cuba has successfully developed and implemented a systems approach to reduce the risk of *Anastrepha* spp. infestations in mango varieties produced for export.

ACKNOWLEDGMENTS

The authors would like to acknowledge the growers for their help in establishing the trapping grids and for allowing the access to their home backyards to search for putatively infested fruits. We would also like to acknowledge the agricultural engineer N. Sellés from the quarantine department for assistance with the taxonomical identification of fruit flies. Last but not least, we would also like to acknowledge the two anonymous reviewers and the editorial staff of this book for their help in improving this manuscript.

NOTE

1. The Cuban national surveillance program is based on continuous year-round monitorization with three different types of traps (McPhail, Rebell, and Jackson as described in Borges-Soto et al., 2016) to verify the presence of several species of tephritid fruit flies. Traps are established in a triangle grid of 100 ha, setting one trap every 33 ha. Traps are switched in a counterclockwise fashion. In addition, all merchandise and people entry points (airports and ports) have each a complete set of traps, following the National law CNSV (2002).

REFERENCES

Aluja, M., and J. Rull. 2009. Managing pestiferous fruit flies (Diptera: Tephritidae) through environmental manipulation. In *Biorational Tree-Fruit Pest Management*, eds. M. Aluja, T.C. Leskey, and C. Vincent, pp. 171–213. Wallingford, UK: CAB international.

Aluja, M., J. Arredondo, F. Díaz-Fleischer, A. Birke, J. Rull, J. Niogret, and N. Epsky. 2014. Susceptibility of 15 Mango (Sapindales: Anacardiaceae) cultivars to the attack by *Anastrepha ludens* and *Anastrepha obliqua* (Diptera: Tephritidae) and the role of underdeveloped fruit as pest reservoirs: Management implications. *Journal of Economic Entomology* 107(1): 375–388.

Aluja, M., T. C. Leskey, and C. Vincent. 2009. *Biorational Tree-Fruit Pest Management*. Wallingford, UK: CAB International.

Armenteros, G. J. 2005. Reseña sobre la cuarentena exterior en Cuba. *Fitosanidad* 9(1): 47–64.

Birke, A., and M. Aluja. 2011. *Anastrepha ludens* and *Anastrepha serpentina* (Diptera: Tephritidae) do not infest *Psidium guajava* (Myrtaceae), but *Anastrepha obliqua* occasionally shares this resource with *Anastrepha striata* in nature. *Journal of Economic Entomology* 104(4): 1204–1211. doi: 10.1603/EC11042.

Borges-Soto, M., D. Rodriguez, M. Rodriguez Rubial, B. Sabater-Munoz, D. Hernandez Espinosa, and J. L. Rodriguez Tapial. 2016. A review on the Tephritid fruit flies of economic interest in Cuba: Species, plant hosts, surveillance methods and management programs implementation. In *Proceedings of the 9th International Symposium on Fruit Flies of Economic Importance*, eds. B. Sabater-Munoz, T. Vera, R. Pereira, and W. Orankanok, pp. 295–309. Bangkok, Thailand.

Borges-Soto, M., A. Beltrán, T. Mulkay, J. Rodriguez, D. Hernández, and A. Paunier. 2011. The Cuban experiences on monitoring and management of *Anastrepha* spp. (Diptera: Tephritidae) fruit flies in mango (*Mangifera indica*) and guava (*Psidium guajava*) orchards. In *Proceedings of the 8th International Symposium on Fruit Flies of Economic Importance*, eds. B. Sabater-Munoz, V. Navarro, and A. Urbaneja, pp. 206–211. Valencia, Spain: Editorial Polytechnic University of Valencia.

Borges-Soto, M., A. Beltran-Castillo, Y. Avalos-Rodriguez, B. Sabater-Munoz, D. Hernandez-Espinosa, and M. Rodriguez Rubial. 2015. Role of phytosanitary surveillance of *Anastrepha* spp. fruit flies (Diptera: Tephritidae) in the context of the citrus industry of Cuba. *Acta Horticulturae* 1065: 1027–1032.

CNSV. 2002. Programa de defensa contra moscas de la fruta. Republica de Cuba, Ministerio de la Agricultura, Centro Nacional de Sanidad Vegetal. 116 p. La Habana, Cuba.

Cook, S. M., Z. R. Khan, and J. A. Pickett. 2007. The use of push-pull strategies in integrated pest management. *Annual Reviews of Entomology* 52: 375–400.

David, P., E. Thebault, O. Anneville, P. F. Duyck, E. Chapuis, and N. Loeuille. 2017. Impacts of invasive species on food webs: A review of empirical data. *Advances in Ecological Research* 56: 1–60.

Deguine, J. P., T. Atiama-Nurbel, J. N. Aubertot, X. Augusseau, M. Atiama, M. Jacquot, and B. Reynaud. 2015. Agroecological management of cucurbit-infesting fruit fly: A review. *Agronomy for Sustainable Development* 35: 937–965.

Dias, N. P., M. J. Zotti, P. Montoya, I. R. Carvalho, D. E. Nava. 2018. Fruit fly management research: A systematic review of monitoring and control tactics in the world. *Crop Protection* 112: 187–200.

Drew, R. A. I. 2004. Biogeography and speciation in the Dacini (Diptera: Tephritidae: Dacinae). *Bishop Museum Bulletin in Entomology* 12: 165–178.

Epsky, N. D., P. E. Kendra, and E. Q. Schnell. 2014. History and development of food-based attractants. In *Trapping and the Detection, Control, and Regulation of Tephritid Fruit Flies. Lures, Area-Wide Programs, and Trade Implications*, eds. T. E. Shelly, N. Epsky, E. B. Jang, J. Reyes-Flores, and R. Vargas, pp. 75–118. Springer, Dordrecht, the Netherlands.

FAO. 2003. Cuba's citrus industry: Growth and trade prospects. Committee on commodity problems. Intergovernmental group on citrus fruit.ftp://ftp.fao.org/docrep/fao/meeting/006/y9316e.pdf (last accessed November 18, 2014).

FAOSTAT. 2018. Food and Agriculture Organization of the United Nations, Crop statistics (http://www.fao.org/faostat/en/#data/QC (last accessed on August 14, 2018).

Fernández, A. M., D. Rodriguez, and V. Hernández-Ortiz. 1997. Notas sobre el género *Anastrepha* Schiner en Cuba con descripción de una nueva especie (Diptera: Tephritidae). *Folia Entomológica Mexicana* 99: 29–36.

Follet, P. A. and R. I. Vargas. 2009. A systems approach to mitigate Oriental fruit fly risk in "Sharwil" avocados exported from Hawaii. *Acta Horticulturae* 880: 439–446.

Godefroid, M., A. Cruaud, J. P. Rossi, and J. Y. Rasplus. 2015. Assessing the risk of invasion by Tephritid fruit flies: Intraspecific divergence matters. *PLoS One* 10(8): e0135209.

ISPM 35 (international Standards for Phytosanitary Measures). 2012. Systems approach for pest management of fruit flies (Tephritidae), no. 35. Rome, IPPC, FAO. http://www.fao.org/docrep/016/k6768e/k6768e.pdf (last accessed August 14, 2018).

Jang, E., C. Miller, and B. Caton. 2015. Systems approaches for managing the risk of citrus fruit in Texas during a Mexican fruit fly outbreak. USDA. https://www.aphis.usda.gov/plant_health/plant_pest_info/fruit_flies/downloads/texas-citrus-systems-approach-risk-assesment.pdf (last accessed on August 2018).

Meats, A., A. Beattie, F. Ullah, and S. Bingham. 2012. To push, pull or push-pull? A behavioural strategy for protecting small tomato plots from tephritid fruit flies. *Crop Protection* 36: 1–6.

Moore, S. D., W. Kirkman, S. Albertyn, C. N. Love, J. A. Coetzee, and V. Hattingh. 2016. Partial cold treatment of citrus fruit for export risk mitigation for *Thaumatotibia leucotreta* (Lepidoptera: Tortricidae) as part of a systems approach. *Journal of Economic Entomology* 109(4): 1578–1585.

Qin, Y., D. R. Paini, C. Wang, Y. Fang, and Z. Li. 2015. Global establishment risk of economically important fruit fly species (Tephritidae). *PLoS One* 10(1): e0116424.

Rodríguez Velásquez D., A. M. Fernández, and V. Hernández-Ortiz. 2001. Catálogo de los Tefrítidos (Diptera: Tephritidae) de Cuba. *Fitosanidad* 5: 7–14.

Shelly, T. E. 2014. Fruit fly alphabets. In *Trapping and the Detection, Control, and Regulation of Tephritid Fruit Flies. Lures, Area-Wide Programs, and Trade Implications*, eds. T. E. Shelly, N. Epsky, E. B. Jang, J. Reyes-Flores, and R. Vargas, pp. 3–11. Springer, Dordrecht, the Netherlands.

Vázquez, L. L., I. Pérez, A. Navarro, and J. C. Casín. 1999. Occurrence and managing of the fruit flies in Cuba. *EPPO Bulletin* 29: 163–166.

Yahia, E. M. 2011. Mango (*Mangifera indica* L.). In *Postharvest Biology and Technology of Tropical and Subtropical Fruits: Cocona to Mango*, Vol. 3, ed. E.M. Yahia, pp. 492–567. Woodhead Publishing, Sawston, UK.

25 Fruit Fly Area-Wide Integrated Pest Management in Dragon Fruit in Binh Thuan Province, Viet Nam

Nguyen T.T. Hien, Vu T.T. Trang, Vu V. Thanh, Ha K. Lien, Dang Đ. Thang, Le T. Xuyen, and Rui Pereira*

CONTENTS

25.1 Background 343
25.2 Methods 344
25.3 Results 345
25.4 Conclusions 346
References 347

Abstract The area-wide integrated pest management (AW-IPM) to suppress fruit flies attacking dragon fruit was implemented in Ham Hiep village (Ham Thuan Bac district- Binh Thuan province, Viet Nam) since October 2016. The two targeted economically important tephritid fruit flies species were *Bactrocera dorsalis* (Hendel) and *Bactrocera correcta* (Bezzi). A pilot project consisting of a core zone (581 ha) and a buffer zone (986 ha) was implemented. Suppression strategies included both field sanitation and male annihilation technique (MAT) blocks in both zones. Additionally, in the core zone, protein bait spray was applied. A contiguous area under farmer suppression practice was used as a control. The average number of fruit flies per trap per day (FTD) was 1.8 and 2.2 in the core and buffer zones, respectively, compared to 11.6 in the farmers practice area. Another notable achievement was the involvement of the farmers in the surveillance activities, including trapping inspection, data collection, and sanitation by collecting and removing host fruits in the core and buffer zones. The results clearly indicated the advantage of integrating several methods in an AW-IPM approach. Further integration should include the sterile insect technique (SIT) in the overall suppression strategy.

25.1 BACKGROUND

Binh Thuan province is located in Southern Viet Nam. There are two seasons: wet (April–November) and dry (November–March). The temperature ranges from 20°C to 28°C during the year. The province has 28,000 ha of dragon fruit (*Hylocereus undatus*), which represent more than 70% of the total production in Viet Nam (Hien et al., 2012). Of these, 80% are for export. Farmers in 30%

* Corresponding author.

of the dragon fruit-growing areas adhere to the Vietnamese Good Agricultural Practices (VietGAP, 2008) and 8.7% to the Good Agricultural Practices (GlobalGAP) standards. However, most of them have limitations in the control of fruit flies (Diptera: Tephritidae), which are subject to strict quarantine measures and a barrier to fruit export for a large number of markets. Both *Bactrocera dorsalis* and *Bactrocera correcta* have been recorded to attack dragon fruit (Hien et al., 2011).

Since 2009, the Vietnamese government has been supporting the control of fruit flies; however, infestation is a limitation for fruit trade (Khanh et al., 2016). This is despite of fruit fly area-wide integrated pest management (AW-IPM), which is one of the most effective and environmentally friendly pest control strategies, already being applied successfully in many countries against Tephritid and other insect pests (Vreysen et al., 2007).

Since October 2016, an AW-IPM pilot project has been implemented in Binh Thuan province, Viet Nam in a 1,567-ha area, as a follow-up to a smaller-scale pilot project that was initiated in 2012 (Khanh et al., 2016). The objective of both trials was to suppress *B. dorsalis* and *B. correcta* tephritid fruit fly populations in selected dragon fruit-production areas by integrating different available control methods. A further goal would be the future integration of the sterile insect technique (SIT) into the control measures already taking place to aid sustainability to the program and to set areas of low fruit fly pest prevalence in the dragon fruit-production areas to reduce quarantine restrictions and facilitate trade.

25.2 METHODS

The pilot project area (1,567 ha) consisted of a 581-ha core zone where the full suite of available IPM control measures was implemented. The core zone was surrounded by a 986-ha buffer zone, which separated the core zone from the farmer zone (Figure 25.1). This farmer zone used existing farmer practices such as cover insecticide applications or lure traps and served as a control.

FIGURE 25.1 Map of fruit fly suppression in the dragon fruit-production area of Binh Thuan province. The core zone of 581 ha is inside the blue line, and the 986 ha between the blue and yellow line is the buffer zone. The area outside the yellow line is the farmer zone used as a control. Red, blue, and yellow letters refer to the location of the monitoring traps.

Three suppression methods were applied in the core zone. These included: (i) Field sanitation: Fallen and infested fruits were regularly collected and sealed into plastic bags that were exposed to direct sunlight to kill larvae in the fruit. Collected fruits were also burned or buried under the ground, at least 30 cm deep. Sanitation focused on dragon fruit plus fruits collected from backyards, such as mango (*Mangifera indica*), guava (*Psidium guajava*), and star fruit (*Averrhoa carambola*); (ii) Male Annihilation Technique (MAT): attract-and-kill blocks (containing 1 L of Methyl eugenol (ME) + 4 mL of fipronil) that were placed at 50-m intervals to suppress the population of males of both *B. dorsalis* and *B. correcta* (Hien et al. 2012, 2017). Blocks were replaced after 2–3 months (depending on the wet season); and (iii) Bait spray application targeting female fruit flies: Bait mixture (1 L of protein bait + 1 g of fipronil 800WG + 9 L of water) was applied every seven days from fruit maturation until harvest (Hien et al. 2012). Bait mixture was sprayed as spots (50 mL) under leaves or bushes (not applied directly on the fruits). Field sanitation and MAT block methods were also applied in combination in the buffer zone.

All information on host fruit maturation and infestation was recorded weekly during the implementation of the pilot project to obtain the status of the host (Khanh et al., 2016). Additionally, public information and training on AW-IPM for the farmers was conducted every week.

Adult populations were monitored during the full period of the pilot project (October 2016 to date) by using methyl eugenol (ME) traps (FAO/IAEA, 2018) inspected every 10 days and serviced every 2 months. A total of 72 traps were installed: 16 in the core zone, 48 in the buffer zone, and 8 in the control zone. All flies in each inspected trap were sent to the laboratory and the FTD was calculated.

To evaluate the impact of the suppression measures in the different zones and the control, weekly visual observations were conducted for tephritid damage on dragon fruits (FAO/IAEA, 2017). As of April 2017, a total of 300 dragon fruits in each zone were collected and observed for damage at the harvesting stage every month. They were then kept individually to allow larvae within the fruits to pupate and be counted, thus obtaining a percentage of fruit infestation. This study was initiated in April 2017 and is still in operation.

25.3 RESULTS

Flies per trap per day (FTD) varied from 0 to 5.43, from 1.31 to 14.97, and from 1.33 to 38.29 in the core zone, buffer zone, and farmer zone, respectively (for the period of October 2016–July 2018) (Figure 25.2). The number of fruit flies caught in all zones varied over the time period, with higher numbers being caught in the wet periods, from March to August/September and with population peaks in May/June. Fruit flies caught in traps in the core and buffer zones were significantly fewer

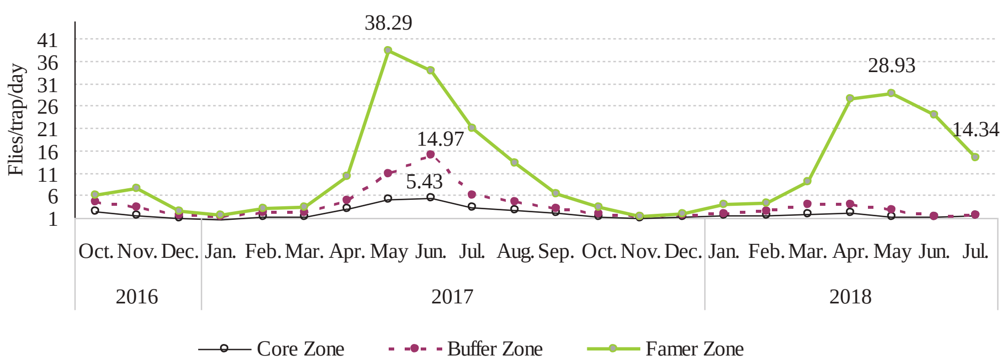

FIGURE 25.2 Mean population of fruit flies captured in the core, buffer, and farmer control zones in the area-wide integrated pest management (AW-IPM) pilot project (October 2016–July 2018) in Binh Thuan Province, Viet Nam.

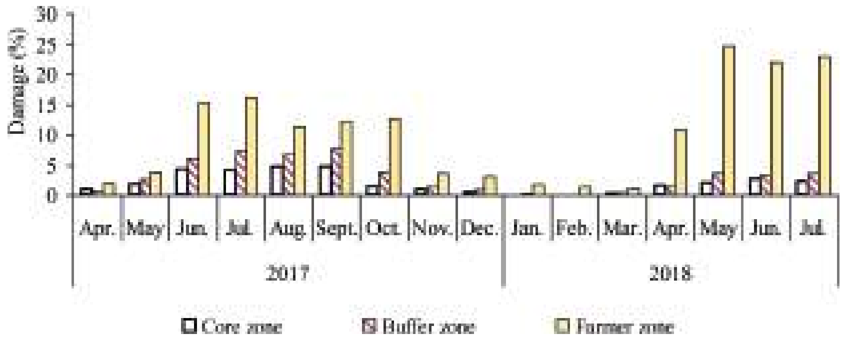

FIGURE 25.3 Mean percentage of damage in dragon fruits from the core, buffer, and farmer control zones in the area-wide integrated pest management (AW-IPM) pilot project (April 2017–July 2018) in Binh Thuan Province, Viet Nam.

than those in the farmer control zone (Figure 25.2). The reduction of the wild population was dramatic in both the core and the buffer zone compared to the control zone in the period of April–July 2018 (wet period). In the dry periods (October–March), fewer flies were caught, with no differences noted in trap catches between the three zones (Figure 25.2).

The average percentage of damaged dragon fruit ranged from 1% to 4.7% in the core zone, 0.7% to 7.7% in the buffer zone, and 2% to 24.7% in farmer's practice (control zone) during the period of April 2017–July 2018 (Figure 25.3).

At each sampling period, it can be clearly seen that fruits from the core area, where the AW-IPM treatments were applied, were far less damaged than in the farmers control fields, where no AW-IPM treatments were applied (Figure 25.3). This was markedly more evident in the wet months of June through October 2017 and even more so during the second year of the project, from April through July 2018, when fruit fly populations were generally higher than in the dry period (Figure 25.2).

25.4 CONCLUSIONS

Area-wide suppression methods using MAT with protein bait sprays and field sanitation were effective for controlling fruit fly populations in dragon fruit farms in the core area of the AW-IPM pilot trial in Binh Thuan province. However, for the continued implementation and maintenance of the AW-IPM program, a good knowledge base on alternative hosts and the effect of climate change is needed (Hien et al. 2012). In addition, further education for the continuation of monitoring and fruit damage evaluations is needed for farmers and stakeholders. The need of fruit sampling is very important, especially in situations where MAT blocks are used because adult males will be removed from the environment in these situations, making trapping data less reliable and requiring fruit sampling evaluations.

Another relevant achievement was the involvement of the farmers in the activities of surveillance, including trapping inspection and data collection, and implementing sanitation by removing host fruits in the core and buffer zones. This is the result of awareness and implementation in the field, which occurs first by leader farmers that attract others to use such methods.

The present results clearly indicate the impact and advantage of integrating several available methods in a controlled AW-IPM strategy. The implementation of the AW-IPM strategy in a planned and knowledge-based way and the lessons learnt during this pilot study should be a priority for the larger dragon fruit industries. The integration of SIT into this already established successful suppression strategy could be considered with additional suppression tools. Research on this integration is planned for 2019.

REFERENCES

FAO/IAEA. 2017. *Fruit Sampling Guidelines for Area-Wide Fruit Fly Programmes*, eds. W. R. Enkerlin, J. Reyes and G. Ortiz. Vienna, Austria: Food and Agriculture Organization of the United Nations.

FAO/IAEA. 2018. *Trapping Guidelines for Area-Wide Fruit Fly Programmes*, eds. W. R. Enkerlin and J. Reyes-Flores. Rome, Italy: IAEA.

Hien, N. T. T., L. D. Khanh, and L. Q. Khai. 2011. Thành phần loài ruồi hại quả (Tephritidae: Diptera) và ký chủ của chúng tại vùng thanh long BìnhThuận. *Journal of Vietnam Agricultural Science and Technology*, 9:41–44.

Hien, N. T. T., L. Đ. Khanh, L. Q. Khai et al. 2012. Nghiên cứu biện pháp quản lý ruồi hại quả thanh long trên diện rộng, nhằm góp phần nâng cao chất lượng sản phẩm quả xuất khẩu tại Bình Thuận. The National project report. Management fruit fly on Dragon fruit in Binh thuan province.

Hien, N. T. T, L. D. Khanh, V. V. Thanh et al. 2017. Influence of adult diet and exposure to methyl eugenol in the mating performance of *Bactrocera correcta*. *Nuclear Science and Technology* 7:42–48.

Khanh, L. D., L. Q. Khai, N. T. T. Hien, V. V. Thanh, T. V. R. Trang, and R. Pereira. 2016. Area-wide suppression of *Bactrocera* fruit flies in dragon fruit orchards in Binh Thuan, Viet Nam. In *Proceedings of the 9th International Symposium on Fruit Flies of Economic Importance*, eds. B. Sabater-Muñoz, T. Vera, R. Pereira and W. Orankanok, pp. 93–100. Bangkok, Thailand: International Fruit Fly Steering Committee.

VietGAP. 2008. Bộ Nông Nghiệp và PTNT. *Quyết định ban hành quy trình thực hành sản xuất nông nghiệp tốt cho rau, quả tươi an toàn*. Global Good Agricultural Practice.

Vreysen, M. J. B., A. S. Robinson, and J. Hendrichs. 2007. *Area-Wide Control of Insect Pests from Research to Field Implementation*. Dordrecht, the Netherlands: Springer.

Taylor & Francis
Taylor & Francis Group
http://taylorandfrancis.com

26 Area-Wide Approach for the Control of Mango Fruit Flies in a Metropolis Containing Polycultures in Urban and Peri-Urban Areas in Nigeria

*Vincent Umeh**, *Vivian Umeh, and John Thomas*

CONTENTS

26.1 Introduction ... 350
26.2 Materials and Methods ... 351
26.2.1 Study Site ... 351
26.2.2 Distribution and Placement of Traps ... 351
26.3 Results ... 353
26.4 Conclusions ... 358
References ... 358

Abstract Fruit flies impact the production of many fruit species and cause economic yield losses in all countries in West Africa. In such endemic areas, including metropolitan cities, fruit flies do not occur only in orchards but extend their infestation to trees in household backyards, private gardens, and stockpiled fruits for local and international markets. This scenario occurs in almost all towns and cities in Nigeria, contributing to fruit fly population explosions if left uncontrolled. We, therefore, attempted, for the first time in Nigeria, to implement a mass trapping technique over an area of about 20 km2 to capture mainly fruit flies infesting mango and other major alternative hosts. This study evaluated the population dynamics of the major mango fruit flies *Bactrocera dorsalis* (Hendel) and *Ceratitis cosyra* (Walker) during on and off season periods in Ibadan metropolis, Nigeria. The influence of environmental factors, such as temperature and humidity (rainfall), on the abundance of both species was also evaluated. Results of the implementation of fruit fly management techniques, which included orchard sanitation by picking dropped fruits, mass trapping using parapheromones, and the application of protein baits, are discussed. *B. dorsalis* dominated the trap catches, whereas the presence of *C. cosyra* on mango was very negligible throughout the study period. Although a higher number of *C. cosyra* was observed in the dry season months of January–March, it was totally absent in other months. The presence of *B. dorsalis* was recorded throughout the year, with higher populations occurring during the rainy season. The relative abundance of *B. dorsalis* across alternative hosts indicated that *Irvingia* harbored higher fly numbers compared to citrus. Fruits incubated during first- and second-year harvests showed a significant

* Corresponding author.

suppression of fruit fly populations by not less than 70%–82% for *B. dorsalis* and *C. cosyra*, respectively, in all fruit species compared to areas where no control was applied. Fruit fly population dynamics are influenced by environmental factors. Application of management strategies in a metropolis that is characterized by polycultures and diverse hosts can suppress populations. However, there is a need for awareness campaigns aimed at communities in the metropolis for their direct involvement in the control of fruit flies.

26.1 INTRODUCTION

Mango (*Magnifera indica*) and citrus are some of West Africa's most important crops and play a major role in local, national, regional, and international markets. They are also a major source of nutrition for rural populations in West Africa. In Nigeria, most of the fruit produced is consumed as fresh fruit, and ripe fruits can be made into juice and be preserved. Although Nigeria occupies the ninth position among the 10 leading mango-producing countries of the world, it does not feature among the 10 leading mango fruit exporters (FAOSTAT, 2007).

Pests and diseases are the primary constraints for fruit production in Nigeria. Although some insect pests are noted for contributing to the decline of citrus and mango (Umeh et al., 2000), some play an important role in reducing fruit yields and rendering them unacceptable to consumers (Drew et al., 2005; Umeh et al., 2008). Fruit flies are considered the most destructive insect pests of fruits (Ekesi et al., 2009; Vayssieres et al., 2007; Vayssieres et al., 2008). The oriental fruit fly, *Bactrocera dorsalis* (Hendel), is responsible for extensive economic losses of horticultural crops throughout West Africa, increasing the damages already caused by native fruit flies. This invasive species was recently identified in parts of Africa, which implies a further increase in yield losses.

The distribution and abundance of tephritids depend on several abiotic factors (e.g., temperature, relative humidity, rainfall) and several biotic factors (e.g., host plants, natural enemies) (Vayssières et al., 2008). Temperature and relative humidity have a significant effect on fruit flies, especially on their developmental stages. A decrease in temperature increases the duration of each stage. Rwomushana et al. (2008) reported high rates of survival for all immature stages in *B. invadens* (currently *B. dorsalis*) at 20°C–30°C. Similarly, Duyck et al. (2004) reported that a temperature ranging between 20°C and 30°C allows high survival rates of *B. zonata* (Saunders). Lower survival rates have been generally observed at extreme temperatures of 15°C–35°C for all developmental stages of tephritid fruit flies (Brévault and Quilici, 2000; Duyck and Quilici, 2002; Duyck et al., 2004; Rwomushana et al., 2008).

The main control methods employed in orchards are regular protein baiting of host trees and the implementation of the male annihilation technique (MAT). The bait application technique (BAT) is directed at killing both male and female flies, whereas MAT attracts and kills only male flies through the use of parapheromones. Presently, BAT has also been used in area-wide eradication programs on its own or in combination with other control methods. BAT is frequently used to eradicate exotic species entering into an area, and bait applications are used with sterile releases for the eradication of fruit flies (Permalloo et al., 1997). Methyl eugenol (4-allyl-1, 2 dimethoxy benzene-carboxylate) is used for the detection of the oriental fruit fly *B. dorsalis*. Trimedlure [t-Butyl-2-methyl-4-chlorocyclohexane carboxylate], a powerful lure for the Mediterranean fruit fly (*Ceratitis capitata* Wied), is used to detect incipient infestations of the destructive insect and is used in combination with an insecticide to reduce male populations to such low levels that mating does not occur. All these species have been introduced and have become severe pests of tropical fruits (Leblanc et al., 2011; Vargas et al., 2007).

MAT is aimed at reducing the number of male flies on an area-wide, long-term basis with the eventual effect of reducing female fertility due to the greatly reduced number of males available for mating. The male annihilation technique is a fruit fly control method that aims to remove male insects, thus reducing the male population. This affects the male-to-female ratio and reduces the insect's chances of mating, with females producing fewer progeny. Consequently, insect populations in target areas decline and insects can ultimately be eradicated (Stonehouse et al., 2008; Zaheeruddin, 2007). Lures in monitoring traps are used in MAT programs. The use of this method on incipient infestations of the oriental fruit fly should prevent the further development and spread of this species, with eradication being a definite possibility. Male attractants for other tropical fruit flies are strong enough to warrant consideration as possible male annihilation agents (Christenson, 2009). It has been reported that methyl eugenol and Cue-lure traps used in close proximity, about 3 m, to fruit trees show a high performance and are considered as the best attractants in mixed fruit orchards (Ullah et al., 2017).

The main objectives of this study were: (i) to evaluate the influence of environmental factors, such as temperature, relative humidity, and rainfall, on fruit fly population dynamics across a metropolis constituted of urban and peri-urban areas containing polycultures in Nigeria, and (ii) to assess the effect of mass trapping, using parapheromones and protein baits, and the cultural practice of picking dropped fruits, on the suppression of populations of the major mango fruit flies in polycultures.

26.2 MATERIALS AND METHODS

26.2.1 Study Site

High presence of mango was a determinant factor for the selection of the study site, which was located between N07° 30″, E003° 46″ and N07° 22″, E003° 53″. Other major economic fruit species common in the target area that are alternative hosts of *B. dorsalis* were also considered. The assessed alternative hosts were limited to citrus and bush mango *Irvingia* spp. The target area covered parts of urban and peri-urban areas in Ibadan metropolis, and it mostly comprised sole crops, polycultures, and homestead stands of mango, citrus, and *Irvingia* spp. Parts of the target area did not contain any fruit trees, whereas others had patches of small or big orchards ranging from 1–30 ha. Large orchards belong to the National Horticultural Research Institute (NIHORT) and the Forestry Research Institute of Nigeria (FRIN) (Figure 26.1).

26.2.2 Distribution and Placement of Traps

Trap layout (spatial distribution of traps) and trap density were influenced by various factors, including the sensitivity to the parapheromone of the fruit fly species associated with the host, type of survey (monitoring or control), trap efficiency, and assessed pest risk. Pest risk assessment was initially performed to identify the risk areas, with the lowest-risk areas requiring the lowest trap densities and the highest-risk areas requiring the highest trap densities. The identified and characterized risk factors (individually or as added effects) included the following:

- Host availability in the target area (number of species present, abundance, and distribution over space and time)
- Host preference (major and minor hosts)
- Human settlements (urban and peri-urban)
- Distance of host to infested areas
- Historical profile of pest occurrence in the area

A total of 330 traps were distributed in an area of about 20 km^2 to capture mainly fruit flies of mango and other alternative host plants, namely citrus and bush mango (*Irvingia* spp.), that are characteristic of the area. Tephri traps were used for the parapheromone baits. The parapheromones used were methyl eugenol and terpinyl acetate in a total of 60 traps each; whereas only methyl eugenol was used for citrus in a total of 60 traps. *Ceratitis capitata* populations in the target area were found to be negligible over the past 6 years. Thus, the parapheromone (Trimedlure) used for *C. capitata* associated with citrus was not included in this study. *Irvingia* stands were also supplied with a

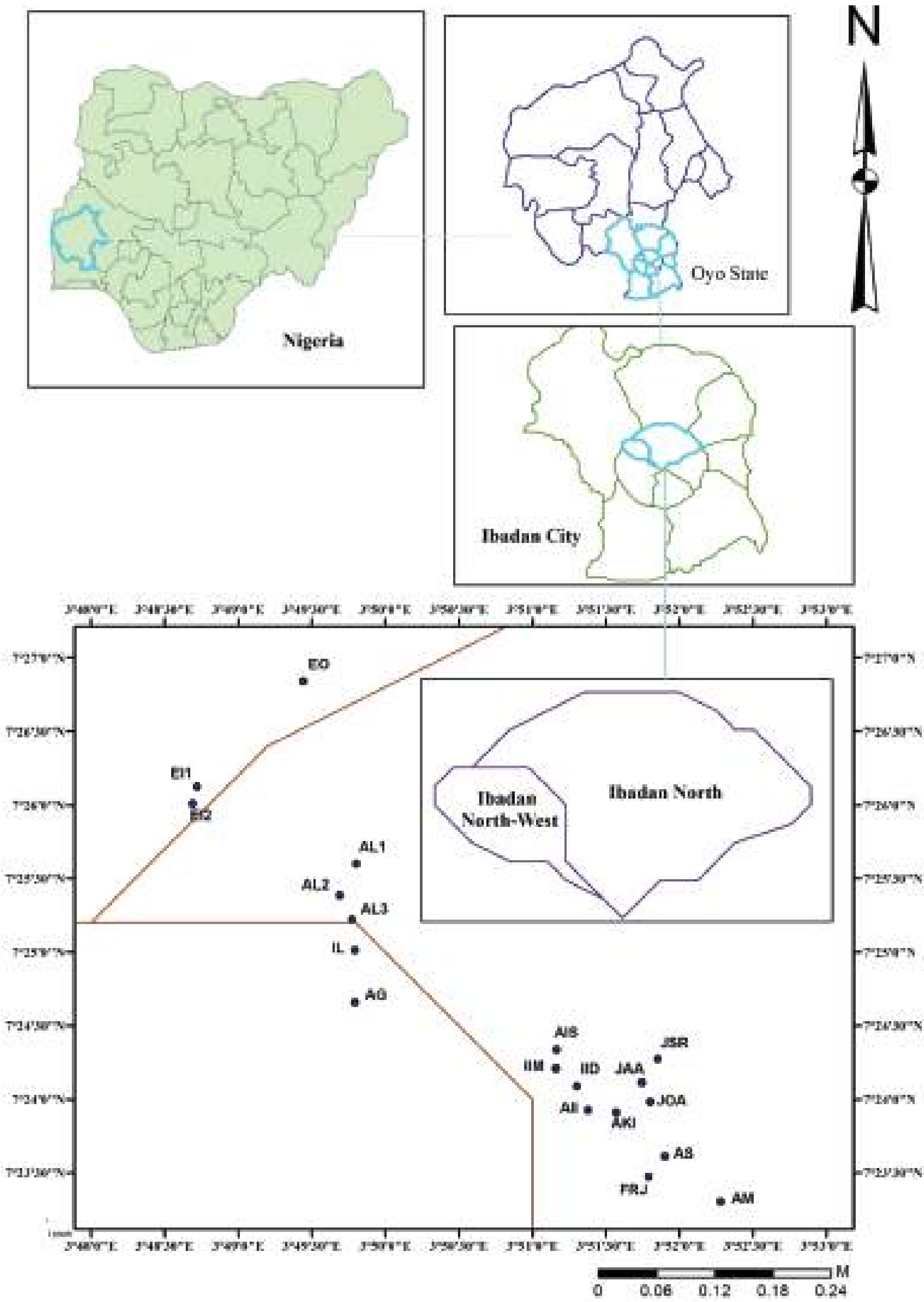

FIGURE 26.1 Map of surveyed area in Ibadan, Nigeria.

total of 60 traps baited with methyl eugenol and distributed in the target area. The fumigant DDVP was also placed in each trap device (i.e., parapheromone + fumigant). Traps were hung on mango, citrus, and *Irvingia* trees either in orchards or homestead stands. Protein baits, made of Torula® yeast pellets dissolved in warm water at 50°C, using 2 pellets per 150 mL of water, were also used. A total of 30 Torula yeast traps were placed in mango, citrus, and *Irvingia* trees in the target area.

The total number of trap devices for each plant type was divided into three batches and distributed according to the selected crop stands. Flies caught in the parapheromone traps were recorded and collected at weekly intervals, and the traps were repositioned. Parapheromone attractants were replaced at monthly intervals (IAEA, 2003). Torula yeast traps were replaced at weekly intervals after recording the number of trapped fruit flies. Three portions within the surveyed area were assigned as a control treatment and no traps were placed in those sites for any of the three fruit species (i.e., mango, citrus, and *Irvingia*). Picking and removal of dropped fruits was carried out throughout the target area.

We also carried out extension actions and publicity regularly to sensitize the stakeholders whose trees were included in the study by informing them about what to do to avoid disrupting the control activities. Fallen fruits in the control area were not picked. Monthly mean atmospheric temperature values and rainfall dates were obtained from a meteorological station belonging to NIHORT and located in the study area.

During harvest, 20 fruits of mango, citrus, and *Irvingia* each were collected in the experimental and control portions of the orchards for three consecutive harvesting regimes according to the maturation time of each of the fruit species. Collected fruits were incubated in small cages layered with sieved fine sand. Developed pupae were sieved and reared to adulthood in a cylindrical transparent plastic container covered with wire gauze.

The number of emerging fruit flies in the different treatments was recorded and the mean number of emerging fruit flies from each fruit batch was computed as mean number/fruit. Data were analyzed with an analysis of variance (ANOVA) and significant means were identified using the Student Newman Keuls (SNK) test. All tests were considered to be significant at $P = 0.05$.

26.3 RESULTS

Bactrocera dorsalis populations dominated the trap catches in mango. Its presence was recorded throughout the year. The population rose steadily from February 2017 and increased to a maximum mean of 14.5 fruit flies per trap per day (FTD) in June, which coincided with the rainy season (Figure 26.2).

The population remained relatively high during the rainy season but started to decline as the dry season began and stretched into the early part of 2018. After this time, the population started to increase again in a pattern similar to the trend observed in 2017 (Figure 26.2). The population of *C. cosyra* in mango was low throughout the study period compared to *B. dorsalis*. It ranged between 1 and 3 FTD in the dry season months of January–March, with a marked decrease to zero fruit flies recorded in the rainy season between August and November.

Although a relatively higher number of *C. cosyra* was observed during the harvest period of mango in the dry season, availability of early mango varieties also influenced its presence. Furthermore, the population decreased and became totally absent as the rainy season progressed and the mango season ended in the area (Figure 26.2). Observations made in traps baited with Torula yeast placed only in mango showed a dominance of female fruit flies from both *B. dorsalis* and *C. cosyra* (Figure 26.3) and a minimal number of *C. capitata* females and *B. dorsalis* males. These followed the same population trends that were observed in the parapheromone traps for male catches (i.e., a higher number of *B. dorsalis* females compared to *C. cosyra*).

Fluctuations in the number of FTD observed in the protein baits could be associated with the ripening period of mango. More visits to mango were made by female fruit flies during the ripening period in the months of March–June, when ripe fruits were still available. This agrees with the findings of other authors who observed similar trends (Manrakhan, 2016; Papadopoulos et al., 2003).

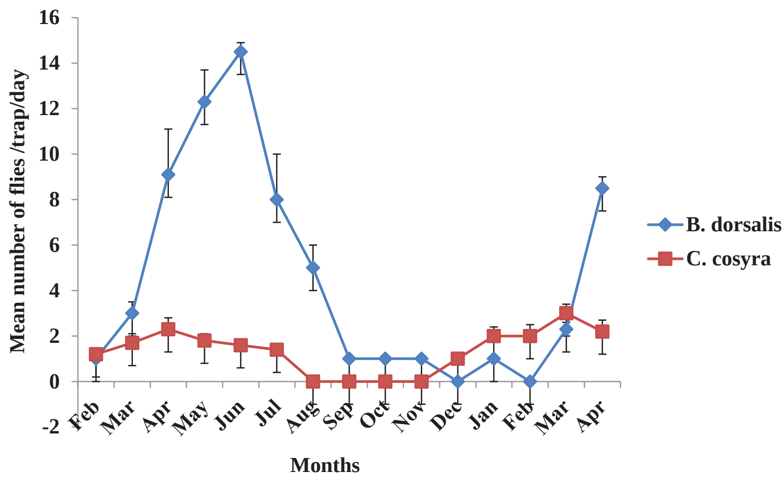

FIGURE 26.2 *Bactrocera dorsalis* and *Ceratitis cosyra* male population trends from trap catches in mango. Mean population of fruit flies from each of 30 traps replicated three times and separately baited with methyl eugenol and terpinyl acetate.

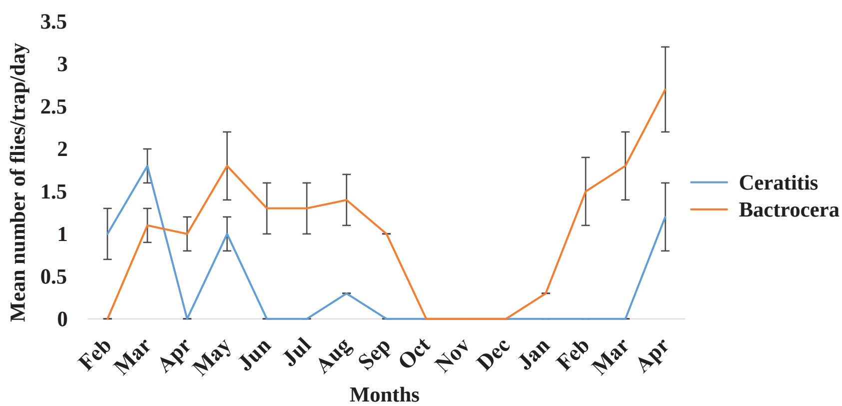

FIGURE 26.3 Population trends of *Ceratitis cosyra* and *Bactrocera dorsalis* females from protein bait catches in mango. Mean population of fruit flies from 10 torula yeast traps replicated three times.

The generally lower population of female fruit flies observed in this food-based attractant system may be attributed to the nature of the attractant, which can only be lethal if the flies drown in the liquid bait, unlike the parapheromone trap device, which has an insecticidal fumigant that kills the trapped male flies.

The relative abundance of *B. dorsalis* across other sampled alternative hosts, citrus and bush mango (*Irvingia* spp.), indicated that *Irvingia* attracted higher numbers of *B. dorsalis* compared to citrus (Figures 26.4 and 26.5). However, the population dynamics of *B. dorsalis* in citrus followed the same trend as that observed in mango, whereas the population of *B. dorsalis* in *Irvingia* differed slightly from the one in mango. The availability of *Irvingia* fruits in the months of January–March, which is usually a dry period when *B. dorsalis* populations are low, resulted in the unusual presence of *B. dorsalis* in traps in *Irvingia* earlier than in mango. Thus, this indicates that, apart from other environmental factors, the availability of preferred fruit types also influenced the population levels of this species.

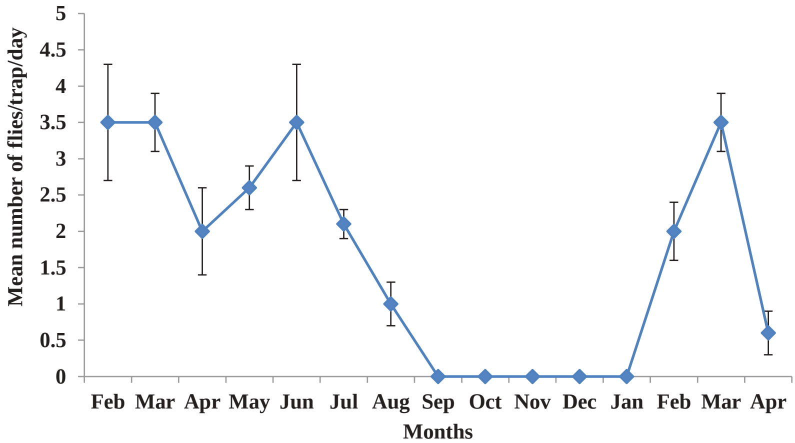

FIGURE 26.4 *Bactrocera dorsalis* male population trend from trap catches in citrus. Mean population of fruit flies from 30 traps replicated three times.

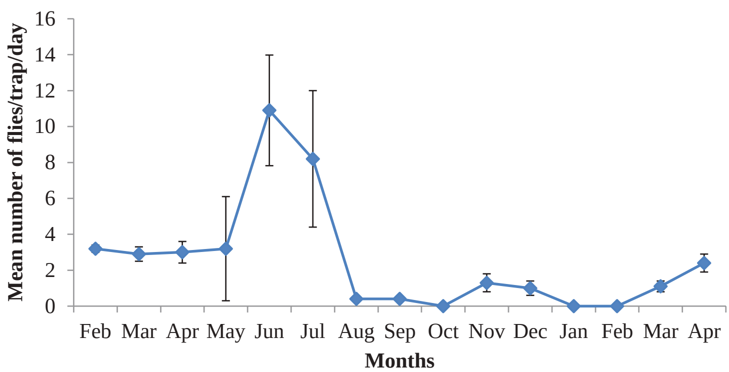

FIGURE 26.5 *Bactrocera dorsalis* male population trend from trap catches in *Irvingia*. Mean population of fruit flies from 60 traps replicated three times.

Population dynamics of *B. dorsalis* and *C. cosyra* in relation to temperature are shown in Figures 26.6 and 26.7 and are shown in relation to rainfall in Figures 26.8 and 26.9. Correlation analyses showed that the population of *B. dorsalis* was not significantly (P >0.05) correlated with environmental temperature across the studied months, and the correlation coefficient was negative (r = –0.037; n – 1 = 14). On the other hand, the population of *C. cosyra* was positively correlated with environmental temperature (r = 0.752; n – 1 = 14; P <0.05). These findings show that drier periods favor populations of *C. cosyra*, hence the larger population observed in the early part of the year until the beginning of the rainy season. In Ibadan, Nigeria, the highest annual temperatures are recorded during the months with a high abundance of *C. cosyra* (February–April) (Umeh and Onukwu, 2016). In the case of rainfall, there was a positive correlation with the population of *B. dorsalis* (r = 0.434576: n – 1 = 14; P <0.05), whereas a weak negative correlation was observed between mean *C. cosyra* populations and rainfall levels (r = –0.342: n – 1 = 14; P >0.05). These results are in line with findings by other authors in West Africa, especially the positive effect of humidity on *B. dorsalis* populations (Amice and Sales, 1997; Rwomushana et al., 2008; Sarada et al., 2001; Vayssières et al., 2009).

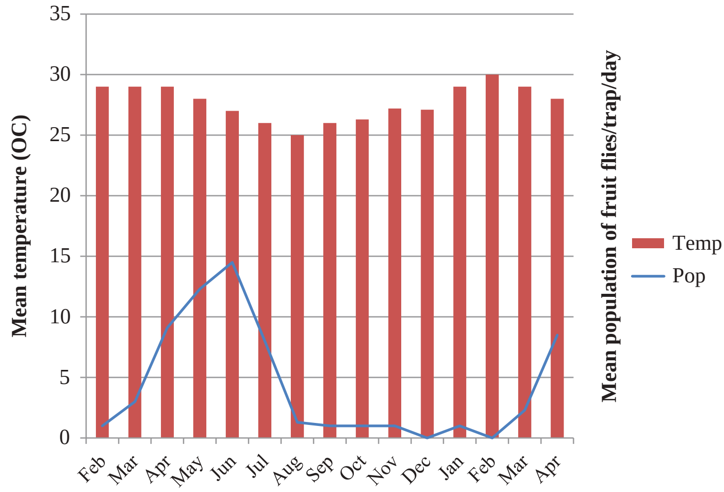

FIGURE 26.6 Relationship between *Bactrocera dorsalis* trap captures and temperature.

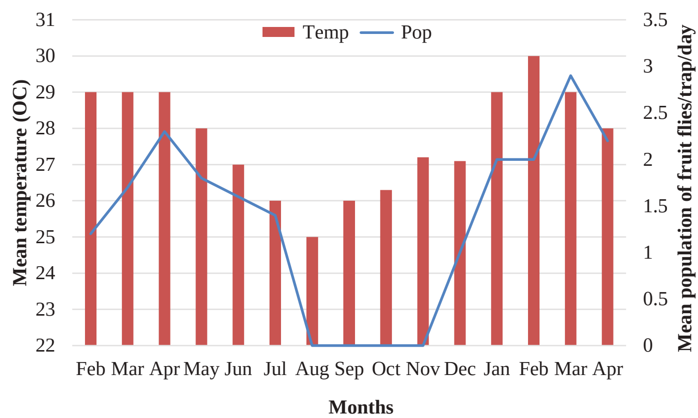

FIGURE 26.7 Relationship between *Ceratitis cosyra* trap captures and temperature.

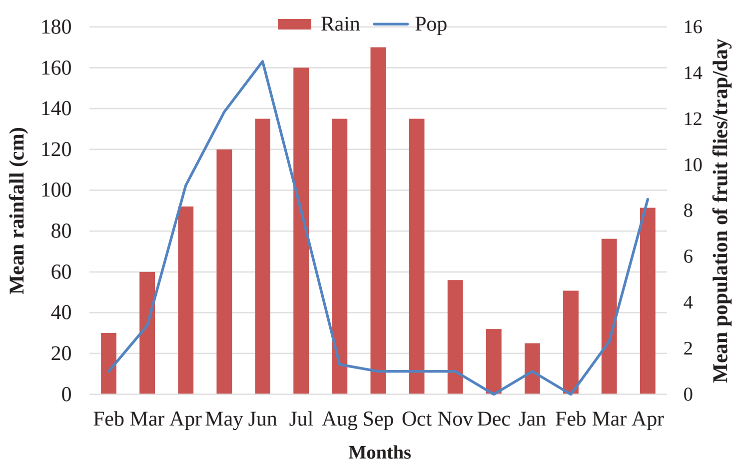

FIGURE 26.8 Relationship between *Bactrocera dorsalis* trap captures and rainfall.

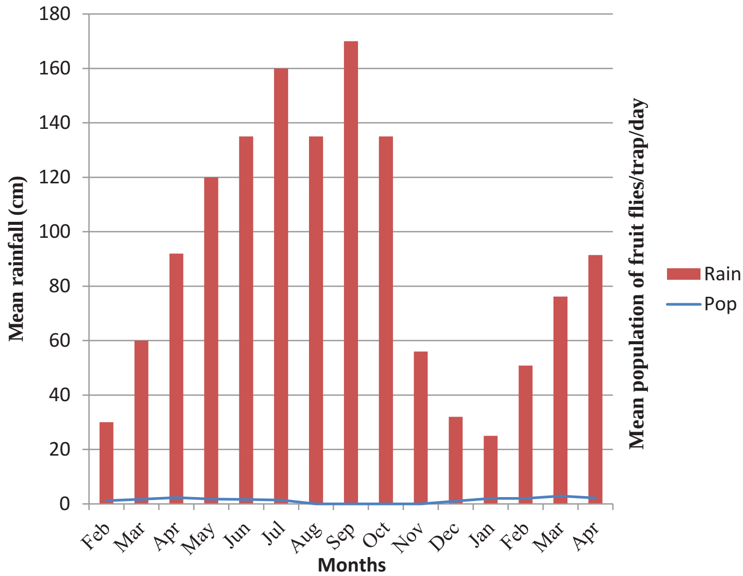

FIGURE 26.9 Relationship between *Ceratitis cosyra* trap captures and rainfall.

There seems to be an interplay of factors that affect the populations of these fruit fly species. These include the presence of preferred fruits, apart from temperature and humidity. Theron et al. (2017) reported, using a time series analyses, that adult populations of *B. dorsalis* increased 2 months after an increase in mean temperature in all sites of the study, 4 months after rainfall in natural and interface sites, and 1 and 3 months after fruit infestation in commercial and natural and interface sites, respectively.

Fruit flies obtained from fruits sampled in the different treatments showed various levels of fruit fly emergence per fruit. However, the mean number of *B. dorsalis* that emerged from fruits collected in areas where MAT traps were set up in mango, citrus, or *Irvingia* was significantly (P <0.05) lower than that from those collected in the control area, indicating a decrease in the population of fruit flies due to mass trapping (Table 26.1).

TABLE 26.1
Relative Abundance of Fruit Fly Species Emerging from Fruits Collected from Different Treatment Plots in 2017 and 2018

	Mean Number of Fruit Flies/Fruit							
	Mango				Citrus		Bush Mango (*Irvingia*)	
Treatments	2017		2018		2017	2018	2017	2018
	Bd	Cc	Bd	Cc	Bd	Bd	Bd	Bd
Methyl eugenol	3.6 b	—	2.6 b	—	3.2 b	1.8 b	3.8 b	2.3 b
Terpinyl acetate	—	0.6 b	—	0.4 b	—	—	—	—
Control	10.2 a	3.8 a	7.8 a	2.0 a	7.2 a	5.6 a	9.4 a	6.4 a

Means in the same column followed by the same letter are not significantly different according to SNK (P >0.05). Mean number of fruit flies obtained from 20 mango fruits (mean weight of 10.4 kg), 20 citrus fruits (mean weight 8.5 kg), and 20 Irvingia fruits (mean weight of 6.00 kg) are shown.
Bd, *Bactrocera dorsalis*; Cc, *Ceratitis cosyra*.

The number of *B. dorsalis* and *C. cosyra* per fruit recorded in the MAT fields ranged from 2.6 to 3.6/fruit and 0.4 to 0.6/fruit, respectively, compared to the control fields where recorded numbers were 7.8–10.2/fruit and 2–3.8/fruit, respectively. Similarly, the number of *B. dorsalis* that emerged per fruit in the alternative hosts citrus and *Irvingia* in the MAT fields ranged from 1.8 to 3.8/fruit compared to 5.6 to 9.4/fruit observed in the corresponding control fields. However, a lower *B. dorsalis* and *C. cosyra* adult emergence was generally observed in fruits collected in 2018 compared to those collected in 2017, which is probably due to the reduced population of fruit flies observed in 2018, possibly as a result of the effectiveness of MAT captures in 2017. Thus, fewer attacks resulted in 2018. A reduction of more than 70% in the population of fruit flies was obtained in the MAT fields, compared to the control area, in mango, citrus, and *Irvingia*.

26.4 CONCLUSIONS

Fruit fly population dynamics are influenced by environmental factors. The implementation of a combination of management strategies, such as the removal and disposal of dropped fruits, the application of the MAT, and the use of the BAT, in a metropolis that is characterized by polycultures and diverse hosts can suppress populations. However, there is a need for education campaigns aimed at communities in the cities for their direct involvement in fruit fly control using the tested techniques. Studies conducted by fruit fly experts indicate that the success of AW-IPM programs is highly dependent on the monitoring of fruit flies, appropriate and quick responses to incursions, and an active participation by all growers and the rest of the community in the area under the program. For a rapid population suppression and better results, the introduction of the sterile insect technique (SIT) will go a long way in achieving the desired result, especially in an area-wide approach.

REFERENCES

Amice, R., and F. Sales. 1997. Seasonal abundance of fruit flies in New Caledonia. In: *Management of Fruit Flies in the Pacific*, eds. A. J. Allwood and R. A. I. Drew, pp. 134–139. Camberra, Australia: ACIAR.

Brévault, T., and S. Quilici. 2000. Relationship between temperature, development and survival of different life stages of tomato fruit fly. *Neoceratitis Cyanescens. Entomologia Experimentalis et Applicata* 94: 25–30.

Christenson, L. D. 2009. The male annihilation technique in the control of fruit flies: New approaches to pest control and eradication. *Advances in Chemistry* 41: 31–35.

Drew, R. A. I, K. Tsuruta, and I. M. White. 2005. A new species of pest fruit fly from Sri Lanka and Africa. *African Entomol*ogy 13: 149–154.

Duyck P. F., and S. Quilici. 2002. Survival and development of different life stages of three *Ceratitis* spp. (Diptera: Tephritidae) reared at five constant temperatures. *Bulletin of Entomological Research* 92: 461–469.

Duyck, R. A. I., J. F. Sterlin, and S. Quilici. 2004. Survival and development of different life stages of *Bactrocera zonata* (Diptera: Tephritidae) reared at five constant temperatures compared to other fruit fly species. *Bulletin of Entomological Research* 94: 89–93.

Ekesi, S, M. K. Billah, P. W. Nderitu, S. Lux, and I. Rwomushana. 2009. Evidence for competitive displacement of *Ceratitis cosyra* by the invasive fruit fly *Bactrocera invadens* on mango and mechanisms contributing to the displacement. *Journal of Economic Entomology* 102 (3): 981–991.

FAOSTAT. 2007. *FAO Statistics*, Food and Agriculture Organization of the United Nations, Rome, Italy. http://faostat.fao.org/.

IAEA. 2003. *Trapping Guidelines for Area-Wide Fruit Fly Programmes*. Vienna, Austria: IAEA.

Leblanc, L., R. I. Vargas, B. MacKey, R. Putoa, and C. P. Jaime. 2011. Evaluation of cue-lure and methyl eugenol Solid Lure and Insecticide dispensers for fruit fly (Diptera: Tephritidae) monitoring and control in Tahiti. *Florida Entomologist* 94 (3): 510–516.

Manrakhan, A. 2016. Fruit fly. In: *Integrated Production Guidelines for Export Citrus. Integrated pest and Disease Management*, ed. T. G. Grout, pp. 1–10. Nelspruit, South Africa: Citrus Research International.

Papadopoulos, N. K., B. I. Katsoyannos, and D. Nestel. 2003. Spatial autocorrelation analysis of a *Ceratitis capitata* (Diptera: Tephritidae) adult population in a mixed deciduous fruit orchard in Northern Greece. *Environmental Entomology* 32: 319–326.

Permalloo, S., S. I. Seewooruthun, A. Soonnoo, B. Gungah, L. Unmole, and R. Boodram. 1997. An area wide control of fruit flies in Mauritius. In: *Proceedings of the Second Annual Meeting of Agricultural Scientists*, eds. J. A. Lalouette, D. Y. Bachraz, N. Sukurdeep, and B. D. Seebaluck, pp. 203–210. Reduit, Mauritius: Food and Research Council.

Rwomushana, I., S. Ekesi, C. K. P. O. Ogol, and I. Gordon. 2008. Effect of temperature on development and survival of immature stages of *Bactrocera invadens* (Diptera: Tephritidae). *Journal of Applied Entomology* 132: 832–839.

Sarada, G., T. U. Maheswari, and K. Purushotham. 2001. Seasonal incidence of population fluctuation of fruit flies of mango and guava. *Indian Journal of Entomology* 63: 272–276.

Stonehouse, J. M., J. D. Mumford, A. Verghese et al. 2008. Village-level area-wide fruit fly suppression in India: Bait application and male annihilation at village level and farm level. *Crop Protection* 26: 788–793.

Theron, C. D., A. Manrakhan, and C. W. Weldon. 2017. Host use of the oriental fruit fly, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae), in South Africa. *Journal of Applied Entomology* 141: 810–816.

Ullah, F., M. W. Khan, F. Maula, M. Younus, and H. Badshah. 2017. Impact of close proximity of traps baited with various attractants on fruit fly catch. *Journal of Entomology and Zoology Studies* 5(6): 1843–1845.

Umeh, V. C., I. O. O. Aiyelaagbe, A. A. Kintomo, and M. B. Giginyu. 2000. Insect pest situation and farmers cultural practices in citrus orchards in southern Guinea savanna agro-ecological zone of Nigeria. *Nigerian Journal of Horticultural Science* 7: 26–32.

Umeh, V .C., L. E. Garcia, and M. De Meyer. 2008. Fruit flies of citrus in Nigeria: Species diversity relative abundance and spread in major producing areas. *Fruits* 63: 145–153.

Umeh, V. C. and D. Oukwu. 2016. Integrated management of fruit flies: Case studies from Nigeria. In: *Fruit Fly Research and Development in Africa—Towards a Sustainable Management Strategy to Improve Horticulture*, eds. S. Ekesi, S.A. Mohammed, and M. De Meyer, pp. 553–574. Cham, Switzerland: Springer International Publishing.

Vargas, R. I., L. Leblanc, R. Putoa, and A. Eitam. 2007. Impact of introduction of *Bactrocera dorsalis* (Diptera: Tephritidae) and classical biological control releases of *Fopius arisanus* (Hymenoptera: Braconidae) on economically important fruit flies in French Polynesia. *Journal of Economic Entomology* 100: 670–679.

Vayssières, J. F., Y. Carel, M. Coubes, and P. F. Duyck. 2008. Development of immature stages and comparative demography of two cucurbit-attacking fruit flies in Reunion Island: *Bactrocera cucurbitae* and *Dacus ciliatus* (Diptera Tephritidae). *Environmental Entomology* 37: 307–314.

Vayssières, J. F, S. Korie, and D. Ayegnon. 2009. Correlation of fruit fly (Diptera: Tephritidae) infestation of major mango cultivars in Borgou (Benin) with abiotic and biotic factors and assessment of damage. *Crop Protection* 28: 477–488.

Vayssieres, J. F, A. Sinzogan, and A. Adandonon. 2008. The new invasive fruit fly species, *Bactrocera invadens* Drew Tsuruta and white. IITA-CIRAD leaflet No. 2

Vayssieres, J. F., F. Sango, and M. Noussourou. 2007. Inventory of the fruit fly species (Diptera: Tephritidae) linked to the mango tree in Mali and tests of integrated control. *Fruits* 63: 329–341.

Zaheeruddin, M. 2007. Study of diffusion and adoption of male annihilation technique. *International Journal of Education and Development using Information and Communication Technology* 3: 89–99.

Section VIII

Social, Economic, and Policy Issues of Action Programs

Taylor & Francis
Taylor & Francis Group
http://taylorandfrancis.com

27 Compendium of Fruit Fly Host Plant Information

The USDA Primary Reference in Establishing Fruit Fly Regulated Host Plants

Nicanor J. Liquido[*], *Grant T. McQuate, Karl A. Suiter, Allen L. Norrbom, Wee L. Yee, and Chiou Ling Chang*

CONTENTS

27.1 Introduction 364
27.2 Methods 364
27.3 Results and Discussion 365
27.3.1 Comprehensive Fruit Fly Species-Specific Host Plant Databases and Provisional Host Lists 365
27.3.2 Tephritidae Databases 366
27.3.3 Host Plants of the Dacinae of the Pacific Islands 367
27.4 Conclusion 367
Acknowledgments 367
References 368

Abstract The inherent ecological adaptiveness of fruit flies (Diptera: Tephritidae) ranks them among the worst invasive pest species, requiring vigilant detection, effective suppression, and regimented area-wide eradication. The US Department of Agriculture-Animal and Plant Health Inspection Service-Plant Protection and Quarantine (USDA-APHIS-PPQ) has a strategic goal to develop decision tools to prevent the entry and spread of quarantine-significant fruit flies posing threats to the health of US agriculture and natural resources. To achieve this strategic goal, USDA-APHIS-PPQ developed the *Compendium of Fruit Fly Host Information* (in short, CoFFHI: https://coffhi.cphst.org/), an interactive application integrating verified records of fruit fly infestations on their documented host plants, worldwide. Pertinent publications and manuscripts were acquired through the use of searchable online databases. Infestation data retrieved from the literature were classified as providing field infestation data, laboratory infestation data, interception data, or a mere listing of a fruit or vegetable as a host without providing any verifiable infestation data (i.e., listing only data). The taxonomy of recorded host plants was verified using the USDA-Agricultural Research Service (ARS) Germplasm Repository Information Network (GRIN, http://www.ars-grin.gov/) and other

[*] Corresponding author.

taxonomic resources. CoFFHI, Edition 4.0 has four integral components: (1) comprehensive fruit fly species-specific host plant databases of 24 select quarantine-significant fruit fly pests of horticultural commodities; (2) provisional host lists for the same 24 select fruit fly pests; (3) the *Tephritidae Databases*, which comprise name, host plant, and distribution data for all fruit fly species; and (4) infestation records of the Dacinae of the Pacific Islands. CoFFHI, Edition 4.0 is a vital USDA decision tool in achieving the core mission of APHIS-PPQ in preventing the introduction and establishment of exotic fruit flies into the United States and in facilitating safe domestic and international agricultural trade.

27.1 INTRODUCTION

Tephritid fruit flies exotic to the United States are regulated through the US Plant Protection Act of 2000 (7 U.S.C. 7701–7772) and relevant parts and subparts of the *Code of Federal Regulations (7 CFR – Agriculture)*. Fruit fly infestations in host commodities impose enormous constraints on the diversification of agricultural production, emplace formidable trade barriers, and limit the expansion of safe agricultural commerce globally. The perennial detection and eradication of multiple species of fruit flies in the United States, especially in southern parts of the country, prompted the US Department of Agriculture-Animal and Plant Health Inspection Service-Plant Protection and Quarantine's (USDA-APHIS-PPQ) demand for up-to-date and readily accessible fruit fly host plant information. APHIS-PPQ has a strategic goal to develop decision tools to prevent the entry and spread of exotic fruit flies. To achieve this goal, one of the initiatives supported by APHIS-PPQ is the USDA Compendium of Fruit Fly Host Information Project. The project has the mandate to provide APHIS-PPQ with up-to-date, interactive, validated, and readily accessible information on suitable host plants of fruit flies of economic importance, as well as taxonomic and geographic information on fruit fly pests. The primary product of the project is the application *Compendium of Fruit Fly Host Information*, referred to in short as CoFFHI, and available online at https://coffhi.cphst.org/. Currently in its fourth edition, CoFFHI is interactive and integrates comprehensive botanical, geographic, and worldwide infestation biology data on reported host plants of quarantine-significant fruit flies. This scientific note presents the cataloged and managed databases in CoFFHI, Edition 4.0, and the impacts these databases have in achieving the core goals of APHIS-PPQ to strengthen fruit fly pest exclusion systems, optimize domestic fruit fly suppression and eradication programs, and promote safe domestic and global trade of fresh fruits and vegetables.

27.2 METHODS

Pertinent publications and manuscripts were acquired through the use of searchable online databases, as well as from searches of the USDA-APHIS-PPQ's pest interception databases. Infestation data retrieved from the literature were classified as providing field infestation data, laboratory infestation data, interception data, or a mere listing of a fruit or vegetable as a host without providing any verifiable supporting data (i.e., listing only data). Provisional host lists were prepared as lists of plant species ("suitable host plants") for which there are recorded infestations under natural field conditions. Each validated suitable host plant satisfies the definition and attributes of a fruit fly natural, suitable host plant consistent with the terms used in the International Plant Protection Convention (IPPC) International Standards for Phytosanitary Measures (ISPM) No. 37: "Determination of host status of fruit to fruit flies" (FAO, 2016) and the North American Plant Protection Organization (NAPPO) Regional Standard for Phytosanitary Management (RSPM) No. 30: "Guidelines for the determination and designation of host status of a fruit or vegetable for fruit flies '(Diptera: Tephritidae)'" (NAPPO, 2008). Lists of undetermined hosts, or hosts of uncertain regulatory status, were also prepared. The undetermined host category is conferred to a recorded host plant that has no validated record of infestation under natural field conditions, and its host association is based on reported laboratory infestation, interception at a port of entry, or a mere listing as a host without any accompanying verifiable data. The taxonomy of both suitable and undetermined host plants was verified according to current botanical classification using the USDA-Agricultural Research Service (ARS) Germplasm Repository Information Network (GRIN, http://www.ars-grin.gov/) and other taxonomic resources.

27.3 RESULTS AND DISCUSSION

CoFFHI has four integral components: (1) comprehensive fruit fly species-specific host plant databases of select quarantine-significant fruit fly pests of horticultural commodities, with summaries of field and laboratory infestation data, interceptions at ports of entry, and "listing only" host records; (2) provisional suitable host plant lists of select quarantine-significant fruit flies; (3) the *Tephritidae Databases* with name, distribution, and host plant data for all of the nearly 5,000 known tephritid species; and (4) host plants of the Dacinae of the Pacific Islands.

27.3.1 Comprehensive Fruit Fly Species-Specific Host Plant Databases and Provisional Host Lists

CoFFHI has provisional host lists for 24 tephritid fruit fly species of economic importance, with comprehensive documentation of host plant records for many of these species (see Table 27.1). The following species are included (in brackets, respectively, are the total number of recorded host plants [= the sum of suitable and undetermined host plants] and the total number of infestation records): Inga fruit fly, *Anastrepha distincta* Greene [73, 299]; South American fruit fly complex, *Anastrepha fraterculus* (Wiedemann) complex [267, 2133]; Mexican fruit fly, *Anastrepha ludens* (Loew) [95, 751]; West Indian fruit fly, *Anastrepha obliqua* (Macquart) [150, 924]; sapote fruit fly, *Anastrepha serpentina* (Wiedemann) [111, 729]; guava fruit fly, *Anastrepha striata* Schiner [100, 640]; white striped fruit fly, *Bactrocera albistrigata* (Meijere) [23, 137]; carambola fruit fly, *Bactrocera carambolae* Drew & Hancock [140, 257]; guava fruit fly, *Bactrocera correcta* (Bezzi) [73, 168]; Oriental fruit fly, *Bactrocera dorsalis* (Hendel) [647, 4363]; mango fruit fly, *Bactrocera frauenfeldi* (Schiner) [120, 605]; *Bactrocera kirki* (Froggatt) [62, 313]; Solanum fruit fly, *Bactrocera latifrons* (Hendel) [82, 425]; Chinese citrus fruit fly, *Bactrocera minax* (Enderlein) [20, 206]; *Bactrocera pedestris* (Bezzi) [28, 42]; peach fruit fly, *Bactrocera zonata* (Saunders) [134, 1384]; Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann) [655, 8805]; greater pumpkin fruit fly, *Dacus bivittatus* (Bigot) [76, 311]; lesser pumpkin fly, *Dacus ciliatus* Loew [99, 758]; European cherry fruit fly, *Rhagoletis cerasi* (Linnaeus) [40, 485]; western cherry fruit fly, *Rhagoletis indifferens* Curran [15, 53]; apple maggot fly, *Rhagoletis pomonella* (Walsh) [73, 398]; melon fly, *Zeugodacus cucurbitae* (Coquillett) [273, 3953]; and *Zeugodacus tau* (Walker) complex [108, 297].

The CoFFHI team is in the process of adding comparable data for these additional fruit fly species of economic importance: papaya fruit fly, *Anastrepha curvicauda* (Gerstaecker); South American cucurbit fruit fly, *Anastrepha grandis* (Macquart); *Bactrocera occipitalis* (Bezzi); Japanese orange fly, *Bactrocera tsuneonis* (Miyaki); Queensland fruit fly, *Bactrocera tryoni* (Frogatt); Pacific fruit fly, *Bactrocera xanthodes* (Broun); mango fruit fly, *Ceratitis cosyra* (Walker); Natal fruit fly, *Ceratitis rosa* Karsch; eastern cherry fruit fly, *Rhagoletis cingulata* (Loew); walnut husk fly, *Rhagoletis completa* Cresson; blueberry maggot, *Rhagoletis mendax* Curran; *Zeugodacus caudatus* (Fabricius); three-striped fruit fly, *Zeugodacus diversus* (Coquillett); and striped fruit fly, *Zeugodacus scutellatus* (Hendel).

The fruit fly species-specific lists of provisional suitable host plants prepared by the CoFFHI team are reviewed by scientists and regulatory staff of APHIS-PPQ and State Plant Health Regulatory Officers (SPROs) of various states to establish the official USDA lists of fruit fly regulated host plants, which are published as federal orders. The vetting process follows a systematic procedure developed by the APHIS Fruit Fly Exclusion and Detection Working Group on host plants of quarantine-significant fruit flies.

TABLE 27.1
Tephritid Fruit Fly Species of Economic Importance Included in the USDA *Compendium of Fruit Fly Host Information*

	Suitable Hosts[a]			Undetermined Hosts[b]			
Fruit Fly Species	Taxa	Genera	Families	Taxa	Genera	Families	No. Records[c]
Anastrepha distincta	32	14	11	41	19	10	299
Anastrepha fraterculus	143	63	32	124	66	39	2133
Anastrepha ludens	45	24	17	50	32	18	751
Anastrepha obliqua	77	37	22	73	41	25	924
Anastrepha serpentina	52	27	16	59	38	20	729
Anastrepha striata	52	30	20	48	27	17	640
Bactrocera albistrigata	21	14	13	2	2	1	137
Bactrocera carambolae	100	58	38	40	29	16	257
Bactrocera correcta[d]	73	50	35	—	—	—	168
Bactrocera dorsalis	488	215	80	159	101	51	4363
Bactrocera frauenfeldi	94	51	33	26	20	15	605
Bactrocera kirki	42	28	26	20	15	9	313
Bactrocera latifrons	59	25	13	23	17	13	425
Bactrocera minax	15	2	1	5	3	1	206
Bactrocera pedestris	26	19	12	2	2	2	42
Bactrocera zonata	54	38	23	80	32	19	1384
Ceratitis capitata	408	179	68	247	148	62	8805
Dacus bivittatus	39	19	9	37	22	10	311
Dacus ciliatus	64	25	10	35	23	11	758
Rhagoletis cerasi[e]	15	5	4	25	8	5	485
Rhagoletis indifferens[d]	15	4	2	—	—	—	53
Rhagoletis pomonella	60	9	1	13	11	7	398
Zeugodacus cucurbitae	136	62	30	137	80	39	3953
Zeugodacus tau	77	44	23	31	21	16	297

Source: *Compendium of Fruit Fly Host Information* (CoFFHI) https://coffhi.cphst.org/.

Note: A provisional host list is included for each species, with comprehensive and annotated host infestation records for some of the species.

[a] Suitable hosts have validated records of field infestations under natural field conditions.

[b] The undetermined host category is conferred to a recorded host plant that has no validated record of infestation under natural field conditions, and its host association is based on reported laboratory infestation, interception at a port of entry, or a mere listing as a host without any accompanying verifiable data.

[c] No. records is the total number of infestation records documented in CoFFHI, Edition 4.0.

[d] Only host plants with field infestation records are recorded in CoFFHI, Edition 4.0.

[e] Includes infestation records in 87 cultivars of *Prunus avium* and 6 cultivars and varieties of *P. cerasus*.

27.3.2 Tephritidae Databases

The *Tephritidae Databases* compile taxonomic and host plant information for all recognized species in the family. Developed by Allen Norrbom and colleagues at the USDA-ARS Systematic Entomology Laboratory (SEL), earlier versions of the databases were searchable on the SEL website, which is no longer available. The *Tephritidae Databases* are now incorporated into CoFFHI, allowing integration of data and development of more efficient search capabilities. This makes records in the *Tephritidae Databases* available on a reliable server and more usable to scientists and regulators in conjunction with the other CoFFHI databases. The taxonomic database, originally developed as part of the *Biosystematic Database of World Diptera* (currently *Systema Dipterorum*, https://diptera.dk/) and published as a world catalog (see Thompson, 1999), now includes more than 10,000 valid and invalid scientific names for the nearly 5,000 currently recognized fruit fly species. The host plant database comprises over 36,000 records, and the distribution database more than 23,000 records. Although the host plant data are not comprehensive, the *Tephritidae Databases* document most of the known fruit fly/host plant relationships. Likewise, the distribution database is incomplete in regard to references documenting many records, but it provides the most comprehensive geographic distribution information available for all fruit fly species.

The *Tephritidae Databases* can be searched for information such as: (1) what fruit fly species have been reported to infest a particular host plant; (2) what are the reported hosts of a particular fruit fly species; (3) what are all of the names (valid or invalid) that have been used for a fruit fly species (i.e., to generate a list of associated synonyms and other invalid names, or to check the status of a name previously used in the literature); (4) what are all of the fruit fly species occurring in a particular country, or where does a particular fruit fly species occur; and (5) author and reference information pertaining to fruit fly taxonomy, distribution, and host plants. The name, host plant, and to a lesser extent, the distribution databases also provide citations to the references documenting each record. The *Tephritidae Databases* can be used to complement the fruit-fly-species-specific databases in CoFFHI by providing host plant data for the many fruit fly species for which comprehensive host plant databases have not been developed. It should be noted, however, that the components of the *Tephritidae Databases*, particularly the host and distribution databases, are working tools that are in a continuous state of development; thus, not all records have yet been fully verified and not all of the vast tephritid host and distribution literature has been incorporated.

27.3.3 Host Plants of the Dacinae of the Pacific Islands

Contributed by Luc Leblanc (University of Idaho), the Host Plants of the Dacinae of the Pacific Islands database provides records of infestation of 76 *Bactrocera* and *Zeugodacus* spp. and four *Dacus* spp. in 241 species of host plants; 31 of these fruit fly species are found only in Pacific Island countries and territories.

27.4 CONCLUSION

Using databases in CoFFHI, Edition 4.0, scientists and regulatory staff of APHIS-PPQ and SPROs of various states establish the official USDA lists of regulated host plants or regulated articles of select quarantine-significant fruit flies. As the USDA's primary reference on establishing fruit fly regulated articles, CoFFHI is designed to provide key information to regulatory scientists and regulatory officials to assess and mitigate the risk of fruit flies in fresh horticultural commodities and to serve as a decision tool in the design and implementation of effective fruit fly detection, monitoring, suppression, and eradication programs. CoFFHI is a vital USDA decision tool in achieving the core mission of APHIS-PPQ in preventing the introduction and establishment of exotic fruit flies that pose significant threats to US agriculture and natural resources.

ACKNOWLEDGMENTS

The development of CoFFHI would not be possible without the programming assistance of Sandra Sferrazza and technical support of Megan Hanlin, Amanda Birnbaum, Kelly Nakamichi, Kelly Ann Lee, Alexander Ching, Jessika Santamaria, and Melissa Seymour.

REFERENCES

FAO. 2016. International Standards for Phytosanitary Measures (ISPM) No. 37: Determination of host status of fruit to fruit flies. Rome, Italy, International Plant Protection Convention, Food and Agriculture Organization (FAO) of the United Nations. 18p.

NAPPO. 2008. *Regional Standard for Phytosanitary Measures (RSPM) No. 30: Guidelines for the Determination and Designation of Host Status of a Fruit or Vegetable for Fruit Flies (Diptera: Tephritidae)*. Ottawa, ON: North American Plant Protection Organization. 19p.

Thompson, F. C. (ed.). 1999. *Fruit Fly Expert Identification System and Systematic Information Database*. Myia 9: 524p. and Diptera Data Dissemination Disk (CD-ROM) 1: \names\fruitfly\ffessib.pdf.

28 Tephritid-Related Databases

TWD, IDIDAS, IDCT, DIR-SIT

Abdeljelil Bakri, Walther Enkerlin, Rui Pereira, Jorge Hendrichs, Emilia Bustos-Griffin, and Guy J. Hallman*

CONTENTS

28.1 Introduction 370
28.2 Methods 370
28.3 Results 370
28.3.1 Tephritid Workers Database (TWD) 370
28.3.2 The International Database on Insect Disinfestation and Sterilization (IDIDAS) 374
28.3.3 International Database on Commodity Tolerance (IDCT) 376
28.3.4 The World-Wide Directory of SIT Facilities (DIR-SIT) 379
28.4 Conclusion 383
References 383

Abstract The purpose of the databases developed by the Food and Agriculture Organization (FAO) and the International Atomic Energy Agency (IAEA) is to facilitate the collection and sharing of data among fruit fly workers and to provide access to information that details findings on doses required for phytosanitary irradiation (PI) and for the purpose of applying the sterile insect technique (SIT) as part of area-wide integrated pest management (AW-IPM) programs. These include: Tephritid Workers Database (TWD), the International Database on Insect Disinfestation and Sterilization (IDIDAS), and the World-Wide Directory of SIT Facilities (DIR-SIT). These databases have been continuously updated and populated with new data, including the TWD list of over 1500 members and more than 7000 literature references relevant to tephritid fruit flies. Furthermore, TWD hosts the web pages of the three regional tephritid worker groups and their respective Steering Committees: the Tephritid Workers of the Western Hemisphere (TWWH), the Tephritid Workers of Europe, Africa and the Middle East (TEAM) and the Tephritid Workers of Asia, Australia and Oceania (TAAO). IDIDAS includes 373 insect datasheets with radiation doses for sterilization and phytosanitary irradiation extracted from over 5400 references. DIR-SIT lists 38 mass-rearing facilities, including details about the insect species, the production capacity, and the irradiation sterilization parameters. The newly developed International Database on Commodity Tolerance (IDCT) helps to determine the tolerated PI dose for the disinfestation of fresh products. Up-to-now, data have been retrieved for IDCT from 243 references and have returned 156 different cultivars belonging to 89 fresh commodities (fruit, vegetables, and cut flowers). IDCT is an added value to IDIDAS and both share several common resources. With IDIDAS and IDCT data, food safety officers can select the optimum dose that balances between the insect/mite pest sterility or lethality and the commodity tolerance. In addition, technical resources, news,

* Corresponding author.

newsletters, event calendars, and photo galleries have been included in these databases. The monitoring and evaluation of the performance of these sites in terms of the audience and visits are tracked via Google Analytics.

With these four databases, TWD, IDIDAS, IDCT, and DIR-SIT, FAO and IAEA are offering a valuable repository of information and a comprehensive networking service to their member states. The objective of this chapter is to provide an overview of these resources to the community of tephritid fruit fly workers, including some information on their metrics.

28.1 INTRODUCTION

Four databases have been developed with the support of the Insect Pest Control Section (IPCS) of the Joint Food and Agriculture Organization/International Atomic Energy Agency (FAO/IAEA) Division of Nuclear Techniques in Food and Agriculture, which provide information related to tephritid fruit flies and area-wide integrated pest management (IPM), including the sterile insect technique (SIT) and phytosanitary irradiation (PI; disinfestation). These databases include: the Tephritid Workers Database (TWD), the International Database on Insect Disinfestation and Sterilization (IDIDAS), the World-Wide Directory of SIT Facilities (DIR-SIT), and the newly developed International Database on Commodity Tolerance (IDCT).

28.2 METHODS

To develop the databases, the first step was to design and set up an architecture suitable for the information we would like to convey. Information technology is a rapidly evolving science, thus, keeping up to date is a challenging endeavor. Since the development of the first database, the databases had to be migrated from a couple of systems not always compatible. Nonetheless, each time the architecture and data had to be adapted, and advantage was taken of the new functions available. These databases are continuously updated and populated with information and new resources. Extensive fine tuning has been carried out to ensure high-quality and user-friendly functions of the database platform based now on Microsoft SharePoint.

Analyzing scientific articles and technical documents and extracting the relevant data concerns mainly IDIDAS and IDCT. The taxonomy in general, either for insects or plants, is also an evolving science, and we had to take in consideration the changes in the names of species or their groups. The main IDIDAS data collected and assigned to the species datasheet were: the treated life stage, the irradiation conditions and doses, the quality control parameters either for PI or for insect sterilization, and the references. IDCT follows a similar procedure but for plant cultivars. The datasheet includes: the pre- and postharvest conditions, the irradiation doses with the tolerance aspects, and the references. For DIR-SIT, a standard form is sent to the focal points of all facilities worldwide to help collect data on the production of sterile insects and the irradiation process. TWD data are essentially publications on tephritid fruit flies and news on the same topic. Data were collected from various sources of academic databases and search engines such as the International Nuclear Information System (INIS), and from a number of specialized scientific journals in entomology, crop protection, PI, and related radiation biology.

28.3 RESULTS

28.3.1 Tephritid Workers Database (TWD)

This is a unique hub for tephritid fruit flies established 14 years ago (2004) by the Insect Pest Control Section of FAO/IAEA. The objective of the TWD is to provide a networking platform, news source, literature resource, a directory of fruit fly workers with information about their area of expertise, just to name a few (Figure 28.1). The most relevant news to tephritid workers

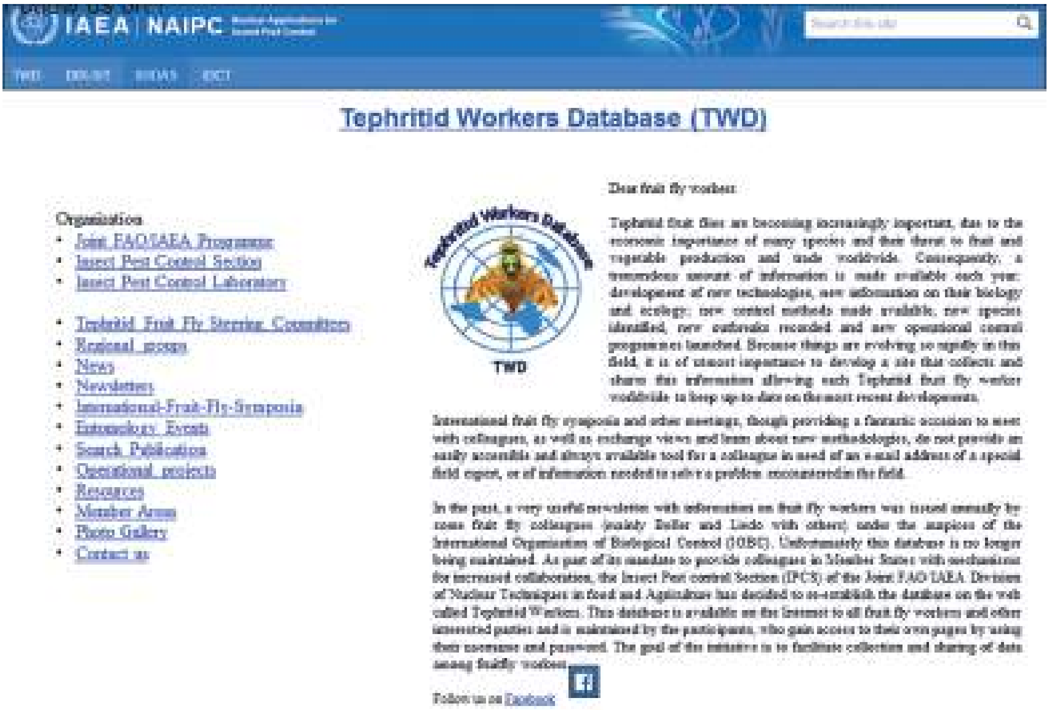

FIGURE 28.1 Home page of the Tephritid Workers Database (TWD).

are posted on TWD and its associated Facebook page (Figure 28.2) where users can freely add their comments and interact with other members. The Steering Committees (SC) page lists members of the International Fruit Fly Steering Committee (IFFSC) and those of the Tephritid Workers of the Western Hemisphere (TWWH), Tephritid Workers of Europe, Africa and the Middle East (TEAM), and Tephritid Workers of Asia, Australia and Oceania (TAAO). This page is regularly updated as new members (one third of the committee members) are elected every 4 years. In addition, the regional groups communicate with their members through newsletters and mailing lists by posting information about their activities such as meetings and ongoing fruit fly programs. The Fruit Fly News (FFN) newsletter (Figure 28.3), which is edited by a group of independent volunteer editors, is also distributed to the community and posted on the TWD and Facebook. Other information related to tephritids, such as events (e.g., meetings, symposium, workshops, and training courses), technical manuals/guidelines, and a photogallery, are regularly updated.

The TWD Facebook page (Figure 28.2) allows members to freely communicate, post comments, share findings, experience and expertise, exchange documents, inform about job opportunities, alerts, or other breaking news. Members can also get information about coming fruit fly events and express their wish and intention to participate. The result is shown on a dashboard indicating how many are planning to attend the event, which can be helpful for the meeting organizers.

Currently, 36 FFN have been issued since 1972, 16 TEAM newsletters since 2005, and six TAAO newsletters since 2015 (Figure 28.3).

As of July 2018, the TWD contains 1529 members from 120 countries. The top 10 countries in terms of the number of tephritid workers represented in the database in decreasing order are Mexico, United States, Thailand, Brazil, Spain, Australia, Argentina, South Africa, India, and China

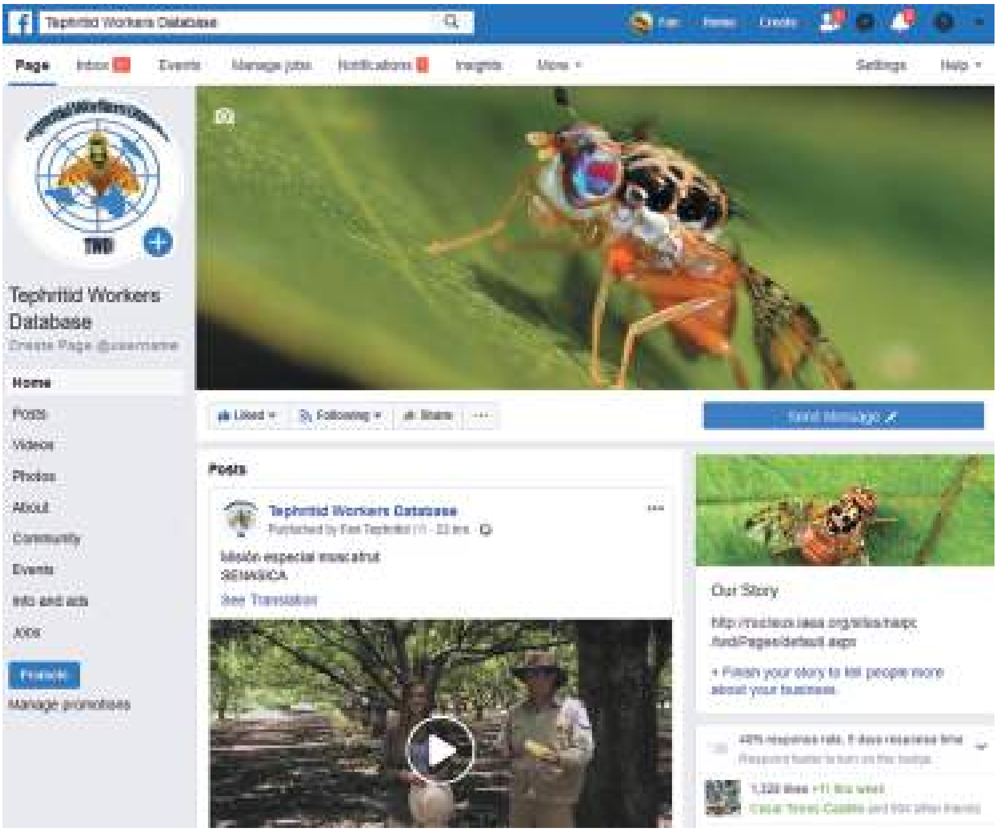

FIGURE 28.2 Facebook page of Tephritid Workers Database (fb-TWD).

FIGURE 28.3 Presentation of the latest eight issues of the Fruit Fly News (FFN) e-newsletters. There are 37 FFN issues since 1972.

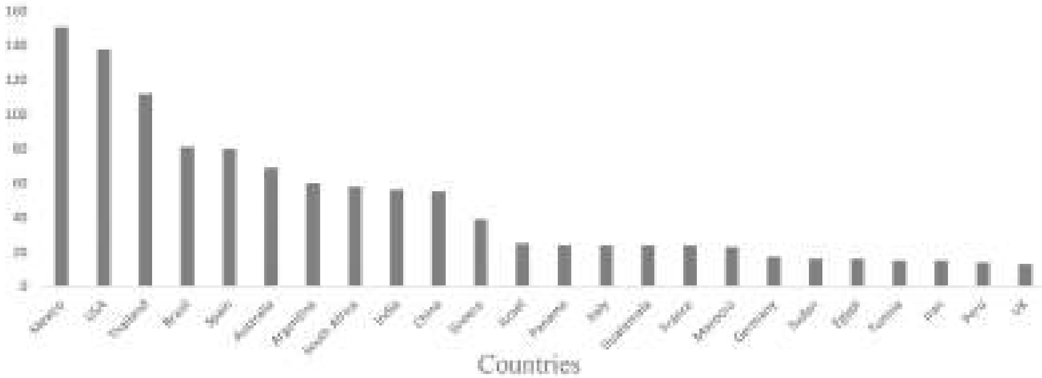

FIGURE 28.4 Top 25 countries based on the number of Tephritid Workers Database (TWD) members.

(Figure 28.4). Those countries most well represented are likely to have large tephritid fruit fly control programs and have hosted one of the past regional or international meetings.

Of the five continents, the Americas have the highest number of members (556), followed by Asia (368), Europe (261), Africa (234), and Oceania (89) (Figure 28.5).

These members are distributed in three regional groups: TWWH (Americas), TEAM (Europe, Africa, and the Middle East), and TAAO (Asia, Australia, and Oceania). Each regional group is likely to share similar challenges vis-a-vis the same fruit fly species present in their region (e.g., *Anastrepha* in the Americas and *Bactrocera* in Asia) and may have the same pest-management priorities. This makes the regional meetings more specific and relevant for the members of the regional group. Nonetheless, all these regional meetings remain open to all members from the other regional groups who might share their experience and learn from colleagues from the other geographical areas.

Three SCs were established to coordinate the activities within their respective regional groups. The IFFSC, however, coordinates the activities related to the International Symposium of Fruit Flies of Economic Importance (ISFFEI), such as receiving proposals and selecting the best proposals and venues to host the ISFFEI symposia that takes place every 4 years, providing support to the local organizing committee, editing and publishing proceedings, and other related tasks.

FIGURE 28.5 Distribution of Tephritid Workers Database (TWD) members by continents (2018).

TABLE 28.1
Meeting and Symposia on Tephritid Fruit Flies

ISFFEI	TWWH	TEAM	TAAO
1st ISFFEI (Greece 1982)	1st TWWH October 1992 (San José, Costa Rica)	1st TEAM April 2008 (Palma de Mallorca, Spain)	1st TAAO 15–18 August 2016 (Kuala Lumpur, Malaysia)
2nd ISFFEI (Greece 1986)	2nd TWWH August 1996 (Viña del Mar, Chile)	2nd TEAM July 2012 (Kolymbari, Crete, Greece)	2nd TAAO 18–21 August 2020 (Beijing, China)
3rd ISFFEI (Guatemala 1990)	3rd TWWH July 1999 (Guatemala City, Guatemala)	3rd TEAM April 2016 (Stellenbosch, South Africa)	
4th ISFFEI (United States 1994)	4th TWWH May 2001 (Mendoza, Argentina)	4th TEAM 2020 (La Grande Motte, France)	
5th ISFFEI (Malaysia 1998)	5th TWWH May 2004 (Fort Lauderdale, USA)		
6th ISFFEI (South Africa 2002)	6th TWWH September 2006 (Salvador, Brazil)		
7th ISFFEI (Brazil 2006)	7th TWWH November 2008 (Mazatlán, México)		
8th ISFFEI (Spain 2010)	8th TWWH July–August 2012 (Panama City, Panama)		
9th ISFFEI (Thailand 2014)	9th TWWH 16–22 October 2016 (Buenos Aires, Argentina)		
10th ISFFEI (Mexico 2018)	10th TWWH 16–20 March 2020 (Bogota, Colombia)		
11th ISFFEI (Australia 2022)			

Free proceedings are posted in TWD. (See Figure 28.5 for more details)

Up to now, 24 meetings specific to fruit fly tephritids have been organized, namely 10 ISFFEI symposia, 10 TWWH meetings, 3 TEAM meetings, and 1 TAAO meeting (Table 28.1). These meetings often include satellite meetings on a specific fruit fly topic, for example, Coordinated Research Meetings (CRP) or Consultants Group Meetings.

The global ISFFEI is the largest gathering of the tephritid fruit fly workers, and recent symposia can reach up to 400 attendees from all over the world (Figure 28.6).

Membership is open and freely available to all people working on tephritid fruit flies. For registration, one simply follows the steps indicated on the TWD website.

All the registration information required is about the fruit fly species being worked on, the subject of research, and how to reach the registrant in case colleagues need that persons' expertise and advice or wish to establish a collaborative project.

There are more than 7,100 relevant publications hosted on the TWD. Based on publication's search in TWD from the 1960s to 2018, the most widely represented genus are *Bactrocera* with 1034 publications, followed by *Ceratitis* with 934. The most well-represented single pest species is *Ceratitis capitata* (Wied.), with 844 publications, followed by *Bactrocera dorsalis* (Hendel), with 366.

28.3.2 The International Database on Insect Disinfestation and Sterilization (IDIDAS)

IDIDAS (Figure 28.7) compiles and analyzes information about insect and mites species that are subject to ionizing radiation mainly for reproduction sterilization (e.g., sterile insect technique [SIT]), phytosanitary disinfestation, sperm precedence studies, and host-parasitoid interaction studies. The information on irradiation doses (Gy) required for the various development stages

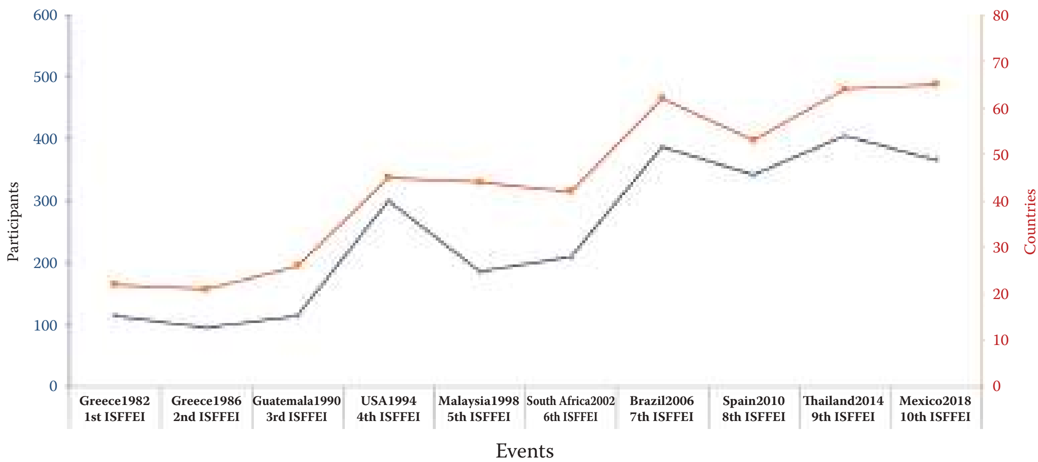

FIGURE 28.6 Trends in the International Symposium on Fruit Flies of Economic Importance (ISFFEI) attendance, 1982–2018.

(eggs, larvae, nymphs, pupae, and adults) were retrieved from more than 5,400 references. Data in IDIDAS also indicate the biotic and abiotic conditions of the irradiation treatment.

Three-hundred and seventy-three insect and mite pest species are recorded in IDIDAS, covering 13 orders, 82 families, and 211 genera. Tephritid fruit flies are the most widely represented in IDIDAS with 41 species from 7 genera included, namely *Anastrepha* (7 species), *Bactrocera* (17 species), *Ceratitis* (5 species), *Dacus* (1 species), *Myiopardalis* (1 species), *Rhagoletis* (7 species), *Toxotrypana* (1 species), and *Zeugodacus* (formerly Bactrocera) (2 species) (Table 28.2). In the

FIGURE 28.7 The International Database on Insect Disinfestation and Sterilization (IDIDAS) home page.

TABLE 28.2
Tephritidae Species Represented in the International Database on Insect Disinfestation and Sterilization (IDIDAS)

Anastrepha fraterculus	*Ceratitis capitata*
Anastrepha grandis	*Ceratitis cosyra*
Anastrepha ludens	*Ceratitis fasciventris*
Anastrepha obliqua	*Ceratitis quilicii*
Anastrepha serpentina	*Ceratitis rosa*
Anastrepha striata	*Dacus ciliatus*
Anastrepha suspensa	*Myiopardalis pardalina*
Bactrocera aquilonis	*Rhagoletis cerasi*
Bactrocera carambolae	*Rhagoletis cingulate*
Bactrocera correcta	*Rhagoletis completa*
Bactrocera dorsalis	*Rhagoletis fausta*
Bactrocera jarvisi	*Rhagoletis indifferens*
Bactrocera latifrons	*Rhagoletis mendax*
Bactrocera minax	*Rhagoletis pomonella*
Bactrocera occipitalis	*Toxotrypana curvicauda*
Bactrocera oleae	*Zeugodacus cucumis*
Bactrocera papayae (Syn *B. dorsalis*)	*Zeugodacus cucurbitae*
Bactrocera passiflorae	*Zeugodacus tau*
Bactrocera philippinensis (Syn *B. dorsalis*)	
Bactrocera tau	
Bactrocera tryoni	
Bactrocera tsuneonis	
Bactrocera zonata	

case of Tephritidae, sterilizing irradiation doses range, on average, from 83 Gy (low) to 85 Gy (mean) and to 108 Gy (high). These doses correspond to mean and 95% confidence limits (upper L2, lower L1) (Sokal and Rohlf 1995). For uniformity, the same irradiation conditions were considered to calculate the dose range. The data are for in-air irradiation of males treated mostly in late puparial stages. The ranges of the irradiation doses for each tephritid genus and species are reported in Bakri and Hendrichs (2004) and Bakri et al. (2005a, 2005b).

28.3.3 International Database on Commodity Tolerance (IDCT)

The IDCT assembles the responses of different cultivars to doses used PI. To date, the IDCT (Figure 28.8) includes the responses of 158 different cultivars belonging to 89 fresh commodities including 43 fruit (48%), 18 vegetables (20%), and 28 cut-flowers (32%) to radiation doses. The information was retrieved from 243 references.

The 158 cultivars belong to 22 families (Figure 28.9) and 28 genera (Figure 28.10). The top four commodities belong to Rosaceae (58 cultivars), Rutaceae (28 cultivars), Anacardiaceae (17 cultivars), and Sapindaceae (13 cultivars). The five top genera (Figure 28.10) are *Prunus* (37 cultivars), *Citrus* (28 cultivars), *Malus* (17 cultivars), *Mangifera* (17 cultivars), and *Litchi* (9 cultivars).

It is important to note that the doses (Gy) reported in the database correspond to the minimum and maximum dose range yielding acceptable marketability of the commodity, given the information presented in the reference cited. These doses are based on the data presented in the references and indicate the doses tolerated by the commodities in question. Pretreatment, treatment, and posttreatment conditions are described to help understand if the handling of the commodity is in line with current commercial marketing situations and if responses might be

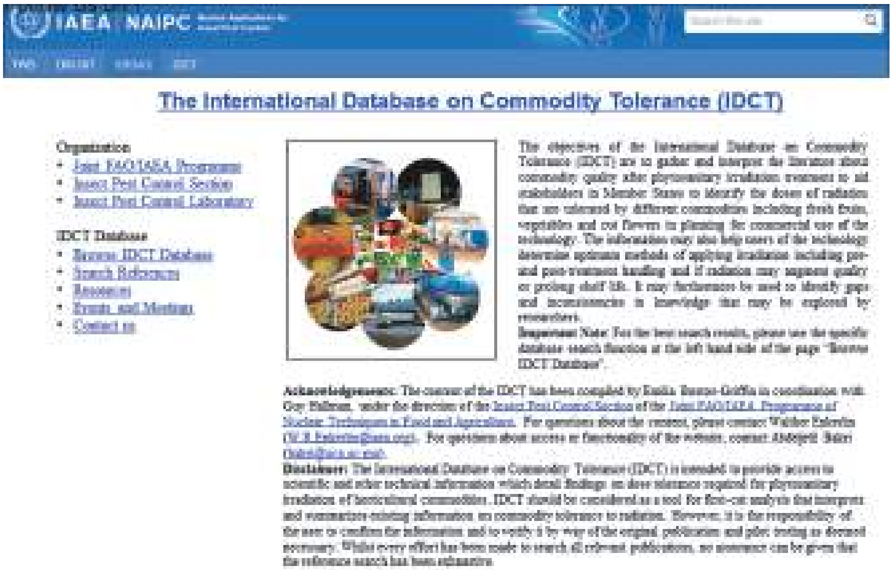

FIGURE 28.8 The International Database on Commodity Tolerance (IDCT) home page.

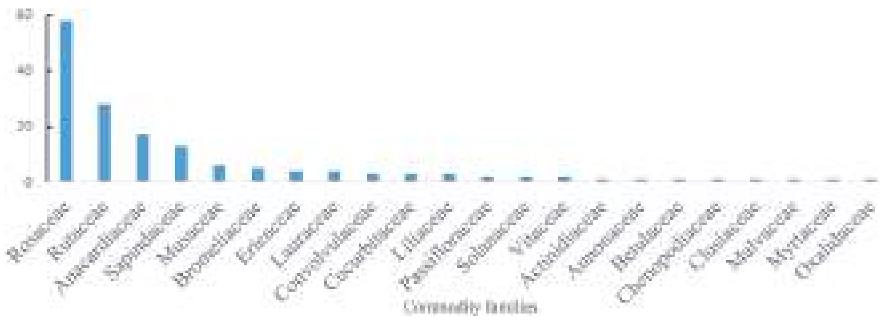

FIGURE 28.9 The number of cultivars, grouped per families, of fresh fruit, vegetables, and cut-flowers subject to phytosanitary irradiation. (From IDCT, https://nucleus.iaea.org/sites/naipc/IDCT/Pages/Browse-IDCT.aspx, 2018.)

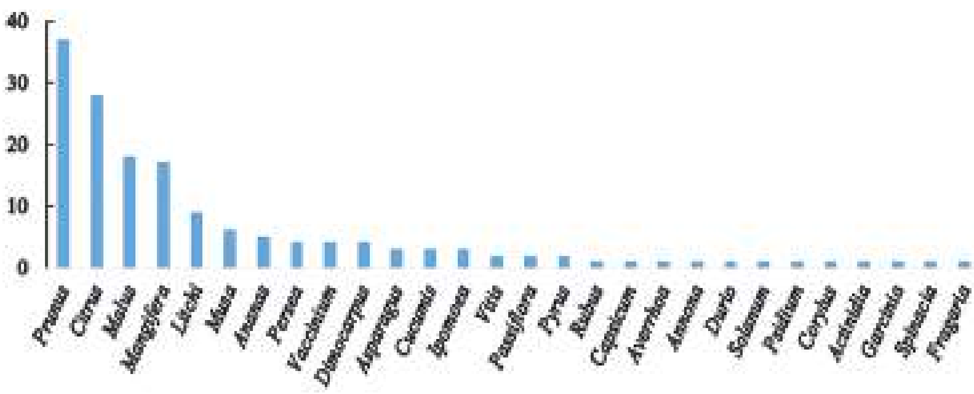

FIGURE 28.10 The number of cultivars, grouped per genera, of fresh fruit, vegetables, and cut-flowers subject to phytosanitary irradiation. (From IDCT, https://nucleus.iaea.org/sites/naipc/IDCT/Pages/Browse-IDCT.aspx, 2018.)

TABLE 28.3
Example of the Dose Range Variation for Phytosanitary Irradiation (PI) of Different Apple Cultivars

Family	Latin Name	Common Name	Cultivar	Dose (Gy)
Rosaceae	*Malus domestica*	Apple	Apple "?"[a]	1,000–1,500
			Apple "Ambri"	at least 500
			Apple "Boskoop"	Not estimated
			Apple "Cortland"	at least 288
			Apple "Fuji"	between 825 and 990
			Apple "Gala"	at least 440 and <880
			Apple "Golden Delicious"	Between 500 and 1,000
			Apple "Granny Smith"	at least 430 to <650
			Apple "Jonathan"	about 500
			Apple "Lobo"	Not estimated
			Apple "McIntosh"	at least 500 to <1000
			Apple "Red Delicious"	at least 600 to 1000
			Apple "Rhode Island Greening"	<384
			Apple "Rich-A-Red"	at least 600
			Apple "Rome Beauty"	at least 100 to <500
			Apple "Royal Delicious"	least 500
			Apple "Yellow Newton Pippin"	<750

[a] The question mark (?) indicates that the cultivar is unknown or not indicated by the author.

modified by handling or evaluation techniques. Users may check the original references for more details.

Considering PI at the cultivar level is very important as the example in Table 28.3 shows. For the same species, here apple, *Malus domestica* (Rosales: Rosaceae), the reported doses tolerated may vary considerably. Even for the same cultivar, the tolerated dose may vary widely according to the experimental conditions and the interpretations by the different researchers.

Beside the references to literature relevant to PI, the IDCT includes links to resources such as technical documents and e-learning courses about PI technology, as well as related meeting and event information.

28.3.4 The World-Wide Directory of Sit Facilities (DIR-SIT)

Up to now, DIR-SIT (Figure 28.11) includes data of 38 insect mass-rearing facilities from 25 countries. Out of these, 19 facilities from 15 countries produce the largest numbers of sterile tephritid fruit flies (at least 5 million/week) (Table 28.4). It is worth mentioning that the production capacity indicated in the table is the production when the program is running at its full capacity. For some facilities, the current production might be lower or nil depending on the current country program activity in managing fruit flies with SIT.

FIGURE 28.11 The World-Wide Directory of Sit Facilities (DIR-SIT) home page.

TABLE 28.4
Worldwide Mass-Rearing Facilities of Tephritid Fruit Flies (Diptera: Tephritidae), Their Production Capacity, Species and Strains, and the Radiosterilization Dose

Country	Facility Location and Name	Insect Reared	Strain	Production Capacity (million/week)	Dose (Gy)
Argentina	Mendoza, Bioplanta	*Ceratitis capitata*	TSL VIENNA 8	200	110
	San Juan, Bioplanta	*Ceratitis capitata*	TSL 2006	50	—
Australia	Camden (NSW), Queensland Fruit Fly Production Facility	*Bactrocera tryoni*	—	15	70
	Adelaide, National SITplus Facility	*Bactrocera tryoni*	—	50	70
	Perth, Sterile Medfly Production Facility	*Ceratitis capitata*	—	10	—
Austria	Seibersdorf, FAO/IAEA Insect Pest Control Laboratory	*Ceratitis capitata* *Bactrocera oleae* *Bactrocera dorsalis* *Anastrepha grandis* *Anastrepha ludens* *Anastrepha fraterculus* *Anastrepha obliqua* *Bactrocera aquilonis* *Bactrocera carambolae* *Bactrocera correcta* *Zeugodacus cucurbitae* *Bactrocera tryoni* *Bactrocera zonata* *Ceratitis quilicii* *Ceratitis rosa* *Zeugodacus tau*	A number of strains for each species were kept in small scale at Seibersdorf laboratory for research and development and to supply requests from member states	—	—
Brazil	Juazeiro, Bahia, Biofábrica Moscamed Brazil	*Ceratitis capitata*	TSL VIENNA 8/2004	100	100
Chile	Arica, Centro Produccion Insectos Esteriles	*Ceratitis capitata*	TSL VIENNA 8 Mix/2006	50	140

(Continued)

TABLE 28.4 (*Continued*)
Worldwide Mass-Rearing Facilities of Tephritid Fruit Flies (Diptera: Tephritidae), Their Production Capacity, Species and Strains, and the Radiosterilization Dose

Country	Facility Location and Name	Insect Reared	Strain	Production Capacity (million/week)	Dose (Gy)
Costa Rica	San José, Programa Nacional Moscas de la Fruta, Servicio Fitosanitario del Estado-MAG	*Ceratitis capitata*	Bisexual	5	150
Greece	Heraklion, University of Crete-Fruit Flies	*Bactrocera oleae*	Democritos/1966	5	95
		Ceratitis capitata	T(Y;5)1–61/1995	5	95
Guatemala	El Pino, Moscamed Guatemala	*Ceratitis capitata*	TSL strain/ Vienna7/Toliman 99/2.5 years	2000	100 Gy (local Program); 145 Gy (Exports)
		Anastrepha ludens	—	—	80
Israel	Sde-Eliyahu, Bio-Fly	*Ceratitis capitata*	TSL VIENNA 8	90	100
		Bactrocera oleae	Argov (2008) Yael (2010)	0.25	100
Japan	Naha, Okinawa Prefectural Plant Protection Center	*Zeugodacus cucurbitae*	Taiwan 6/2011	200	72
		Bactrocera latifrons	Yonaguni	1	70
Mexico	Metapa, Chiapas, Dr. Dieter Enkerlin Schallenmüller	*Anastrepha ludens*	Original strain with many refreshments (bisexual strain)	290	80
		Anastrepha ludens	Tapachula 7 (GSS color pupa)	10	80
		Anastrepha obliqua	Original strain with many refreshments (bisexual strain)	65	80
	Metapa, Chiapas, Moscamed, Jorge Gutiérrez Samperio	*Ceratitis capitata*	TSL VIENNA 7-Tol/October 2002	500	125
Peru	La Molina, Centro de Producción y Esterilización Mosca de la Fruta	*Ceratitis capitata*	GSS Vienna 8 TSL	300	120
Philippines	Quezon City, Philippine Fruit Fly Mass-Rearing Facility	*Bactrocera dorsalis* (Syn. *B. philippinensis*)	No strain	15	64–104
South Africa	Stellenbosch, Western Cape, FruitFly Africa (Pty) Ltd	*Ceratitis capitata*	V7-D53/Mix 2001 (December 2001) replaced with VIENNA 8	2	150

(*Continued*)

TABLE 28.4 (*Continued*)
Worldwide Mass-Rearing Facilities of Tephritid Fruit Flies (Diptera: Tephritidae), Their Production Capacity, Species and Strains, and the Radiosterilization Dose

Country	Facility Location and Name	Insect Reared	Strain	Production Capacity (million/week)	Dose (Gy)
Spain	Valencia, Bioplanta de Insectos Estériles	*Ceratitis capitata*	Vienna 8/refreshed 2015	500	95
Thailand	Pathumthani, Irradiation Center for Agricultural Development	*Bactrocera dorsalis*	Pakchong/July 30, 2000	30	90
		Bactrocera correcta	Thailand	40	80
Tunisia	Sidi Thabet, CNSTN, Medfly Facility	*Ceratitis capitata*	TSL VIENNA 8	5	100
USA	Hilo, Hawaii, USDA Pacific Basin Lab Research	*Bactrocera dorsalis*	1993	5	—
		Ceratitis capitata	1993	5	120
	Waimanalo, Hawaii, CDFA/USDA	*Ceratitis capitata*	—	—	150
	Texas, Mexican Fruit Fly Rearing Facility	*Anastrepha ludens*	Willacy County, 2010	200	70
	Gainesville, Florida Department of Agriculture	*Anastrepha suspensa*	—	50	70

Source: DIR-SIT, https://nucleus.iaea.org/sites/naipc/DIR-SIT/SitePages/All%20Facilities.aspx 2018.

CDFA, California Department of Food and Agriculture; CNSTN, Centre National des Sciences et Techniques Nucléaires; FAO/IAEA, Food and Agriculture Organization/International Atomic Energy Agency; USDA, US Department of Agriculture.

28.4 CONCLUSION

With these four open access databases, namely TWD, IDIDAS, IDCT, and DIR-SIT, FAO and IAEA are offering their member states a valuable repository of information and comprehensive networking services pertaining to tephritid fruit fly communities, as well as SIT and PI. With IDIDAS and IDCT data, food safety officers can select the optimum dose that balances between insect/mite pests' sterility or lethality and the commodity tolerance.

REFERENCES

Bakri, A., and J. Hendrichs. 2004. Radiation doses for sterilization of tephritid fruit flies. In *Proceedings, Symposium: 6th International Symposium on Fruit Flies of Economic Importance*, 6–10 May 2002, Stellenbosch, South Africa, eds. B. N. Barnes, pp. 475–479. Irene, South Africa: Isteg Scientific Publications.

Bakri, A., N. Heather, J. Hendrichs, and I. Ferris. 2005a. Fifty years of radiation biology in entomology: Lessons learned from IDIDAS. *Annals of the Entomological Society of America* 98: 1–12. doi:10.1603/0013–8746 (2005)098[0001:FYORBI]2.0.CO;2.

Bakri, A., K. Mehta, and D. R. Lance. 2005b. Sterilizing insects with ionizing radiation. In *Sterile Insect Technique. Principles and Practice in Area-Wide Integrated Pest Management*, eds. V. A. Dyck, J. Hendrichs, and A. S. Robinson, pp. 233–268. Dordrecht, the Netherlands: Springer.

Directory of the Sterile Insect Technique Facilities (DIR-SIT). 2018. Directory of the Sterile Insect Technique Facilities. https://nucleus.iaea.org/sites/naipc/DIRSIT/SitePages/All%20Facilities.aspx.

International Database on Commodity Tolerance (IDCT). 2018. International Database on Commodity Tolerance. https://nucleus.iaea.org/sites/naipc/IDCT/Pages/Browse-IDCT.aspx.

International Database on Insect Disinfestation and Sterilization (IDIDAS). 2018. International Database on Insect Disinfestation and Sterilization. https://nucleus.iaea.org/sites/naipc/ididas/Pages/Browse-IDIDAS.aspx.

Sokal, R. R., and F. J. Rohlf. 1995. *Biometry: The Principles and Practice of Statistics in Biological Research*, 3rd ed. New York: W. H. Freeman and Company.

Tephritid Workers Database (TWD). 2018. Tephritid Workers Database. https://nucleus.iaea.org/sites/naipc/twd/Pages/default.aspx.

29 Stewed Peaches, Fruit Flies, and STEM Professionals in Schools

Inspiring the Next Generation of Fruit Fly Entomologists

*Carol Quashie-Williams**

CONTENTS

29.1 Introduction 385
29.2 Methods 387
29.3 Results 388
29.4 Discussion and Conclusion 388
Acknowledgments 389
References 389

Abstract This chapter describes the science, technology, engineering and mathematics (STEM) Professionals in Schools volunteer program, and explains how STEM volunteers can use their experience and expertise to share agricultural and entomology skills with primary schools in Canberra, Australia, to inspire and engage students to consider careers in science in general and, entomology, in particular. STEM Professionals in Schools volunteers provide a valuable resource for teachers (e.g., using the fruit fly life cycle to demonstrate parts of the Australian Biological Sciences curriculum) and increase community engagement by involving entomologists with the wider community. The students and teachers learned about the Tephritidae fruit fly life cycle, which provided an alternative to the Lepidopteran life cycle, which is usually studied as part of the Australian biological sciences curriculum. The differences between true fruit flies and Drosophilidae flies were also observed and discussed. The school community also learned methods to reduce the incidence of fruit fly infestation in their gardens using environmentally friendly techniques.

29.1 INTRODUCTION

During the last few years, there has been a decline in the rate of students enrolling at universities in undergraduate science, technology, engineering, and mathematics (STEM) subjects in a number of countries, including the United States (Fairweather, 2008) and Australia (Figure 29.1) (PwC, 2014). Australia has one of the lowest rates of undergraduates enrolling in STEM subjects according to the Organization for Economic Cooperation and Development (OECD) (Singhal, 2017). This is of

* Corresponding author.

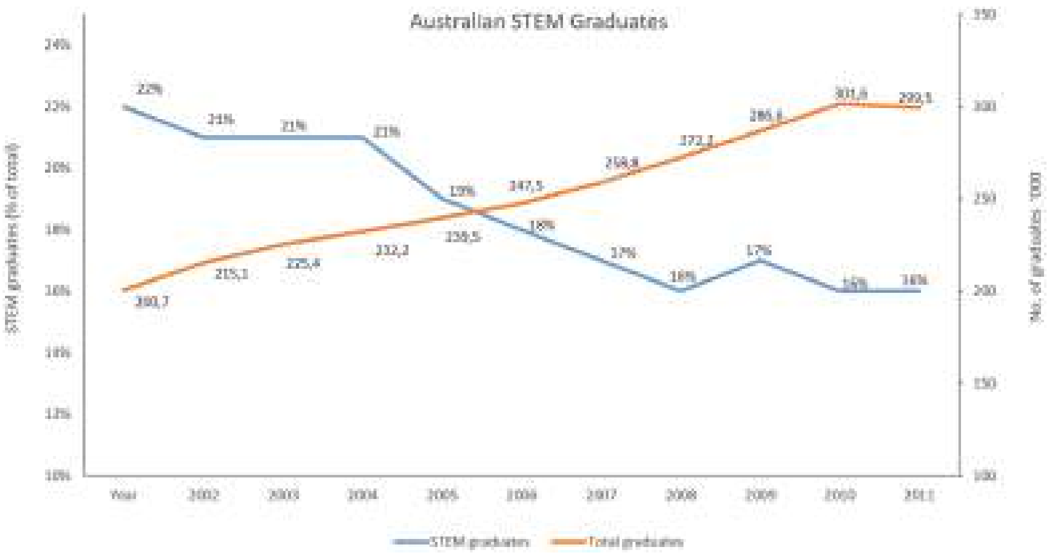

FIGURE 29.1 Australian STEM graduates as a percentage of total school graduates. (PwC, Fuelling NextGen digital innovation through education, http://www.digitalinnovation.pwc.com.au/education/, 2014)

concern when considering that 75% of the fastest-growing occupations require STEM skills and knowledge, and a lack of skilled personnel is cited as the number one barrier to industry innovation (PwC, 2014).

Under the National Science and Innovation Agenda (Department of the Prime Minister and Cabinet, 2015), the Australian government has invested almost A$100 million to inspire STEM literacy at all education levels and to help young Australians prepare for jobs in the future. The National STEM School Education Strategy 2016–2026 (Education Council, 2016) is endorsed by all Australian state and territory governments to invest in improving national STEM education through supporting the development of teachers STEM skills and increasing student engagement in STEM subjects. Australia's Chief Scientist's report *Science, Technology, Engineering and Mathematics: Australia's Future*, also focuses on STEM education in Australian schools to ensure young Australians are equipped with the necessary STEM skills for the future (Office of the Chief Scientist, 2014).

Science, Technology, Engineering and Maths Professionals in Schools (CSIRO, 2015) is Australia's leading STEM education volunteering program and is a major innovation in the national STEM education scene (CSIRO, 2015). *STEM Professionals in Schools* is an initiative of the Australian Government Department of Education and Training. It was established in 2007 as *Scientists in Schools* when the Department of Education and Training provided funding to the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Education and Outreach to deliver the program through a national program team (Howitt and Rennie, 2008, Tytler et al., 2016). The program's establishment was supported by Australia's then Chief Scientist, Jim Peacock (Howitt and Rennie 2008), to address concerns with the decline in student enrolment in STEM subjects at tertiary level and the lack of support for teachers to teach contemporary scientific practices.

The general objective of the *STEM Professionals in Schools* program is to coordinate partnerships between primary and secondary school teachers and STEM professionals to facilitate real industry experience and encourage STEM learning skills in the classroom. Since 2007, the program has facilitated almost 6,000 partnerships across Australia. The aim is to enable teachers to build their knowledge and confidence in STEM subjects and inspire students to pursue STEM subjects and STEM-related careers.

Each partnership is unique, as the teacher and STEM professional determine what works best for them based on availability and location, with remote partnerships also encouraged. Activities can range from presentations (e.g., basic insect biology), classroom exercises, investigations and experiments (e.g., the science of popping corn, fruit preservation, fruit fly rearing, etc.), site visits and project mentoring (e.g., school projects for Science Week) to helping in their vegetable gardens (e.g., pest and disease diagnostics, crop rotations, basic horticulture), as well as after-school activities and participation in citizen-science projects.

The Australian Sciences curriculum includes *Living things grow, change and have offspring similar to themselves* as part of the primary school Year 2 curriculum (ACARA, 2018), and the life cycle of a butterfly is often studied in Year 2. Arthropods offer many opportunities as teaching tools when applied as part of inquiry teaching in primary and secondary education (Matthews et al., 1997), improving students' attitudes toward STEM subjects, enhancing their performance, and promoting scientific and environmental literacy (Golick and Heng-Moss, 2013). Tackling real-world problems is used to engage children and get them excited about what they are learning in STEM classes.

The *STEM Professionals in Schools* program aligns with the *Science Strategy 2013–2018* (DAFF, 2013) of the Australian Department of Agriculture (DA), which is committed to actively engaging DA scientists with schools and the community to increase STEM awareness. The department currently has more than 20 staff members volunteering in the *STEM Professionals in Schools* program throughout Australia.

This chapter describes how the STEM Professionals in Schools volunteer program uses the experience and expertise of STEM volunteers to share agricultural and entomology skills at a primary school in Canberra, Australia, to inspire and engage students to consider careers in science in general, and entomology in particular.

29.2 METHODS

Farrer Primary School in Canberra, Australia, has partnered with a DA *STEM Professionals in Schools* volunteer with more than 20 years' experience as an agricultural entomologist working in crop protection including Tephritidae fruit fly issues (e.g., biology, biosecurity, market access, and risk-mitigation management). The school has an environment center in which the students learn about sustainable agriculture. As well as animals, the environment center has raised garden beds for growing seasonal vegetables and a range of fruit trees. Working on solutions to real-world problems is the heart of any STEM investigation (Jolly, 2017), and while harvesting peaches, the presence of maggot-infested fruit allowed the students to study the fruit fly life cycle during *STEM Professionals in Schools* volunteer sessions.

Students collected infested peach fruit from the trees and the ground. The maggot stages were observed by cutting open the fruit. Potting mix was placed in the base of large glass jars or plastic ice cream containers, and the infested fruit was placed on top of the potting mix. The jars or containers were covered with mesh and secured with elastic bands to prevent emerging insects from escaping.

After a week, the fruit was checked for maggots and the potting mix was checked for the presence of pupae. All fruit without maggots were removed from the containers. After 2 weeks, adult flies began to emerge. They were fed by placing the following on the surface of the mesh: water-soaked pieces of sponge, checked daily to prevent the sponges from drying out, sugar for energy, and thin layers of VEGEMITE as a protein source for the fruit flies. VEGEMITE is a dark brown savory food spread, which is popular with Australian children. It is also one of the richest known natural sources in the vitamin B group. It is made from brewer's yeast similar to the product in protein bait sprays.

As the adult flies emerged, their colors and patterns were observed. Once they developed and matured, they started mating and laying eggs. Eggs were observed and collected from the mesh. Digital images were taken of all insect stages. The children, with the assistance of the *STEM*

Professionals in School volunteer, identified the fruit fly species as the Queensland fruit fly, *Bactrocera tryoni* (Froggatt). While learning about the life cycle of Tephritidae fruit flies, the students also learned to identify the differences between Tephritidae fruit flies and Drosophilidae flies because the latter also emerged from the infested peaches.

29.3 RESULTS

Approximately 20 Year-2 (7-year-old) students took part in this activity, which was carried out during the Australian summer in Term 1 of the school year (i.e., February). It was the end of a long drought period in Australia, and most of the children had not observed maggots in fruit before. Following the activity with that class, the environment teacher taught the whole school about the difference between true fruit flies (Tephritidae) and vinegar "fruit flies" (Drosophilidae).

Evidence that the students had retained knowledge of the differences between these flies occurred the following year when the school had a new environment teacher. When she called the small *Drosophila* flies buzzing around the compost heap "fruit flies," a number of children corrected her and told her they were "vinegar flies" and not fruit flies.

Although the Year-2 students had not seen maggoty fruit before, a number of their grandparents who lived near the school came into the environment center and reported that they had not had maggots in their backyard fruit (e.g., feijoa, apricots, peaches) since they had moved into the suburb in the early 1970s. They asked how they could prevent or reduce the incidence of maggoty fruit and were advised to pick up any rotting fruit and place it in plastic bags and expose the secured bags to the sun for 48 h and then dispose of the fruit through deep burial. The use of paper bags over young fruit to reduce the incidence of fruit fly attacks was also suggested. Infested fruit was also processed into jam to demonstrate sustainable uses of fruit once the infested sections were removed and disposed of.

In addition to the fruit fly life cycle, the author has also given entomological presentations on butterfly and moth life cycles, and a presentation on bees, their biology, life cycle, and pollination is also in development. The author has been advised by the teachers that these activities and presentations provide students and teachers alike with improved biological science education and awareness from an entomological perspective.

29.4 DISCUSSION AND CONCLUSION

STEM Professionals in Schools is a highly effective program that provides teachers, students, schools, the community, and STEM professionals with significant benefits. Benefits include raising the profile of STEM subjects in schools, increased opportunities for professional learning through communication with scientists and other teachers, inspiring and engaging students in science subjects and alerting them to science-related careers, aligning with DA workplace policy and improving professional scientific communication skills, and sharing a passion for science and information about entomology to increase community understanding of science (Tytler et al., 2016). The program has been evaluated four times (Howitt and Rennie, 2008, Rennie, 2012, Rennie and Howitt, 2009, Tytler et al., 2016), and the key strengths identified in the *STEM Professionals in Schools* program are that the partnerships between STEM professional and teacher are collaborative, flexible, and ongoing (Tytler et al., 2016) and that they have significant national reach with remote partnerships using social media and technology to communicate. The author has recently been partnered remotely with a school in the northernmost Torres Strait Islands where entomology as well as biosecurity knowledge will be shared.

Recommendations for the *STEM Professionals in Schools* program include expanding the program by recruiting more STEM professionals to be partnered with schools. For the author, expansion includes working with the teacher to identify parts of the Australian biological sciences curriculum where entomology can be used to further improve the teaching of biology. For example, discussing the differences in external features of insects from different orders (i.e., Diptera or Lepidoptera), different life stages of insects and how they feed (i.e., chewing or sucking mouthparts) and different life cycles (i.e., complete metamorphosis [Diptera] and incomplete metamorphosis [Hemiptera]), and undertaking a mini-beast excursion to identify insects found on plants grown in the environment center gardens.

Similar STEM programs are run in the United States (AAAS, 2018; STEM-H Center, 2018; Scientist in the Classroom, 2018), Mexico (STEM Movimiento, 2018), the United Kingdom (STEM Ambassadors, 2018), the European Union (STEM Alliance, 2018), Cambodia (STEM Cambodia, 2018), Malaysia (National STEM Movement, 2018), Ghana (STEM Bees, 2018), and many other countries.

These real-world STEM community engagement programs combined with national STEM policy initiatives (e.g., provide specialist STEM schools, update the STEM curriculum, develop smart monitoring, early intervention and access for all, regardless of gender and socioeconomic backgrounds [Timms et al., 2018]) should result in an overall improvement and participation in STEM subjects in schools in Australia and throughout the world.

ACKNOWLEDGMENTS

The success of this program couldn't have been achieved without the commitment of the CSIRO STEM Professions in School team and the Principal, environment center teachers and students of Farrer Primary School.

REFERENCES

AAAS (American Association for the Advancement of Science). 2018. STEM Volunteer Program. http://www.stemvolunteers.org/ (accessed September 29, 2018).

ACARA (Australian Curriculum, Assessment and Reporting Authority). 2018. Science—Foundation to Year 2 ACSSU030. https://www.australiancurriculum.edu.au/Search/?q=ACSSU030 (accessed September 29, 2018).

CSIRO (Commonwealth Scientific and Industrial Research Organisation). 2015. STEM Professionals in Schools. https://www.csiro.au/en/Education/Programs/STEM-Professionals-in-Schools (accessed September 27, 2018).

DAFF. 2013. DAFF Science Strategy, Department of Agriculture, Fisheries and Forestry, Canberra. http://www.agriculture.gov.au/Style%20Library/Images/DAFF/__data/assets/pdffile/0009/2338947/science-strategy-2013.pdf (accessed September 27, 2018).

Department of Education. 2012. Award course completions. https://docs.education.gov.au/documents/2012-award-course-completions (accessed February 24, 2019).

Department of the Prime Minister and Cabinet. 2015. National Innovation and Science Agenda. https://www.industry.gov.au/sites/g/files/net3906/f/July%202018/document/pdf/national-innovation-and-science-agenda-report.pdf (accessed September 27, 2018).

Education Council. 2016. National STEM School Education Strategy, 2016–2026. http://www.educationcouncil.edu.au/site/DefaultSite/filesystem/documents/National%20STEM%20School%20Education%20Strategy.pdf (accessed September 29, 2018).

Fairweather, J. 2008. Linking Evidence and Promising Practices in Science, Technology, Engineering, and Mathematics (STEM) Undergraduate Education: A Status Report for The National Academies National Research Council Board of Science Education. http://otl.wayne.edu/wider/linking_evidence--fairweather.pdf (accessed September 29, 2018).

Golick, D. A., and T. M. Heng-Moss. 2013. Insects as Educational Tools: An Online Course Teaching the Use of Insects as Instructional Tools. *American Entomologist* 59 (3): 183–187.

Howitt, C., and L. J. Rennie. 2008. Evaluation of the Scientists in Schools Pilot Project. Perth: Curtin University of Technology. https://www.csiro.au/en/Education/Programs/STEM-Professionals-in-Schools/How-the-program-works/Program-evaluation (accessed September 27, 2018).

Jolly, A. 2017. The Search for Real-World STEM Problems. Education Week, July 17, 2017. https://www.edweek.org/tm/articles/2017/07/17/the-search-for-real-world-stem-problems.html (accessed September 29, 2018).

Matthews, R. W., L. R. Flage, and J. R. Matthews. 1997. Insects as Teaching Tools in Primary and Secondary Education. *Annual Review of Entomology* 42: 269–289.

National STEM Movement. 2018. Ministry of Higher Education, Ministry of Education, and Ministry of Science, Technology & Innovation of Malaysia. http://www.stem-malaysia.com/ (accessed September 29, 2018).

Office of the Chief Scientist. 2014. Science, Technology, Engineering and Mathematics: Australia's Future. Australian Government, Canberra. https://www.chiefscientist.gov.au/wp-content/uploads/STEM_AustraliasFuture_Sept2014_Web.pdf (accessed September 29, 2018).

PwC (PricewaterhouseCoopers). 2014. Fuelling NextGen digital innovation through education. http://www.digitalinnovation.pwc.com.au/education/ (accessed September 29, 2018).

Rennie, L. J., and C. Howitt. 2009. "Science has changed my life!" Evaluation of the Scientists in Schools Project 2008–2009. Perth: Curtin University of Technology. https://www.csiro.au/en/Education/Programs/STEM-Professionals-in-Schools/How-the-program-works/Program-evaluation (accessed September 27, 2018).

Rennie, L. J. 2012. "A very valuable partnership" Evaluation of the Scientists in Schools Project 2011–2012. Dickson, ACT: CSIRO Education. http://www.scientistsinschools.edu.au/downloads/SiSEvaluationReport 2011–2012.pdf (accessed September 27, 2018).

Scientist in the Classroom. 2018. National Center for Science Education, Inc. Oakland, California, USA. https://ncse.com/scientistinclassroom (accessed September 29, 2018).

Singhal, P. 2017. Australia falling behind in science graduates and public funding: OECD report. Sydney Morning Herald. https://www.smh.com.au/education/australia-falling-behind-in-science-graduates-and-public-funding-oecd-report-20170912-gyfigs.html (accessed September 29, 2018).

STEM Alliance. 2018. European Schoolnet, Bringing Industry and Education Together. http://www.stemalliance.eu/ (accessed September 29, 2018).

STEM Ambassadors. 2018. National STEM Learning Centre, STEM Learning Ltd. University of York, Heslington, UK. https://www.stem.org.uk/stem-ambassadors (accessed September 29, 2018).

STEM Bees. 2018. http://www.stembees.org/ (accessed September 29, 2018).

STEM Cambodia. 2018. Ministry of Education, Youth and Sport. http://www.stemcambodia.org/ (accessed September 29, 2018).

STEM-H Center. 2018. University of New Mexico STEM-H Center for Outreach, Research & Education. Albuquerque, New Mexico, USA. http://stemed.unm.edu/volunteer (accessed September 29, 2018).

STEM Movimiento. 2018. Movimiento STEM A. C., Mexico City, Mexico. http://movimientostem.org/ (accessed September 29, 2018).

Timms, M., K. Moyle, P. R. Weldon, and P. Mitchell. 2018. Challenges in STEM learning in Australian schools: Literature and policy review. https://research.acer.edu.au/cgi/viewcontent.cgi?article=1028&context=policy_analysis_misc (accessed September 30, 2018).

Tytler, R., D. Symington, G. Williams, P. White, C. Campbell, G. Chittleborough, G. Upstill, E. Roper, and N. Dziadkiewicz. 2016. Building productive partnerships for STEM education: Evaluating the model and outcomes of the Scientists and Mathematicians in Schools program 2015, Deakin University, Burwood, Australia. Website: www.csiro.au/~/media/Education-media/Files/STEM-Prof-Schools/Productive-Partnerships-STEM-Education-PDF.pdf (accessed September 29, 2018).

30 Phytosanitary Education

An Essential Component of Eradication Actions for the Carambola Fruit Fly, Bactrocera carambolae*, in the Marajo Archipelago, Para State, Brazil*

Maria Julia S. Godoy[*]*, Gabriela Costa de Sousa Cunha, Luzia Picanço, and Wilda S. Pinto*

CONTENTS

30.1 Introduction 392
30.2 Materials and Methods 393
30.3 Results and Discussion 395
30.4 Conclusions 398
Reference 398

Abstract This chapter presents phytosanitary education actions carried out in support of official control actions implemented to eradicate outbreaks of the quarantine pest *Bactrocera carambolae* (Drew and Hancock) (carambola fruit fly) in the municipalities of Curralinho, Portel, Gurupa, and Breves, Marajo Archipelago, State of Para, Brazil. All actions were carried out from an Emergency Action Plan of Phytosanitary Education, including household visits, meetings with local authorities, technical meetings, lectures, training courses for multiplier agents based on the SOMA Method, radio and TV interviews, notes for websites, participation in local social and agricultural events, workshops, and puppet theatre. The phytosanitary education actions reached 24,750 people (3,058 people in 2014, 6,543 people in 2015, 4,128 people in 2016, and 11,021 people in 2017) in the aforementioned municipalities and also in neighboring ones considered to be at high risk of pest dispersal. Even after pest outbreaks have been declared officially eradicated, phytosanitary education actions must be continued to support passenger baggage transit control that prevents pest host fruit smuggling from the state of Amapa to the state to Para through the Marajo Archipelago boat route to maintain the eradicated area.

[*] Corresponding author.

30.1 INTRODUCTION

In Brazil, especially in the State of Amapa, the carambola fruit fly (CFF), *Bactrocera carambolae* (Drew and Hancock), is considered a quarantine pest that, although present, is not widely distributed and officially controlled. This pest is of great economic importance for Brazilian agribusiness exports. In the states of Para and Roraima, it is considered a transient pest according to the National Programme for Eradication of *Bactrocera carambolae* (PBC) of the Ministry of Agriculture, Livestock and Food Supply (MAPA). Para's Agrihealth State Agency (ADEPARA), under the coordination of the Brazilian National Plant Protection Organization (NPPO), Department of Plant Health (DSV), MAPA, carried out phytosanitary education activities to support the eradication of *B. carambolae* in the municipalities of Curralinho, Portel, Gurupa, and Breves located in the Marajo Archipelago, state of Para, Brazil, from 2014 to 2017 (Figure 30.1).

In these municipalities, there is a great risk of entry and spread through water, land, and air transportation of contaminated fruits due to the proximity to the Marajo Archipelago and the state of Amapa, where *B. carambolae* is being controlled. The cultural habits, especially of the riverine population, are to consume fresh fruits during river journeys, especially of host plants like *Mangifera indica* L., *Averrhoa carambola* L., *Malpighia emarginata* DC., *Syzygium malaccense* L., *Psidium guajava* L., *Citrus x sinensis* Osb., *Solanum lycopersicum* L., and *Capsicum annuum* L. Although

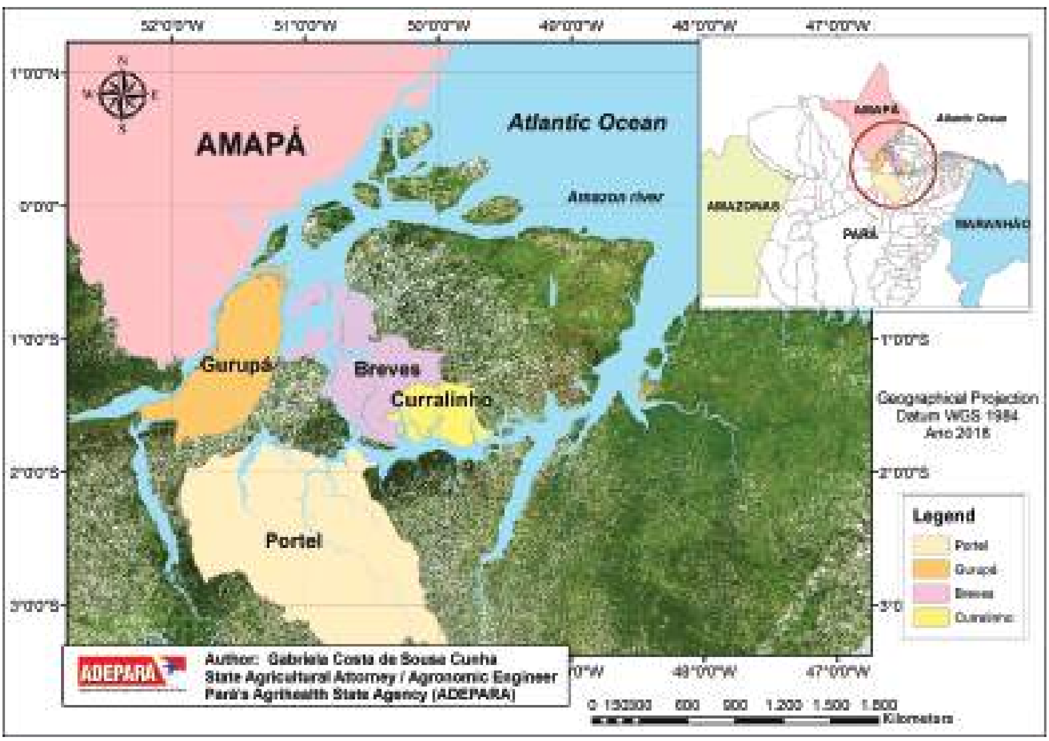

FIGURE 30.1 Map of the municipalities in the Marajo Archipelago, Para, Brazil, in which the carambola fruit fly, *Bactrocera carambolae*, was eradicated.

regulations were immediately enforced and measures were taken when outbreaks were detected, including the prohibition of host fruit transportation and commercialization from infested areas to pest-free areas, it is necessary to raise community awareness about the danger that the movement of this fruit imposes. Raising community awareness regarding the risk of transporting host fruits from areas where CFF is known to occur to CFF-free areas, and also about the importance of eradication of the pest for Brazilian fruit exports, is a key component of any action program. Phytosanitary education supports pest inspection, control and eradication actions, as well as activities aiming to inform and encourage the change of habits in communities and farmers. This is achieved through the development of educational campaigns and community awareness about agriculture and agro-industry activity projects.

The objective of this contribution was to describe the activities undertaken to increase the knowledge of the local people about the *B. carambolae* control program during the 2014–2016 outbreaks in the municipalities of Curralinho, Portel, Gurupa, and Breves located in the Marajo Archipelago, state of Para, Brazil.

30.2 MATERIALS AND METHODS

Based on the Phytosanitary Education Emergency Action Plan, prepared by the team of the National Program for the Eradication of *Bactrocera carambolae* (PBC), and considering the local cultural habitats of the riverine population, phytosanitary education actions are implemented at the time of notification of an outbreak. PBC procedures establish that phytosanitary education and control measures should be implemented together and within 48 h of the notification of the outbreak. Activities involve visits to municipal authorities and state and federal agencies present in the municipality with the purpose of providing official information on the phytosanitary condition of the location of the outbreak. This is followed by radio and TV interviews, presentations of the topic to primary and secondary schools, courses for training multiplier agents using the SOMA method (education tool whose acronym means systemic [S], objective [O], monitoring [M], and evaluation [A]), technical lectures and participation in social and agricultural events, and workshops and puppet plays. According to Albuquerque (2000), the SOMA method allows to quantify the students' knowledge before and after the technical lecture and to identify the learning efficiency of each objective, indicating to the teacher the need to clarify the presented subject. Teachers, rural extension agents, health agents, high school and university students, public servants, community leaders, among others, are invited to participate in the training of multipliers based on the SOMA method. After contacting the municipal authorities, visits are made to the community explaining the detection of the pest, identifying hosts for trapping in backyard orchards as support for the actions of the pest control team, as well as on-site visits to commercial establishments, waterways, and homes in both urban and rural communities. With the accomplishment of a training course for multiplier agents, Municipal Phytosanitary Education Nuclei are implemented with representatives of community agents such as teachers, health agents, and others. The community is informed of the activities that are being carried out, and after the eradication of the outbreak, a Post-Eradication Plan of Phytosanitary Education is implemented to continue carrying out activities in the municipality as shown in Figure 30.2.

During 2014–2017, actions were carried out in partnership with local agricultural and related institutions, as well as with the communities, considering interinstitutional integration and local knowledge. All educational activities were carried out in a continuous way, with alternation of

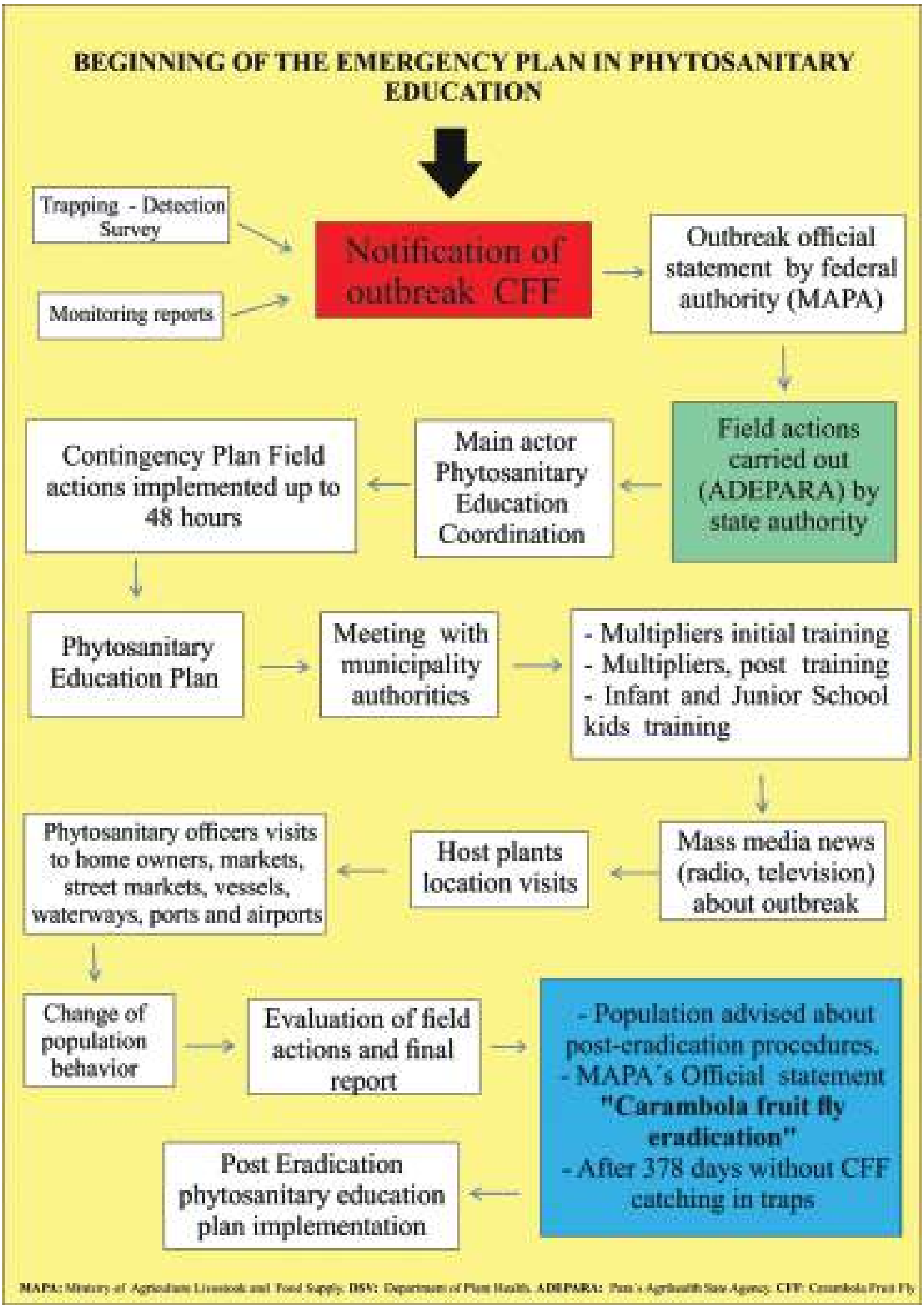

FIGURE 30.2 Flowchart of the Emergency Phytosanitary Education Plan of the National Carambola Fruit Fly Eradication Program. CFF, carambola fruit fly.

FIGURE 30.3 Educational material used in the campaign to eradicate the carambola fruit fly in the Marajo Archipelago, Para, Brazil.

teams in the field and with the minimum interval between them. The crew and passengers of vessels are considered strong allies in actions to prevent the dispersion of the pest. After they receive guidelines, they become co-participative by spreading the acquired knowledge, mainly in relation to host fruit transit restriction and pest identification. Educational materials were used to support all activities, such as banners, stickers for SOMA method courses, flyers, folders, booklets for children, and other printed material for places without electricity (Figure 30.3).

30.3 RESULTS AND DISCUSSION

In compliance with the actions contained in the Emergency Plan for Health Education Actions, technical lectures for children and adolescents, interviews on radio and TV, visits, and courses were held. From 2014 to 2017, a total of 24,750 people participated in the educational activities (3,058 people in 2014; 6,543 people in 2015; 4,128 people in 2016; and 11,021 people in 2017), both in the municipalities of the Marajo Archipelago and in others considered of high risk for pest dispersal (Figures 30.4 and 30.5).

During this period, four outbreaks were detected in the Marajo Archipelago. Restrictions related to movement of host fruits from infested sites to pest-free areas were immediately published. In each municipality, a group of multiplier agents of the program was formed, with a total of 186 multiplier

FIGURE 30.4 Educational activities in fairs and residences and lectures at schools carried out by field teams aimed at supporting the eradication of the carambola fruit fly.

FIGURE 30.5 Interviews on radio and television to clarify carambola fruit fly's outbreak detection.

agents: 14 in Curralinho, 35 in Gurupa, 66 in Portel, and 53 in Breves. Also, another group with 18 students was formed in the municipality of Melgaço (Figure 30.6).

Because SOMA is a method that does not require large audiovisual aids, it can be used in areas without much infrastructure. In addition, because it uses repetition as part of the learning process, it can be implemented in an audience with any level of schooling, including those who are illiterate. Training using this methodology improved the educational tools the community received by improving questionnaires, manual tabulation of data, calculations of average efficiency and learning improvement, and by identifying the weaknesses of the training. The use of this method contributed

FIGURE 30.6 Class of multiplier agents trained through the SOMA method in the municipalities of Curralinho, Portel, Gurupa, and Breves. SOMA, systemic, objective, monitoring, evaluation.

significantly to the immediate efficiency of the teaching-learning process, whose diagnosis facilitated the planning and continuity of future actions.

The Marajo Archipelago, with 104,606.90 km², is divided into 16 municipalities and is the main route of entry of the pest into the Amazon, where the main road network is fluvial. Vessels leave the state of Amapa to Belem, capital of the state of Para, Manaus in Amazonas, and other cities, distributing freight and passengers, thereby becoming a pathway for the distribution of the pest. During the program, health education teams intensified activities with passengers and crew on a daily basis with approaches before boarding and after landing, explaining to the public the restriction of transit of all host fruits, in any quantity, as well as with the distribution of informative material to reinforce the information (Figure 30.7). It is important to emphasize that the control teams,

FIGURE 30.7 Approach carried out in vessels and waterways with passengers and crew in the municipalities of Curralinho, Portel, Gurupa, and Breves.

monitoring agents, phytosanitary educators, and general coordinators were always interconnected and motivated. This was supported through meetings destined to update about new situations found in the field activities, which also contributed to the harmony and success of the activities. The first approach with the local population, including meetings with leaders and city hall authorities, was carried out in an enlightening, convincing, and respectful manner, which favored educational activities aimed at supporting pest eradication. Therefore, control activities became a community action, and the community was not afraid of the program, and the acquisition of knowledge contributed to the good progress of the work.

The communities of the municipalities of Curralinho, Portel, Gurupa, and Breves played a fundamental role in the CFF-eradication process. This was evidenced by behavioral changes, mainly in relation to host fruit transportation, fruit collection, and contribution to the technical staff of the control team to carry out trapping surveys and sprayings around homes. They also provided permission to display posters in commercial areas, looked after the traps, participated in lectures and events promoted by the program, and provided valuable support by reporting houses with host fruits and potential outbreaks.

As a result of control actions, supported by the education program, outbreaks were declared as eradicated in Curralinho on April 24, 2015; in Portel on October 16, 2016; in Gurupa on September 17, 2016; and in Breves on July 2, 2017. Nevertheless, local activities, including the control of passengers moving from the state of Amapa, continued after the declaration of eradication of each outbreak.

30.4 CONCLUSIONS

The local population, through awareness activities, understood the dangers of pest dispersal, as well as the economic and social costs that occur when CFF spreads to production areas. The program also resulted in community participation and in a strengthened partnership between the community and the PBC team. Phytosanitary education activities were found to be essential for the success of the eradication programs against fruit flies. Therefore, such programs should be part of each contingency plan of each federal state and should be carried out jointly with control actions.

REFERENCE

Albuquerque, C. 2000. *Método SOMA: Capacitação de agricultores, educação sanitária, educação ambiental*. Gráfica e Editora Bandeirante, Bandeirante, Brazil.

31 Phytosanitary Education as a Component of Eradication Actions of the Carambola Fruit Fly (CFF) *Bactrocera carambolae* in the Raposa Serra Do Sol Native Reserve, State of Roraima, Brazil

*Maria Julia S. Godoy**, *Gabriela Costa de Sousa Cunha, Elindinalva Antônia Nascimento, Maria Eliana Queiroz, Luzia Picanço, Luiz Carlos Trassato, and Wilda S. Pinto*

CONTENTS

31.1 Background 400
31.2 Materials and Methods 402
31.3 Results 403
31.4 Conclusions 405
References 405

Abstract This chapter presents the results obtained through the phytosanitary education methodology used by the Carambola Fruit Fly (CFF) Eradication Program based on the SOMA Method. Since the initial detection of the quarantine pest *Bactrocera carambolae* (Drew & Hancock) in the Raposa Serra do Sol native reserve, Roraima, Brazil, this program has contributed to the eradication of the CFF and the maintenance of a protected area, which is the minimum area necessary for the effective protection of an endangered area found in the extreme north of Roraima.

* Corresponding author.

31.1 BACKGROUND

Two initial outbreaks of the carambola fruit fly (CFF), *Bractocera carambolae*, in the state of Roraima, Brazil, were detected on December 19, 2010, and February 2, 2011, respectively, in the municipality of Uiramutã, located in the northeast of Roraima, Raposa Serra do Sol. After this detection, the outbreaks were kept under control without dispersion outside the Raposa Serra do Sol region because of the promptness of control actions and phytosanitary education.

The state of Roraima, located in the northern region of Brazil, borders to the north and northwest with Venezuela, to the east with Guyana, to the southeast with the Brazilian state of Para, and to the south and west with the Brazilian state of Amazonas. The municipality of Uiramutã is located at 04° 35′ 45″ N and 60° 10′ 04″ W, border with Venezuela and Guyana. It has a total area of 8,066 km^2 and an estimated population of 8,375. It houses one national park and part of the Raposa Serra do Sol native reserve, and it exhibits tropical savanna climate (Aw) according to the Koppen climate classification. Large plains have savanna lowbush and grass vegetation, and mountains are covered with tropical rainforest. The reserve is located between the Tacutu, Mau, Surumu, and Miang Rivers, and it is occupied by the indigenous groups of ingaricos, macuxis, patamonas, taurepangues, and uapixanas. (https://pt.wikipedia.org).

The municipality of Normandia is located at 3° 52′51″ N and 59° 37′ 22″ W, with a border to the north with Uiramutã and the Co-operative Republic of Guyana, to the south with Bonfim, to the east with the Co-operative Republic of Guyana, and to the west with Boa Vista and Pacaraima. It has a total area of 6,967 km^2 (https://en.wikipedia.org) (Figure 31.1).

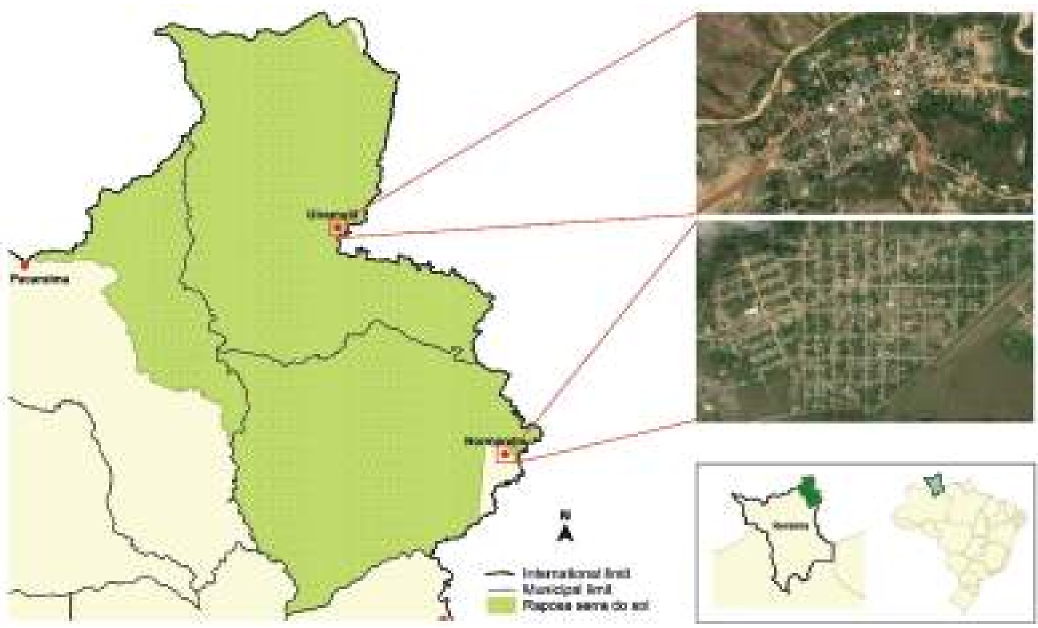

FIGURE 31.1 Location and aerial view of Uiramutã and Normandia, Raposa Serra do Sol, Roraima, Brazil.

Although this region is not an important producer of CFF host fruits, since the occurrence of the outbreaks in 2010, Roraima's host fruit production has not been allowed to be marketed out of the state. For instance, the most important host crop of Roraima is mango, with 860 ha planted and 4,214 tons of fruit harvested in 2017 (Instituto Brasileiro de Geografia e Estatística - IBGE 2017), and it has its main market in the neighboring state of Amazonas. The restriction on host fruit traffic prevents the spread of CFF to Amazonas and from there to the main Brazilian fruit-producing states (Figure 31.2).

Factors that helped the dispersion of CFF into Brazil were the uncontrolled presence of CFF in Guyana; the lack of control actions; continuous and regular informal commercial exchange between native people living in Guyana's regions 7 (Cuyuni-Mazaruni), 8 (Potaro-Siparuni), and 9 (Alto Takutu-Alto Essequibo) and the northeast of Roraima, Brazil; gold prospecting routes; and strong winds (Ezilon Maps, 2018) (Figure 31.3).

According to the Brazilian legislation, emergency plans for CFF eradication must be implemented no later than 48 h after one specimen of the pest has been detected (Normative Instruction Nº. 28, of July 20, 2017). In the case of native people, previous community authorization is mandatory before any control action takes place, which leads to the prioritization of phytosanitary education actions. The Raposa Serra do Sol native reserve has many villages, with Maturuca being the main one, and Willimon, Formoso, Caraparu, Morro, Pedra Branca, and Serra do Sol being other important villages.

FIGURE 31.2 The Mau River, border between Karasabai town, the Co-operative Republic of Guyana, and the state of Roraima, Brazil.

FIGURE 31.3 Administrative regions of Guyana (Ezilon Maps, 2018).

31.2 MATERIALS AND METHODS

The SOMA method, an education tool whose acronym means systemic (S), objective (O), monitoring (M), and evaluation (A) (Albuquerque 2000), was applied in all the communities of the Raposa Serra do Sol native reserve. The SOMA method can be understood as systemic: results are essential, as they guide the system; objectives: need to be well defined and clearly measurable; monitoring: needs to be continuous with the capacity of building a process to allow trainee evolution and evaluation, and to adjust the system to reach expected results; evaluation: all work is done under continuous evaluation, allowing system improvement along the process (Albuquerque 2000).

This method can be used in areas without infrastructure and for a public with any level of education because it uses repetition in the learning process and does not require any specific audiovisual resources. It allows the establishment of results through the improvement of questionnaires based on feedback; manual tabulation of data; average calculations, efficiency, and increase of learning; and identifying the weaknesses of the training. It also contributes significantly to the evaluation and immediate effectiveness of the teaching-learning process, whose diagnosis facilitates the planning/

continuity of future actions. The first contact is with the health secretary of the city hall for the approval of the participation of community health agents, servers linked to the education area and community leaders.

Subsequently, these servers become multipliers of the National Carambola Fly Eradication Program, becoming a focal point in these municipalities. A series of visits are made by the multiplier agents, who then provide feedback of the situation that allows to guide actions in the communities.

During training, the instructors emphasize to multipliers, students, and the general public the importance of actions to control the eradication of CFF and the risks related to the transport of the most common host fruits in the region; these are fruits such as mango, carambola, acerola, lemon cayenne, and chili pepper from the infested areas of Uiramutã and Normandia to cities without the occurrence of the pest within the state of Roraima, as well as to other states where CFF is not present in Brazil. The Raposa Serra do Sol native reserve comprises Uiramutã city, Pacaraima, and Normandia city.

In Uiramutã city, the distance between these communities varies from 500 m to 10 km, with the largest distance being between the Maturuca village and the Mutum and Willimon villages, reaching 60 km. It is important to note that to carry out visits to all the native villages, 700 km have to be covered.

The indigenous population has the habit of carrying host fruits from one locality to another, either to offer them as gifts or to consume during journeys and, in the case of peppers, during festivities in which the indigenous population of Guyana and Brazil take part. Therefore, all involved must be alerted about the risks of uncontrolled transit of host fruits from infested areas to CFF-free areas and about the economic loss of exports of Brazilian fruit to other countries. This method has certainly contributed to sensitizing the population about the risks of dispersion of the pest within the communities, thus promoting an awareness through effective change in behavior.

31.3 RESULTS

The initial activity is the training of multipliers, comprised preferentially of leaders from native villages and municipalities, school teachers, community health agents, and civil servants based in the region. The multipliers integrate the Municipality Phytosanitary Education Group which supports actions carried out by the CFF Eradication Program teams. Through community and school lectures and host plant product transit control, the local population is informed about economic and social losses in the case of CFF dispersion to other states in Brazil, as well as about legal responsibilities assumed by those who disrespect legislations forbidding transit and sale of CFF host fruits. Interviews are regularly held in locally and statewide broadcasted radio programs, which also reach towns bordering neighbor countries. Roraima's team is composed of eight members from the Ministry of Agriculture, Livestock and Food Supply, and the Agri-health State Agency, all of whom have already been trained through the SOMA method (Albuquerque 2000), which is a mandatory condition for membership to the phytosanitary education team.

From 2011 to 2017, the phytosanitary education team in Roraima presented 32 technical lectures for a total audience of 1,533 people, 72 presentations in junior schools for 2,472 students, 168 meetings with native leaders reaching 1,170 people, 24 phytosanitary education blitzes in the borders reaching 9,413 people, and 12 training courses attended by 2,472 CFF Eradication Program multiplying agents (Figure 31.4). The education team also carried out 221 educational activities reaching 8,454 people, including radio programs.

The Raposa Serra do Sol native reserve is partially located in the territories of the Pacaraima, Normandia, and Uiramutã municipalities. Normandia comprises 68 native villages, Pacaraima 60 villages, and Uiramutã 85 villages. Each one of the 213 villages has its own leader and maximum authority named "Tuxaua," which is chosen by village members to rule during a 2-year term. As the main authority, the "Tuxaua" must be the first one to be consulted about any issue related to the village. Thus, the activities related to phytosanitary education and CFF pest control actions could only be carried out after his authorization.

FIGURE 31.4 Training of people in indigenous communities as multipliers of the carambola fruit fly (CFF) Eradication Program, Raposa Serra do Sol, Uiramutã, Roraima, Brazil.

The first activity performed by the phytosanitary education team is usually a lecture given to the community explaining about the CFF, its biological cycle, why it is considered a pest, how it can spread, and the risks it presents to the domestic and export fruit industries. At the end of the lecture, the team members and the community organize priority activities to be carried out, taking into account the outbreak, the public to be worked with, and the physical structure and access routes.

The phytosanitary education team performs activities such as school and community lectures, puppet theater, training courses for multipliers (SOMA method), individual home surveys to locate host plants and control actions, teaching, control actions in commercial establishments, radio and TV interviews, and transit control related to host fruit transportation. Trained multipliers have been working on a regular basis with phytosanitary education teams in education and control actions, resulting in the successful eradication of CFF outbreaks (Figure 31.5).

FIGURE 31.5 SOMA training meeting with indigenous people learning to identify the carambola fruit fly (CFF). SOMA, systemic, objective, monitoring, and evaluation.

FIGURE 31.6 Children trained as trap guardians from the native groups of ingaricos, macuxis, patamonas, taurepangues, and uapixanas.

Children also play an important role in the community; thus, they were trained to become trap guardians (Figure 31.6). However, sporadic CFF outbreaks can occur in the border because of pest pressure, demanding continuous phytosanitary education activities.

31.4 CONCLUSIONS

The first detection of CFF in the state of Roraima occurred in the Raposa Serra do Sol native reserve located close to the border between Brazil and Guyana. This specific situation required prioritization of phytosanitary education actions before control actions could take place due to the need of previous authorization from native community leaders.

Phytosanitary education actions must be performed in a continuous, respectful, and clear manner, taking into account the particularities of the communities and the organization of the people, as well as the education of the indigenous people related to the way of life and beliefs of the community. In this way, the inclusion of indigenous groups led to a successful CFF-eradication process.

The SOMA method was selected because it is understandable for people with different levels of school education, and it uses repetition as a learning basis, allowing previous identification of specific objectives and the creation of local groups supporting phytosanitary education teams. The education activities related to control actions, especially CFF trap maintenance, were key for the successful eradication of CFF and the maintenance of the protected area based on the current Brazilian legislation.

REFERENCES

Albuquerque, C. A. 2000. *Método Soma: Capacitação de agricultores, educação sanitária e educação ambiental*. Gráfica e Editora Bandeirante, Bandeirante, Brazil.

Ezilon Maps. Guyana Map—Political Map Of Guyana. https://www.ezilon.com/maps/south-america/guyana-maps.html. (accessed December 20, 2018).

Instituto Brasileiro De Geografia E Estatística – Ibge. Banco De Tabelas Estatísticas. Produção Agrícola Municipal. https://sidra.ibge.gov.br/pesquisa/pam/tabelas. (accessed December 18, 2018).

Normative Instruction Nº. 28. 2017. The operational procedures for the prevention, containment, suppression and eradication of the quarantine pest present *Bactrocera carambolae* (Carambola Fruit Fly). Ministry of Agriculture and the Agrihealth State Agency. Official Journal of the Union. Brasília, Brazil, July 26, 2014, No. 142, Section 1, p. 8.

Wikipedia The Free Encyclopedia. https://pt.wikipedia.org. (accessed December 18, 2018).

Taylor & Francis
Taylor & Francis Group
http://taylorandfrancis.com

Index

Note: Page numbers in italic and bold refer to figures and tables, respectively.

A

ABC (augmentative biological control), 269
acclimation process, 29
acclimatization process, 29
accumulated mating frequency, 49, *50*
Aganaspis pelleranoi, **270**, 271
agroecology, 284–285
alpha taxonomy, 84
Anastrepha curvicauda (papaya fruit fly), 3, **5**
Anastrepha fraterculus (South American fruit fly), 45–47, 89–90
  biological material, 47
  geographical distribution, 111–113, *113*
  host origin, 109–111
  host plant families for, *109*
  host plants diversity, 91, **92–108**, 109
  mating compatibility test, 47
  sexual compatibility, 50–51
  trophic network interactions, *110*, *112*
Anastrepha grandis (South American cucurbit fruit fly), 301–302
  biogeography, 302, *303*
  biological/morphological/behavioral parameters, **305**, 305–306
  in Brazil, *307*
  damage and hosts, 302–305, *304*
  host plant species, **304**
  systems approach for, 308–311, **309**
Anastrepha ludens (Mexican fruit fly), 32, 129, *214*, 236
  age attraction to traps effect, 182
  bait station, laboratory bioassay, 134, 137–138
  biological material, 179, 210–211
  data analysis, 134–135, 212–213
  desiccation resistant strains, 35–37
  evaluation, 212
  field tests, 132–134, 136–137
  insects, 130–131
  mortality percentage, *137*, *138*
  overview, 210
  population fluctuations, 183, *183*
  results, 213–214
  sterile males, 183, *183*
  Tap-7, 209–211
  wax-based bait stations, 131–132
  wild and sterile, **136**
Anastrepha obliqua (West Indian fruit fly), 236
  data analysis, 272
  overview, 267–268
  pest populations, 268–269
  results, 272–274
Anastrepha obliqua, corncob fractions on
  bacteria/fungi, identification, 193–195
  data analysis, 195
  larval survival, toxicological test for, 194, 196, **196**
  mycotoxin determination, 194–195, 197, **197**
  mycotoxin sequestrants, incorporation, 195, **195**, 197, **197**
  overview, 192–193
Anastrepha obliqua in *Spondias* spp.
  Aganaspis pelleranoi, **270**, 271
  distribution, 269
  Doryctobracon areolatus, **270**, 271
  Opius Anastrephae, 271
  Utetes anastrephae, **270**, 270–271, **273**
Anastrepha spp., 57, 124
  immature stages, 58, **59–81**, 82–84
  for larvae, **83**
  materials and methods, 124, 335–337, **336**, *337*
  overview, 57–58, 334–335
  results, **124**, 124–125
Andean lineage, 46
apple (*Malus domestica*), 378
application time, *Dacus frontalis*, 256–257, *261*, 261–262
area-wide integrated pest management (AW-IPM), 178, 343
  Bactrocera dorsalis, 330–331
  pilot project, *345*, 346, *346*
  SACFF, 301
  SIT program, 327
attract-and-kill devices, 130, 139
augmentative biological control (ABC), 269
autonomous zone groups, 285
AW-IPM, *see* area-wide integrated pest management (AW-IPM)

B

Bactrocera carambolae (carambola fruit fly), 315, *392*
  control flow diagram, *319*
  educational material uses, *395*
  eradication, *396*
  host fruits elimination, 318–319
  insecticide bait application, 318
  MAT, 318
  multipliers, *404*
  outbreak detection, *396*
  overview, 316, 391–393, 400–401
  phytosanitary education actions, 320
  phytosanitary procedures, *322*
  phytosanitary regulations, 319–320
  population fluctuation of, *321*, *322*
  results, 320–322, 403–405, *405*

Bactrocera dorsalis (oriental fruit fly), 9–10, 325, 350
AW-IPM program, 330–331
flight capacity, 17–21, **18–20**
IPM, 329
methyl eugenol/terpinyl acetate, *354*
trap captures/rainfall, *356*
trap captures/temperature, *356*
trap catches in citrus, *355*
trap catches in *Irvingia*, *355*
Bactrocera oleae (olive fruit fly), 16
Bactrocera spp., 9
biological databases, 10
case studies on, 15–16
ecology/biology, **11–12**
flight capacity, 10
flight data for, 13–15
fly 50–100 km, 13
fruit fly movement, reviews on, 16–17
genus classification, 12–13
movements, **14–15**
organizational databases, 10
scientific publications on, 13
Bactrocera tryoni (Queensland fruit fly), 31–32, 171
Bactrocera zonata (peach fruit fly), 142
attraction to bait, *148*, *149*
fly attraction, bait treatments for, **150**
Bactrocera zonata and *Zeugodacus cucurbitae*, WBY attractant in
cost–benefit analysis, 145, 153, **154**
laboratory bioassay, 143–144, 146, 148
modified WBY in, 144, **144**, 150–151
Tephri Traps® in cucurbit fields, 144–145, **145**, 151–152, **152**
Tephri Traps® in fruit orchard, 145, 152, **153**
bait application technique (BAT), 350
bait spray application method, 345
bait stations, 130, 318
with conical hat protection, *132*
in hot spot location, 134
laboratory bioassay, 134, 137–138
site locations and traps, number, **133**
site locations for, *133*
wax-based, 131–132
with waxy matrix, Spinosad, *131*
weathered, *135*
BAT (bait application technique), 350
Binh Thuan province, 343–344, *344*
biogeography, *Anastrepha grandis*, 302, *303*
bioinsecticides, *Dacus frontalis*, 253
biological control
augmentative release, 239
mango production regions, 239–245
overview, 238–239
biological parameters, *Anastrepha grandis*, **305**
Black Pupae Strain (BPS), 130
borax (sodium tetraborate), 145
Brazilian lineage, 46

C

CABI Invasive Species Compendium, 13
carambola fruit fly (CFF), *see Bactrocera carambolae* (carambola fruit fly)
Ceratitis capitata (Mediterranean fruit fly), 31–33, 333, 335
Ceratitis capitata Vienna 8 Strain, 218
egg source, 219, 221
formulation/preparation methods, 220–221
insects, 219
larval weight and recovery, 221–224, 226, *226*
microbiological profile, 228
overview, 218–219
physicochemical profile, 228–229
rearing procedures, 220–222
temperature profile, 221, 223–224, 226, *228*
Ceratitis cosyra (mango fruit fly), 32, 349
overview, 350–351
protein bait catches, *354*
results, 353–358
study site, 351
trap captures/rainfall, *357*
trap captures/temperature, *356*
traps, distribution/placement, 351–353, *352*
CFF (carambola fruit fly), *see Bactrocera carambolae* (carambola fruit fly)
CHCs, *see* cuticular hydrocarbons (CHCs)
Chiapas, 242
chilled adult technique, 245
citrus orchards, survival/longevity in, 183
Coffea arabica, 113
coffee berry borer (*Hypothenemus hampei*), 281
coffee leaf rust, *see Hemileia vastatrix* (coffee leaf rust)
coffee plantation altitude *versus* rust damage, *289*
CoFFHI, *see* Compendium of Fruit Fly Host Information (CoFFHI)
coffee system, 285, *286*
Combretaceae, 109
commodity tolerance, 164
Commonwealth Scientific and Industrial Research Organisation (CSIRO), 386
community pest management center (CPMC), 328
Compendium of Fruit Fly Host Information (CoFFHI), 364
databases/provisional host lists, 365
Pacific Islands, Dacinae, 367
Tephritidae databases, 366–367
USDA, **366**
conflict zone group, 285
cost–benefit analysis, 145, 153, **154**
CPMC (community pest management center), 328
CSIRO (Commonwealth Scientific and Industrial Research Organisation), 386
cultivars, dose tolerated in, 166, **166**
Curralinho, location/aerial view, *317*
cuticular hydrocarbons (CHCs), 3
Anastrepha curvicauda, 3, **5**
overview, 4
results, 5–6
in tephritids, 35
cuticular lipids, 35

D

Dacus frontalis (Greater melon fly), 251–252, *255*
application time, 256–257, *261*, 261–262
bioinsecticides, 253
formulation, 256, *260*, 260–261

insect culture, 253
larval experiment, 254, **256**, 257
overview, 252–253
pupal/adult experiment, 254, **256**, 257
pupal age experiment, 254–255, 257–258
rate effect, 256, 258, *259*
decision-making process, *287*
Department of Agricultural Extension (DOAE), 326–327
desiccation resistance
artificial selection for, 27–28
definition, 28
importances, 29–30
mechanisms, 38
selection for, 38–39
strains development, 35–38
Diachasmimorpha longicaudata, 236, 239, 267
diets
evaluated starter/finalizer, **229**
larval development speed, 224, *225*
larval recovery and, 225
microbiology, 223
physicochemical properties, 223
physicochemical records, **229**
direct fitness reduction, 202
Doryctobracon areolatus, **270**, 271
double-strand breaks (DSBs), 169
drench application, 256

E

ecosystem, 285
egg-hatching, percentage, *182*
egg-larva transformations, *224*
eggs and larvae, 30–31
egg source, 219
enterprise agroindustrial
Ciego de Avila, 339, *340*
Victoria de Giron, 338, *338*
enterprise citricos
Arimao, 338–339, *339*
Ceiba del Agua, 339
entomopathogenic fungi, *Dacus frontalis*, 251–252
methods, 253–257
results, 257–262
sources/isolates, **253**
epicuticle, 4, 35
EPPO Global Database, 16
European Plant Protection Organization (EPPO), *334*
Eurosta solidaginis (goldenrod gall fly), 30
exit zone group, 285

F

farmer zone, 344
fecundity, 36
Female Relative Performance Index (FRPI), 37, 48, *48*
fertility, 36
FFN (Fruit Fly News) newsletter, 371, *372*
field sanitation method, 345
flies per trap per day (FTD), 181, 311, *330*, 334, 343, 345
fly population, 315
formulation, *Dacus frontalis*, 256, *260*, 260–261
fresh horticultural commodities, 164
FRPI (Female Relative Performance Index), 37, 48, *48*
fruit collection/burial, 318–319, **319**
fruit fly
biological control, 239–245
in mango orchards, 238
movement, reviews on, 16–17
parasitism analysis, 242–245, *244*
region analysis, 240–242
species, relative abundance, **357**
suppression, *344*
wild populations/damage produced, 237–238
fruit fly AW-IPM in dragon fruit
methods, 344–345
overview, 343–344
results, 345–346
Fruit Fly News (FFN) newsletter, 371, *372*
fruit sampling, 124
FTD, *see* flies per trap per day (FTD)
Fusarium spp., 193

G

gamma-H2AvB (γH2AvB), 171–172
gamma-H2AX (γH2AX), 170–171
generalized linear model (GLM), 195–196
genetic sexing strain (GSS), 178, 210, 331
geographical distribution, 111–113, *113*
geographical information system (GIS), 325, *328*
goldenrod gall fly (*Eurosta solidaginis*), 30
Greater melon fly (*Dacus frontalis*), *see Dacus frontalis* (Greater melon fly)
GSS (genetic sexing strain), 178, 210, 331
Guerrero, 240–241, *241*
Guyana, administrative regions of, *402*

H

Hemileia vastatrix (coffee leaf rust), 288–289
coffee plantations, *289*
components risk, *288*, *292*
geographical analysis, *293*
power relationship, *288*
risk analysis, *290*, *291*
1-heptacosanol, 3, 5, *6*
holistic approach, 288–294
holistic pest management (HPM), 281
decision-making tool in, **295**
hypothetical relationships, 289
versus IPM, **283–284**
overview, 282–287
holistic risk triangle, 290
host fruits elimination, 318–319, **319**
host plants diversity, 91, **92–108**, 109
host plant species, *Anastrepha grandis*, **304**
HPM, *see* holistic pest management (HPM)
Hypothenemus hampei (coffee berry borer), 281

I

IAEA (International Atomic Energy Agency), 178, 326, 369
IDCT, *see* International Database on Commodity Tolerance (IDCT)

IDIDAS, *see* International Database on Insect Disinfestation and Sterilization (IDIDAS)
Index of Sexual Isolation (ISI), 45, 48, *48*
indirect fitness reduction, 202
induced sterility determination, 179–180
insect culture, *Dacus frontalis*, 253
insecticide bait application, 318
integrated pest management (IPM), 210, 236, 281–282
  Bactrocera dorsalis, 329
  versus HPM, **283–284**
  program, 328
interdependence and mobility relationships, 285, *286*
International Atomic Energy Agency (IAEA), 178, 326, 369
International Database on Commodity Tolerance (IDCT), 161, 369, 376, *377*, 378
  collecting and selecting information, 164
  database structure, 166
  data collection framework, **165**
  fresh horticultural products in, **165**
  home page, *377*
  irradiated fresh commodities, tolerance, 163–164
  overview, 162–163
  PI, 163
  project, 164
International Database on Insect Disinfestation and Sterilization (IDIDAS), 162–163, 375
  home page, *375*
  Tephritidae species represented in, **376**
International Plant Protection Convention (IPPC), 302, 364
International Standards for Phytosanitary Measures (ISPMs), 302, 306
International Symposium of Fruit Flies of Economic Importance (ISFFEI), 373–374, *374*
invasive species, 28
ionizing radiation (IR), 170, *171*
IPM, *see* integrated pest management (IPM)
IPPC (International Plant Protection Convention), 302, 364
IR (ionizing radiation), 170, *171*
irradiated fresh commodities tolerance, 163–164
Irvingia spp., 353–354
ISFFEI (International Symposium of Fruit Flies of Economic Importance), 373–374, *374*
ISI (Index of Sexual Isolation), 45, 48, *48*
ISPMs (International Standards for Phytosanitary Measures), 302, 306

J

Joint Food Agriculture Organization/International Atomic Energy Agency (FAO/IAEA), 130, 162, 164

L

larval development speed, 221, *225*
larval diet formulation, first/secind stage, **220**, **222**
larval experiment, *Dacus frontalis*, 254, **256**, 257
life stage/history coverage, 38
light intensity, *211*
lipid and water content, 34–35
lipid catabolism, 34–35
location and aerial view, Para in Brazil
  city of Curralinho, *317*
  city of Portel, *317*
longevity, 36

M

maggot stages, 387
Magnifera indica (mango), 333, 350
male annihilation technique (MAT), 318, 343, 350
  fruit fly management, 325
  implementation, 327
  suppression methods, 345
Male Relative Performance Index (MRPI), 48, *48*
Malus domestica (apple), 378
mango (*Magnifera indica*), 333, 350
mango fruit fly, *see Ceratitis cosyra* (mango fruit fly)
mango orchards, 236, *237*
MAPA (Ministry of Agriculture, Livestock and Food Supply), 307, 316, 392
Marajo Archipelago, 316, 319, 397
mass-reared tephritids, 38–39
MAT, *see* male annihilation technique (MAT)
matasano fruits, 179
matings, **213**, 213–214
  compatibility test, 47
Mau river, *401*
mean lethal time, **259**
Mediterranean fruit fly (*Ceratitis capitata*), 31–33
melon fly (*Zeugodacus cucurbitae*), 142
melon production, *310*
Mesoamerican-Caribbean lineage, 46
Metarhizium anisopliae var *anisopliae* strain F52 (MET52), 252
2-methylactosane, 3, 5, *6*
Mexican fruit fly, *see Anastrepha ludens* (Mexican fruit fly)
Ministry of Agriculture, Livestock and Food Supply (MAPA), 307, 316, 392
mobility and interdependence relationships, 285, *286*
monomorphic profile, 6
Morganella morganii, 193
Moscamed program, 218
Movement of Tephritid Fruit Flies, 13, **14–15**, 15–16
MRPI (Male Relative Performance Index), 48, *48*
mycoses, 257
mycotoxin determination, 194–195
mycotoxin sequestrants, incorporation, 195

N

Normandia, location/aerial view, *400*
Northeast Brazil, fruit fly PFAs in, 306–308

O

Oaxaca region, 241–242
olive fruit fly (*Bactrocera oleae*), 16
Opius Anastrephae, 271
oriental fruit fly, *see Bactrocera dorsalis* (oriental fruit fly)

P

papain, 143, 146, 148, 153
papaya fruit fly (*Anastrepha curvicauda*), 3, **5**
parasitism, 240

parasitoids, 238
shipping/packing/release, 239
species, *274*
PCR (polymerase chain reaction) technique, 193
peach fruit fly, *see Bactrocera zonata* (peach fruit fly)
Pest Free Area (PFA), 301, 306–307
pest management actions, 282
phytosanitary education, 391
actions, 320
materials and methods, 393–395, *394*
overview, 392–393
results, 395–398
phytosanitary irradiation (PI), 161–163, **378**
phytosanitary procedures, *322*
phytosanitary regulations, 319–320, *320*
PI (phytosanitary irradiation), 161–163, **378**
plantation scheme, 337
polymerase chain reaction (PCR) technique, 193
Portel, location/aerial view, *317*
postcopulatory behaviors and mechanisms, 37–38
Pouteria campechiana, 124, **124**
power zone group, 285
pre-oviposition period, 306
protein hydrolysate, 142
pupal age experiment, *Dacus frontalis*, 254–255, 257–258
pupal and adult experiment, *Dacus frontalis*, 254, **256**, 257

Q

Queensland fruit fly (*Bactrocera tryoni*), 31–32, 171

R

radio-phylic/-phobic commodities, 164
rapid agroecological sampling, 288
rate effect, *Dacus frontalis*, 256, 258, *259*
recreational vehicle (RV) Park, 134, 136
Relative Sterility Index (RSI), 37
reproductive interference, 201, *205*
Rhagoletis zephyria (snowberry maggot), 31
Rosaceae, 109
Royal Tongalure bait, 142–143
Rutaceae, 109

S

Saccharopolyspora spinosa, 268
SACFF (South American cucurbit fruit fly), *see Anastrepha grandis* (South American cucurbit fruit fly)
SAFF (South American fruit fly), *see Anastrepha fraterculus* (South American fruit fly)
SAO (subdistrict administrative organization), 327
science, technology, engineering and mathematics (STEM), 385, *386*
SEL (Systematic Entomology Laboratory), 366
Serratia marcescens, 193
sexual behavior, 36–37
Sinaloa, 240, *241*
SIT, *see* sterile insect technique (SIT)
snowberry maggot (*Rhagoletis zephyria*), 31
SOMA, *see* systemic objective monitoring evaluation (SOMA)
South American cucurbit fruit fly (SACFF), *see Anastrepha grandis* (South American cucurbit fruit fly)
South American fruit fly (SAFF), *see Anastrepha fraterculus* (South American fruit fly)
Spinosad, 129, 131, 138
starter and finalizer larval diets, **227**
State Plant Protection Agency (SPPA), 308
STEM (science, technology, engineering and mathematics), 385, *386*
sterile flies, 181
sterile insect technique (SIT), 29, 142, 177, 201–203, 238, 327
Anastrepha fraterculus, 46
application, *204*
background/implementation area, 327
component, 330–331
desiccation resistant strains for, 35–38
IPM program, 328
sterile male releases/surveillance, 329
sterile interference, 201
sterile males competitivity, *182*
sterile-to-wild ratio, *330*, 331
sterility induction, 212, 214
strains
induced sterility, 179–180
male age effect, 179
Tap-7, *see* Tapachula-7 (Tap-7) strain
subdistrict administrative organization (SAO), 327
Systematic Entomology Laboratory (SEL), 366
systemic objective monitoring evaluation (SOMA), 396, *397*, 402, *404*

T

Tapachula-7 (Tap-7) strain, 178
in citrus orchards, 183–184, **184**
large-scale evaluation, *180*, 180–181
Tephritidae, 84
databases, 364, 366–367
fruit fly life cycle, 385
tephritid fruit flies, 16, 334
symposia, **374**
worldwide mass-rearing facilities, **380–382**
tephritid-related databases, 369
DIR-SIT, 379–382
IDCT, 376–378
IDIDAS, 375–376
methods, 370
overview, 370
TWD, 370–375
tephritids, desiccation resistance in, 27–28
adults, 31–33
body mass, *32*
body size, 34
cuticular lipids, 35
eggs and larvae, 30–31
lipid and water content, 34–35
lipid catabolism, 34–35
pupae, 31
taxonomic/life stage/life history coverage, 38
tephritid species, 206

Tephritid Workers Database (TWD), 370
distribution of, *373*
Facebook page, *372*
FFN e-newsletters, *372*
home page, *371*
top 25 countries, *373*
Tephri traps, 351
(Z)-14-tricosenyl formate, 3, 5, *6*
Trok Nong fruit fly control group, 327
Trok Nong subdistrict, *326*
Tuxaua, 403
TWD, *see* Tephritid Workers Database (TWD)

U

Uiramutã, location/aerial view, *400*
USDA-APHIS-PPQ, 364
Utetes anastrephae, **270**, 270–271, **273**

V

VEGEMITE, 387
Venturi-bubbling system, 194

W

waste brewery yeast (WBY), 141–142, 153
Bactrocera zonata and *Zeugodacus cucurbitae*, field cages for, 144, 150–151
bait, 156
water-holding capacity (WHC), 254
watermelon production, *310*
wax-based bait stations, 131–132
WBY, *see* waste brewery yeast (WBY)
West Indian fruit fly, *see Anastrepha obliqua* (West Indian fruit fly)
WHC (water-holding capacity), 254
World Trade Organization (WTO), 306
World-Wide Directory of Sit Facilities (DIR-SIT), 369, 379, *379*

Z

Zeugodacus cucurbitae (melon fly), 142
fly attraction, bait treatments for, **151**
relative attraction to bait, *146*, *147*