Fruit fly surveillance in Togo (West Africa): state of diversity and prevalence of species

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Abstract
The production and marketing of fruits, especially mango, in sub-Saharan Africa are threatened by fruit flies (Diptera: Tephritidae). This baseline study analysed the biodiversity of fruit fly species, in mango orchards, in different ecological zones of Togo. Traps used to monitor the flies in the orchards consisted of dry baits, made from four types of parapheromones specific to the males of different species. Forty species of fruit flies were identified in the mango orchards in Togo. The most common species were Bactrocera dorsalis (Hendel), Ceratitis cosyra (Walker), Ceratitis fasciventris (Bezzi), Ceratitis capitata (Wiedemann), Ceratitis bremii Guérin-Méneville, Dacus bivittatus (Bigot), Dacus humeralis (Bezzi), Dacus punctatitrons Karsch and Zeugodacus cucurbitae (Coquillett). The invasive B. dorsalis and the endogenous species, C. cosyra were dominant in the mango producing areas of Togo because their prevalence were very high (B. dorsalis: 2.1 ≤ flies per trap per day (FTD) ≤ 472.2; C. cosyra: 0.34 ≤ FTD ≤ 97.28). There was no area free from fruit flies in Togo during the study. These results constitute an essential reference in the future evaluation of the effectiveness of any control activities initiated in Togo against fruit flies.

Keywords Surveillance · Tephritidae · Bactrocera dorsalis · Ceratitis cosyra · Invasive exotic species · Togo

Introduction
The consumption of fruits and vegetables is at the core of a healthy diet (Amiot-Carlin et al. 2007; Griep et al. 2010; Zhang et al. 2011). Fruits and legumes are an important source of water, fiber, vitamins (A, B9, C, E), minerals (Calcium, phosphorus, Zinc, Iron, Selenium, Magnesium) and antioxidants necessary for the proper functioning of the body (Amiot-Carlin et al. 2007). The demand for healthy vegetable and fruit products is increasing in West Africa where consumers are increasingly purchasing expensive, good quality fruits and vegetables because of their nutritional importance (FAO and BAD 2015). Moreover, several exploratory and epidemiological studies have shown that high consumption of vegetables and fruits reduces the risk of cardiovascular diseases and the occurrence of some cancerous and other chronic diseases (Zhang et al. 2011; He et al. 2007; CIRAD 2009). To respond in part to the growing urban demand for fruits and vegetables, especially the diversification of diet as a source of welfare, West African countries are developing their horticultural sectors and production has more than doubled in 26 years, increasing from 14,403,034 tons in 1980 to 32,668,682 tons in 2008, with average growth rates of 1% and 1.7% for fruits and vegetables, respectively (FARM 2008). The production and trade in fruits and vegetables is an important income source for countries in general and those of sub-Saharan Africa in particular. In Togo, fruit and vegetable production is estimated at around 560,000 tons in 2017 (InterFaxPress 2019). Apart from their importance in food security, the production and trade in fruits and vegetables is an important income source for sub-Saharan African countries. Indeed, in 2017, the horticultural sector contributed an income of 4.5 billion
The study was carried out in mango orchards in Togo, West Africa. The study area extends from the South to the North of this country, between 06.35964°N and 10.99362°N and from East to West, between 000.31449°E and 001.29350°E. A total of twenty orchards were chosen based on their areas (minimum area of 2 ha); age (between 5 and 40 years); non-application of phytosanitary measures and all the varieties of mangoes identified (Fig. 1 and Table 1). The orchards are geographically located in two of the five West African mango producing belts recognized by the PLMF; one in the South (TG1) or wet area and the other in the North (TG2) or dry area. They are distributed in the five ecological zones of Togo described by Ern (1979) and Brunel (1984) as follows:

- the North-East, North-West, Center and South-East of ecological zone I (orchards TG2V4, TG2V5, TG2V7 and TG2V10) or the northern plains with Sudan-savannas, dry forests, meadows around ponds and agroforestry parks. The climate is Sudano-tropical type with a sin-
Fig. 1 Distribution of orchards under surveillance in ecological zones of Togo
gle rainy season (June-October) and a longer dry season
dominated by the harmattan (November–May). The aver-
age annual rainfall is around 1000 mm and the average
annual temperatures are generally high, reaching 28 °C
while relative humidity is low (53 to 67% RH);
– the North-East, Center and South of ecological zone
II (orchards TG₁V₅, TG₁V₆, TG₁V₁₀, TG₂V₂, TG₂V₃,
TG₂V₆, TG₂V₉, TG₂V₁₀) or part of the Northern mountains
dominated by a mosaic of dry forests, mountain savan-
nas and crop lands. The climate is a Sudano-Guinean
type with one rainy season (April–October) and one dry
season (November to March), including the harmattan.
The temperature and relative humidity are closed to those
of Zone I;
– the South-East, Center and North-East of ecological
zone III (orchards TG₁V₃, TG₁V₄, TG₂V₁) or the cen-
tral plains made of woody Guinea-savannas, dry forests,
cropped lands as well as forest galleries. The climate of
the area is lowland Guinea-type, with one rainy season
(April to October) and one dry season (November to
March). The average annual temperatures vary between
26 and 30 °C while the average annual rainfall is around
1200 mm;
– the South-west of ecological zone IV (orchard TG₁V₇)
or the southern section of “mount Togo” dominated by Semi-
deciduous rainforest, cropped lands and Guinea-savannas.
It is influenced by a transition subequatorial climate, that
is, a mountain climate characterized by one rainy sea-
son (March-November) and one dry season (December-
February) with decreased rainfall in August. The average
monthly temperatures varied between 22 and 26 °C during
the year, the annual average rainfall is around 1,651 mm
and the relative humidity is always high (70 to 99% RH);
– the North-West and West of ecological zone V (orchards
TG₁V₁, TG₁V₂, TG₁V₆, TG₁V₈) or the coastal plain of
Southern Togo characterized by Guinea-savannas, forest
patches, and cropped lands. Here there is a subequatorial
climate characterized by two rainy seasons (April-July
and September–October) alternating with two dry sea-
sons (August and November-March). Average monthly
temperatures vary between 25 and 28 °C during the year
and average annual rainfall is around 930 mm with a high
relative humidity throughout the year (73 to 90% RH).

### Design of the Fruit fly capture device

The fruit fly traps were made with the aid of monitor-
ing traps using a dry bait or parapheromone specific to
males: Tephri Trap of the McPhail type (IAEA 2003). The

| Table 1 Description of orchards for surveillance of fruit flies in Togo |
|-----------------|-----------------|--------------|-----------------|-----------------|
| **Orchard code** | **Location**     | **Orchard Age** | **Area** | **Mango varieties in the orchard** |
| TG₁V₁           | Folli Kopé (Badja) | 10 years      | 2 ha   | Pistolet, Somnole, Gouverneur, Smith, Eldon |
| TG₁V₂           | Agou Widalé     | 5 years       | 36 ha  | Somnole, Kent, Gouverneur, Pistolet, Palmer |
| TG₁V₃           | Sognokopé (Namgbéto) | 15 years | 2 ha   | Smith |
| TG₁V₄           | Agan (Est-Mono)  | 15 years      | 4 ha   | Somnole, Eldon, Smith |
| TG₁V₅           | Babadé (Sotouboua) | 23 years | 2.5 ha | Somnole, Kent, Davis, Palmer |
| TG₁V₆           | Fédémé (Badja)  | 10 years      | 2 ha   | Pistolet, Gouverneur, Papaye |
| TG₁V₇           | Agou Akplolo    | 40 years      | 3 ha   | Somnole, Palmer, Eldon, Smith, Kent, Hade, Bruce |
| TG₁V₈           | Adjakpa (Amoussoukopé) | 18 years | 3 ha   | Somnole, Kent, Gouverneur, Pistolet, Palmer, sensation |
| TG₁V₉           | Kériadé (Koumongou) | 26 years | 5 ha   | Eldon, Chinois |
| TG₁V₁₀          | Watchalo (Sotouboua ville) | 24 years | 2 ha   | Smith, Eldon, Palmer, Somnole, Gouverneur, Valencia, Aden, Davis, Bruce, Kent |
| TG₂V₁           | Sada (Tchaoudjo) | 15 years      | 25 ha  | Eldon, Smith, Kent |
| TG₂V₂           | Tagbadé (Assoli) | 10 years      | 4.5 ha | Eldon, Pistolet, Smith, Somnole |
| TG₂V₃           | Kpanzindé (Kozah) | 25 years | 3.5 ha | Smith, Bruce, Kent, Sensation |
| TG₂V₄           | Gando (Oti)     | 10 years      | 4 ha   | Pistolet, Smith, Gouverneur, etc |
| TG₂V₅           | Samloaga (Kpendjal) | 23 years | 2 ha   | Smith, Bruce, Kent, Sensation |
| TG₂V₆           | Pya (Akeyi)     | 40 years      | 3 ha   | Kent, Somnole |
| TG₂V₇           | Kanté (Até)     | 8 years       | 2 ha   | Pistolet, Gouverneur, Eldon, Kent, Palmer, Irwin |
| TG₂V₈           | Kassena (Tchaoudjo) | 18 years | 2 ha   | Maloula, Francis, Somnole, Palmer, Pistolet, Sprint Field, Kent, Davis |
| TG₂V₉           | Sagbadaï (Sokodé) | 18 years | 2.25 ha | Pistolet, Eldon, Gouverneur, Rubi, Kent, Somnole |
| TG₂V₁₀          | Dapaong        | 39 years      | 3 ha   | Gouverneur, Alphonse, Davis, Zaïre |

*TG₁ Mango producing area, 1; TG₂ Mango producing area, 2; V₁-V₁₀ Orchard 1 to 10*
parapheromones used have well known spectra (IAEA 2003; Vayssières et al. 2004; FAO 2014) and consist of: (i) Methyl Eugenol (ME) which attracts mainly males of Bactrocera spp. and species of the subgenus Ceratitis McLeay (Pardalaspis); (ii) Cue Lure (CUE) which attracts mainly males of several species of the genus Daucus and individuals of the Zeugodacus cucurbitae (Coquillett) species; (iii) Terpynn Acetatet (TA) and (iv) Trimedlure (TM) which attract males of the genus Ceratitis. An organophosphate chemical insecticide, DDVP or dichlorvos (2,2-dichlorovinyl dimethyl phosphate) was used to kill entrapped flies. The parapheromones were renewed every 6 weeks and the chemical insecticide every two months to maintain the effectiveness of the trap during the study period (Gomina et al. 2012). The traps were installed in the orchards from May 3 to June 8, 2018 according to the fruit fly monitoring system set up by the PLMF. In effect, a mango tree located at the center of each orchard was marked. Around this central point, 4 other mango trees forming a rhombus, with sides 100 m and having as center the previously identified central point were also marked. On 4 mango trees located around each of these 4 points forming the rhombus, 4 traps each containing a parapheromone were installed: Methyl Eugenol, Cuelure, Trimedlure and Terpineyl Acetate traps with North, South, East and West orientation respectively. Sixteen traps were installed per orchard, each with parapheromone, repeated 4 times. A total of 320 traps were installed for monitoring fruit flies in the selected 20 orchards. The traps were placed under the crown, shaded by leaves 2 m from the ground. They were inspected during a period of one month and 6 days started from 3rd May to 8th June 2018. The collection of the traps’ catches of fruit flies were carried out weekly from 25th May 2018. A total of 2 surveys were carried out in this period. Individuals of the Tephritidae species captured were stored per type of parapheromone and orchard in 70% ethanol and transported to the laboratory for identification.

**Identification of fruit flies**

The Tephritidae captured by each trap were sorted and identified at the Applied Entomology Laboratory (LEA) of the University of Lomé, using dichotomous keys (De Meyer 1996; De Meyer 2000; White 2006; De Mayer and White 2008; Virgilio et al. 2014) and identification key leaflets of the main fruit fly species in West Africa, provided by the PLMF. Also, comparisons with the reference collection of Tephritidae from LEA (samples of whose species have been confirmed by the entomology section of the Royal Museum for Central Africa (MRAC) in Tervuren in Belgium) were made to revise the identification.

**Data analysis**

The trapped fruit flies were counted by species, orchard and date of collection. The diversity of Tephritidae in orchards was expressed in terms of alpha diversity (α) and beta diversity (β). The calculations were done in R (R Core Team 2018) with the entropart package (Marcon and Hérault 2015).

The α diversity is the number of species coexisting in a uniform habitat of fixed size (Marcon 2015, 2018). It was determined by the species richness or number of species of fruit flies per orchard. The Simpson and Shannon–Wiener diversity index as well as the Pielou evenness index that often comes with the Shannon–Wiener index and Engen rarity variance (EVS) (Marcon 2018) were estimated on the basis of the Tephritidae samples from the catches. The Simpson Index (SI) measures the probability that two randomly selected individuals are of different species. It varies from 0 to 1, diversity is highest for SI close to 1 and lowest for SI close to 0. This diversity is also a decreasing function of the regularity of the species. Considered a measure of biodiversity as well as a quantitative measure, the Shannon–Wiener index (H ) varies from 0 (single species, or one species dominates all the others) to log2 (S) (all species have the same abundance) where S is the number of species. It is maximum when the frequencies of the species encountered show little difference between them. The Pielou evenness index (E) defines the regularity of the distribution of species and corresponds to the ratio of the Shannon index to its maximum value. It is close to 0 if the abundances of the species encountered are very dissimilar and close to 1 if all the species have similar abundance. The Engen rarity variance is the variance of the information function, Shannon’s entropy. The closer its value is to 0, the more equitable is the geographic area. The beta diversity measures the difference or similarity between habitats or samples in terms of species diversity. It permits comparison of the diversity between the communities and was estimated by the Jaccard index (J) between two orchards. The Jaccard index is 1 if there is complete similarity between the localities compared and 0 if the latter have no common species. A projection of the dissimilarity matrix from the Jaccard indexes on the first main coordinates made it possible to highlight similarities and dissimilarities between the orchards in terms of diversity of fruit flies using the R ade4 package (Bougeard and Dray 2018).

The analysis of the mean number and percentage of fruit fly species was performed using analysis of variance (ANOVA), followed by Student–Newman–Keuls (SNK) comparison tests when the value of F was significant at the 5% level.

The prevalence of the dominant fruit fly species was determined by calculating the number of flies per trap...
per day (FTD) according to IAEA (2003) and Rodríguez-Rodríguez et al. (Rodríguez-Rodríguez et al. 2018), applied in the case where no control measures were taken in the orchards considered. According to IAEA (2003), the value of FTD determines the type of phytosanitary measure to be considered in the implementation of international standards for phytosanitary measures:

- if FTD’ ≤ 1, the area is considered infested with fruit flies and requires the full complement of phytosanitary measures;
- if 0.1 ≤ FTD ≤ 1, the actions to be taken are suppressing the species of fruit fly;
- FDT < 0.1 calls for an eradication process applied in an area free from fruit flies;
- FTD = 0 calls for exclusion measures which are processes applied to minimize the risk of introducing or reintroducing the species in an area free from fruit flies. Trapping is applied to determine the presence of species that are subject to exclusion measures and confirms or rejects the status of a free zone.

Results

Alpha diversity

Species richness of fruit flies in the study area

A total of 40 species of Tephritidae were identified in the five ecological zones based on the trap catches using the four types of phytosanomone (Table 2). Under the study conditions, ecological zone II was the richest (36 species) while ecological zone I the poorest (10 species). Ecological zones III, IV and V recorded 25, 22 and 20 species respectively. The species identified belong to three subfamilies (Dacinae, Tephritinae and Trypetinae) and 7 genera (Bactrocera Macquart, Ceratitis McLeay, Celidodacus Hendel, Dacus Fabricius, Elaphomyia Bigot, Trirhithrum Bezzi and Zeugodacus Hendel). The subfamilies Tephritinae and Trypetinae were absent from ecological zones I, III, IV and V. The genera Ceratitis and Dacus were the most diverse in species with 17 and 14 species respectively. The other genera were represented by one species only. Four Tephritidae are yet to be precisely identified to the generic and species level.

The number of species caught per orchard varied from 4 (10% of the species) in the TG2V10 orchard to 26 (65% of the species) in TG2V2. The relatively more species-rich orchards were found in ecological zones II, III and IV. The majority of orchards, relatively poor in species were located above latitude 09° 30’ 0" N, in the north of Togo in the ecological zone I (Fig. 1).

Species diversity of Tephritidae

During the survey, an average total number of 19,506.45 individuals of Tephritidae were caught per orchard, all species combined. Out of this total number of fruit flies, B. dorsalis represented in average 88.81% (17,546.50 individuals per orchard) and C. cosyra, 8.10% (1,598.95 individuals per orchard) (Table 3). The remaining 38 species represented only 3.09% of the population of fruit flies per orchard (361 individuals per orchard). Whether in zone 1 or zone 2, the mean numbers and proportions of B. dorsalis and C. cosyra in the mango orchards were still higher than other fruit fly species numbers (Table 3).

Analysis of the species diversity of Tephritidae showed that the Simpson diversity indexes from the different orchards were generally low, indicating a low diversity of species (Table 4). These results are confirmed by the low values of the Shannon–Wiener diversity indexes which are well below the maximum value (Hmax). The Pielou evenness index with relatively very low values correspond to orchards TG1V6, TG1V10 and TG2V9 (Ecological Zone II) and TG2V5 (Ecological Zone I). The weak Simpson index from these orchards indicated that they had a low regularity of occurrence of the species. The distribution of species in these orchards was marked by the dominance of the B. dorsalis species.

Computation of the Engen rarity variance showed that orchards TG1V2 and TG1V1 present the most homogeneous sample distribution, while orchards TG2V5 (lower species richness) and TG2V10 show the greatest disparities marked by an unequal distribution of probabilities and low species richness.

Beta diversity

Species community analysis of the Tephritidae species showed that several orchards at the study site had similar species because, the Jaccard index was higher than 0.50 (Table 5). The highest similarity was observed between orchards TG1V2 and TG2V9, TG1V7 and TG1V9; TG1V2 and TG1V6, with Jaccard indexes estimated at 0.94, 0.87 and 0.84, respectively. Orchards TG1V7 and TG2V4, TG1V9 and TG2V4 were those in which very low similar species were recorded, with a Jaccard index of 0.13 each.

Bactrocera dorsalis, C. cosyra and F. fasciventris were the three Tephritidae species that were present in all the orchards studied (Table 1). They are followed by C. capitata, D. humeralis and D. punctatiprons which were present in 16 orchards and C. bremii, D. bivittatus and Z. cucurbitae which were trapped in 15 orchards.
Table 2 Presence of the Tephritidae species in different mango orchards in Togo*

| Species                      | TG1V1 | TG1V2 | TG1V3 | TG1V4 | TG1V5 | TG1V6 | TG1V7 | TG1V8 | TG1V9 | TG1V10 | TG2V1 | TG2V2 | TG2V3 | TG2V4 | TG2V5 | TG2V6 | TG2V7 | TG2V8 | TG2V9 | TG2V10 |
|------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Bactrocera dorsalis (Hendel) | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     |
| Celidodacus sp.              | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     |
| Ceratitis anonae Graham      | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     |
| Ceratitis bremii Guérin-     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     |
| Méneville                    | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     |
| Ceratitis capitata (Wiedem-  | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     |
| ann)                         |       |       |       |       |       |       |       |       |       |         |       |       |       |       |       |       |       |       |       |         |       |
| Ceratitis colae Silvestri    | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     |
| Ceratitis cosyna (Walker)    | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     |
| Ceratitis ditissima (Muro)   | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     |
| Ceratitis fasciventris (Bezzi)| ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     |
| Ceratitis flav Meyer & Freud- | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     |
| berg                         |       |       |       |       |       |       |       |       |       |         |       |       |       |       |       |       |       |       |       |         |       |
| Ceratitis flexuososa Walker  | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     |
| Ceratitis penicillata Bigot  | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     |
| Ceratitis punctata (Wiedem-  | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     |
| ann)                         |       |       |       |       |       |       |       |       |       |         |       |       |       |       |       |       |       |       |       |         |       |
| Ceratitis quisnaria Bezzi    | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     |
| Ceratitis silvestrii Bezzi  | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     |
| Ceratitis sp1                | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     |
| Ceratitis sp2                | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     |
| Ceratitis sp3                | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     |
| Ceratitis sp4                | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     |
| Dacus armatus Fabricius      | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×     | ×      | ×     |
Table 2 (continued)

| Species | TG1V1 | TG1V2 | TG1V3 | TG1V4 | TG1V5 | TG1V6 | TG1V7 | TG1V8 | TG1V9 | TG1V10 | TG2V1 | TG2V2 | TG2V3 | TG2V4 | TG2V5 | TG2V6 | TG2V7 | TG2V8 | TG2V9 | TG2V10 |
|---------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|
| *Dacus bivittatus* (Bigot) | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| *Dacus diastatus* Munro | | | | | | | | | | | | | | | | | | | | |
| *Dacus fuscovittatus* Graham | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| *Dacus humeralis* (Bezzi) | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| *Dacus langi Curran* | | | | | | | | | | | | | | | | | | | | x |
| *Dacus mediovitatus* White | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| *Dacus punctatiformis* Karsch | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| *Dacus theophrastus* Hering | | | | | | | | | | | | | | | | | | | | x | x | x |
| *Dacus guineensis* Hering | | | | | | | | | | | | | | | | | | | | x | x | x |
| *Dacus vertebra tus* Bezzi | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| *Dacus annulatus* Becker | | | | | | | | | | | | | | | | | | | | x | x | x |
| *Dacus disjunctus* (Bezzi) | | | | | | | | | | | | | | | | | | | | x |
| *Dacus seguyi* (Munro) | | | | | | | | | | | | | | | | | | | | x |
| *Elaphomyia* sp. | | | | | | | | | | | | | | | | | | | | x | x | x |
| Tephritidae1 | | | | | | | | | | | | | | | | | | | | x | x | x |
| Tephritidae2 | | | | | | | | | | | | | | | | | | | | x | x | x |
| Tephritidae3 | | | | | | | | | | | | | | | | | | | | x | x | x |
| Tephritidae4 | | | | | | | | | | | | | | | | | | | | x | x | x |
| Tetrathyrum spl | | | | | | | | | | | | | | | | | | | | x | x | x |
| *Zeugodacus cucurbitae* (Coquillett) | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |

Species richness 12 18 16 19 17 18 22 16 21 21 24 26 21 5 6 8 8 22 16 4

TG1 Mango producing area, 1; TG2 Mango producing area, 2; V1-V10 Orchard 1 to 10; x Presence of the species
The uncommon species that were present in only one orchard were *C. colae* (TG1G1), *C. flexuosa* (TG1G10), *Ceratitis* sp 3 (TG2V2), *D. annulatus* (TG2V1), *Dacus disjunctus* (Bezzi) (TG2V5), *Dacus seguyi* (Munro) (TG2V2) and unidentified Tephritidae 2, 3 and 4 that were recorded in orchards TG2V3, TG2V2, respectively.

The representation of the orchards in the different zones in a principal coordinate analysis based on the Jaccard distances allowed to better group the orchards having similar species (Fig. 2). Four main groups of orchards were identified:

- group 1 comprised orchards TG1V4, TG1V5, TG2V1, TG2V2, TG2V3, TG2V8 and TG2V9 that had more than half of the species similar;
- group 2 are orchards TG1V1, TG1V8, TG1V2, TG1V6, which also had more than half of the species similar;
- group 3 includes orchards TG1V3, TG1V7 and TG1V9 which were similar; and
- group 4: orchards TG2V4, TG2V6 and TG2V7;

Orchards TG2V5, TG2V10 and TG1V10 were not well represented in the projection made.

### Species prevalence

Based on species diversity, *B. dorsalis* and *C. cosyra* were common to all the mango orchards in the study area and singly represented 98.15% of the Tephritidae. Indeed, the number of flies per trap per day (FTD) of *B. dorsalis* was the highest in all the orchards and varies from 2.12 (TG2V4) to 472.1 (TG1V7) (Fig. 3). The prevalence of *C. cosyra* was lower and ranged between 0.34 (TG2V4) and 97.28 (TG1V4).

### Discussion

The trap-capture method used in this study made it possible to record 40 species of Tephritidae, 11 of which were not be identified up to species level. Those identified represent 77%
of the species reported in Togo and 34.2% of those in West Africa (De Meyer 2005; De Meyer et al. 2013). The flies identified up to species level were those of the Dacinae sub-family reported in Togo and other countries of the afrotropical region (Amevoïn 2009; Ouédraogo et al. 2011; Gomina et al. 2012; De Meyer et al. 2013; N’Da 2018; Zida et al. 2020). The relatively high species richness obtained with a single study method applied over a month is an evidence that the species found in the mango orchards (which were at fruit ripening stage) and their surrounding vegetation, a favorable abiotic (temperature, relative humidity, precipitation, etc.) and biotic (resting sites, host plants) conditions for their development (Virgilio et al. 2009; Goergen et al. 2011, Bota et al. 2020). These may explain the diversification in species of the two main genera *Ceratitis* and *Dacus*. Indeed, Vayssières et al. (2010) and Gomina (2015) reported the presence of the host plants of several Tephritidae species identified in this study. The highest species richness was observed in the ecological zones II, III (at the level of the latitude of Sokodé and Bafilo) and IV. This can be explained not only by the diversification level of wild host plants but especially by the fruit trees cultivated in these areas. In fact, the zones II, III and IV are considered in Togo as major fruit producing regions, which is not the case for the ecological zone I in the Northern part of the country where the diversity of host plants may be lower, probably because of the less favorable ecological and climatic conditions. Similar study conducted by Bota et al. (2020) also showed that the population of fruit flies that infest mango orchards in the central Mozambique may come from the marginal area, especially from local varieties of mango which get matured earlier. Among the species of Tephritidae identified in mango orchards in Togo, *B. dorsalis*, *C. cosyra*, *C. capitata*, *C. fasciventris*, *C. silvestrii*, *C. anonae*, *C. quinaria*, and *C. ditisimae* are known to be associated with various fruit plant species in Africa (Vayssières et al. 2004; White and Elson-Harris 1992; Vayssières et al. 2009a, b; Nboyine et al. 2013; Vayssières et al. 2015; Zida et al. 2020). According to Vayssières et al. (2015) the presence of several fruit fly species on mango has considerably reduced the potential economic benefits of growing this fruit tree in West Africa. As for the Tephritidae species of the genera *Dacus* and *Zeugodacus*, they are known to attack mostly plant species belong to *Cucurbitaceae*, *Passifloraceae* and *Apocynaceae* (White 2006; Virgilio et al. 2009). In general, the mango fruit flies identified during our study are native, except of *B. dorsalis* and *Z. cucurbitae* reported as exotic and invasive (Goergen et al. 2011; De Meyer et al. 2013).

The very high proportions and prevalence of *B. dorsalis* in all the mango orchards in Togo is an evidence that this invasive species has settled in Togo and has undoubtedly constituted a threat to mango and other fruits production.

| Orchardcode* | Simpson diversity index (D) | Shannon Wiener diversity index (H') | Maximum diversity (Hmax) | Pielou evenness index (E) | Engen rarity variance (EVS) |
|--------------|-----------------------------|------------------------------------|--------------------------|--------------------------|---------------------------|
| TG1V1        | 0.122                       | 0.503                              | 3.584                    | 0.140                    | 2.596                     |
| TG1V2        | 0.158                       | 0.690                              | 4.169                    | 0.165                    | 3.661                     |
| TG1V3        | 0.183                       | 0.761                              | 4.000                    | 0.190                    | 3.630                     |
| TG1V4        | 0.382                       | 0.882                              | 4.247                    | 0.216                    | 1.092                     |
| TG1V5        | 0.104                       | 0.342                              | 4.087                    | 0.084                    | 1.337                     |
| TG1V6        | 0.215                       | 0.844                              | 4.169                    | 0.206                    | 3.628                     |
| TG1V7        | 0.131                       | 0.502                              | 4.59                    | 0.113                    | 2.344                     |
| TG1V8        | 0.100                       | 0.439                              | 4.000                    | 0.112                    | 2.536                     |
| TG1V9        | 0.089                       | 0.349                              | 4.392                    | 0.079                    | 1.776                     |
| TG1V10       | 0.070                       | 0.269                              | 4.392                    | 0.061                    | 1.399                     |
| TG2V1        | 0.202                       | 0.572                              | 4.584                    | 0.125                    | 1.550                     |
| TG2V2        | 0.182                       | 0.599                              | 4.700                    | 0.127                    | 2.244                     |
| TG2V3        | 0.448                       | 1.135                              | 4.392                    | 0.258                    | 1.642                     |
| TG2V4        | 0.396                       | 1.133                              | 2.321                    | 0.488                    | 2.036                     |
| TG2V5        | 0.047                       | 0.179                              | 2.584                    | 0.069                    | 0.882                     |
| TG2V6        | 0.284                       | 0.806                              | 3.000                    | 0.269                    | 1.958                     |
| TG2V7        | 0.546                       | 1.366                              | 3.000                    | 0.455                    | 1.560                     |
| TG2V8        | 0.171                       | 0.513                              | 4.459                    | 0.115                    | 1.642                     |
| TG2V9        | 0.092                       | 0.328                              | 4.000                    | 0.082                    | 1.478                     |
| TG2V10       | 0.207                       | 0.540                              | 2.00                     | 0.270                    | 1.079                     |

*TG1*: Mango producing area 1; *TG2*: Mango producing area 2; *V1*-V10: Orchard 1 to 10
Table 5 Jaccard indices from the different mango orchards in the study area

|       | TG1V1 | TG1V2 | TG1V3 | TG1V4 | TG1V5 | TG1V6 | TG1V7 | TG1V8 | TG1V9 | TG2V1 | TG2V10 | TG2V2 | TG2V3 | TG2V4 | TG2V5 | TG2V6 | TG2V7 | TG2V8 | TG2V9 |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|-------|-------|-------|-------|-------|-------|-------|-------|
| TG1V1 | 0.43  | 0.58  | 0.56  | 0.45  | 0.45  | 0.71  | 0.48  | 0.69  | 0.50  | 0.44  | 0.23   | 0.27  | 0.38  | 0.21  | 0.38  | 0.25  | 0.18  | 0.42  | 0.47  |
| TG1V10| 0.56  | 0.61  | 0.58  | 0.73  | 0.58  | 0.65  | 0.50  | 0.68  | 0.67  | 0.19  | 0.62   | 0.62  | 0.18  | 0.29  | 0.32  | 0.32  | 0.79  | 0.68  |
| TG1V2 | 0.70  | 0.40  | 0.46  | 0.84  | 0.74  | 0.74  | 0.70  | 0.45  | 0.16  | 0.38  | 0.34   | 0.15  | 0.26  | 0.24  | 0.18  | 0.48  | 0.48  |
| TG1V3 | 0.79  | 0.56  | 0.45  | 0.58  | 0.71  | 0.24  | 0.43  | 0.58  | 0.29  | 0.35  | 0.47   | 0.47  | 0.63  | 0.74  |
| TG1V4 | 0.42  | 0.56  | 0.45  | 0.58  | 0.71  | 0.24  | 0.43  | 0.58  | 0.29  | 0.35  | 0.47   | 0.47  | 0.77  | 0.94  |
| TG1V5 | 0.63  | 0.78  | 0.65  | 0.46  | 0.17  | 0.39  | 0.41  | 0.16  | 0.28  | 0.25  | 0.19   | 0.50  | 0.66  |
| TG1V6 | 0.61  | 0.87  | 0.59  | 0.18  | 0.45  | 0.43  | 0.13  | 0.27  | 0.25  | 0.20  | 0.57   | 0.58  |
| TG1V7 | 0.64  | 0.44  | 0.19  | 0.32  | 0.44  | 0.18  | 0.31  | 0.28  | 0.21  | 0.48  | 0.48   |
| TG1V8 | 0.61  | 0.19  | 0.47  | 0.45  | 0.13  | 0.29  | 0.26  | 0.21  | 0.59  | 0.61  |
| TG1V9 | 0.17  | 0.56  | 0.67  | 0.21  | 0.25  | 0.33  | 0.33  | 0.77  | 0.67  |
| TG2V1 | 0.15  | 0.19  | 0.50  | 0.67  | 0.50  | 0.50  | 0.18  | 0.25  |
| TG2V2 | 0.62  | 0.19  | 0.19  | 0.31  | 0.31  | 0.66  | 0.50  |
| TG2V3 | 0.24  | 0.29  | 0.38  | 0.38  | 0.65  | 0.61  |
| TG2V4 | 0.38  | 0.63  | 0.63  | 0.23  | 0.31  |
| TG2V5 | 0.40  | 0.40  | 0.27  | 0.38  |
| TG2V6 | 0.78  | 0.36  | 0.50  |
| TG2V7 | 0.36  | 0.41  |
| TG2V8 | 0.73  |

Index of the orchards hosting the greatest number of common species
This result confirms the economic importance of *B. dorsalis* reported in several African countries (Bota et al. 2018, 2020; N’Da 2018; Zida et al. 2020). The high proportion and prevalence of *B. dorsalis* in mango orchards do not seem to be explained solely by the effectiveness of the attractant used for this species but mainly by its very good adaptation to the agro-ecological conditions of the study area. In addition to being polyphagous, Gomina (2015) has shown that under the Guinea zone conditions in Togo, *B. dorsalis* was very prolific because the female could lay an average of 538 eggs during its life time with an offspring survival rate estimated at 67%. *C. cosyra* is the second most important species to which special attention must be paid in Togo and in West Africa (Ouédraogo et al. 2011; Zida et al. 2020). This species was considered as adapted to Sahelian and Sudanese zones and absent from agro-ecological zones of the humid forests of West Africa (Vayssières et al. 2014). However, it was found in all ecological zones of the study area in Togo including zone IV dominated by dense semi-deciduous forests. The presence of *C. cosyra* in the humid forest zone in Togo is probably due to human activities which negatively impact ecological zone IV and climate change with its proven consequences in recent years.

The species richness of Tephritidae frugivores in Togo seems to be important but the different diversity indexes pointed out a low species diversity. This helps to note that the potential species diversity in Tephritidae should be high. This result is in line with the work of De Meyer et al. (2013). Thus, the application of other methods such as the incubation of fruits from different ecological zones and the use of other attractants will probably make it possible to accurately record all species present in Togo.

Analysis of the Tephritidae community from the catches shows that several fruit fly species that attack the mango orchards studied were similar. The Jaccard distances analysis showed that orchards in the same ecological zone tend...
to be similar in terms of the fruit fly species present. This result may indicate the homogeneity of the abiotic and biotic conditions (the vegetation in particular represented by the host plants cultivated inside the orchard but also by the wild host plants around the latter) in the same zone allowing the species of Tephritidae to find the same resources for their survival and development. This result is similar to the one of Ouédraogo et al. (2011). The most common and wide-ranging species in our study area were B. dorsalis, C. cosyra, C. fasciventris, C. capitata, D. humeralis and D. punctatifrons, C. bremii, D. bivittatus and Z. cucurbitae. These species are known to be well represented in West Africa (Gomina et al. 2012; De Meyer et al. 2013; Ouédraogo et al. 2011; Vayssières et al. 2015). The species C. colae, C. flexuosa, Ceratitis sp and some species of the genus Dacus that were not be identified up to the species level were present in a single orchard and can probably be considered as being rare in the area but, monitoring over a long period will make it possible to confirm their status.

The prevalence of the two species considered dominant in terms of number of flies per trap per day (FTD) is very high and therefore indicates that all the orchards studied have very high incidence of B. dorsalis and C. cosyra. Thus, they remain the species of economic importance in Togo. According to the recommendations of IAEA (2003), this result indicates that it is necessary to implement phytosanitary protection actions against these formidable species of fruit flies.

Fig. 3 Prevalence variation of the two major fruit fly species in the mango orchards during the first month of monitoring

Conclusion

This study confirms that there is no area that is free from fruit flies in Togo. A total of 40 species of fruit flies were identified in the surveyed mango orchards that were at fruit maturation period. The diversity indexes estimated in this study show that species other than those reported in the study could be present. The most common species are B. dorsalis, C. cosyra, C. fasciventris, C. capitata, D. humeralis and D. punctatifrons, C. bremii, D. bivittatus and Z. cucurbitae. The most abundant of these are the invasive B. dorsalis and the endogenous C. cosyra which have a very high prevalence. Hence, it is essential to determine, in all agro-ecological zones, the economic thresholds of these most abundant fruit flies (B. dorsalis and C. cosyra) of the economically important fruits and vegetables. This will lead to the establishment of a sustainable fruit flies management program in Togo.

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Data Availability All data are available and insect specimens are conserved in laboratory.

Declarations

Conflicts of interest The authors declare no conflict of interest.

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