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

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Abstract: The study established a baseline situation of fruit fly species (Diptera: Tephritidae), using biodiversity analysis in mango orchards scattered in different ecological zones from the South to the North of Togo in West Africa. The fruit fly capture device consisted of orchard monitoring traps using a dry bait, made of four types of parapheromones specific to the males of the species of fruit flies. The sorting and identification of fruit fly species were carried out in the laboratory using a binocular microscope, identification keys and reference collections. Forty species of fruit flies were identified in 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 punctatifrons* Karsch and *Zeugodacus cucurbitae* (Coquillett). The invasive exotic species *B. dorsalis* and the endogenous species, *C. cosyra* were dominant in the mango producing areas of Togo because, they had very high prevalence (*B. dorsalis*: $2.1 \leq FTD \leq 472.2$; *C. cosyra* $0.34 \leq FTD \leq 97.28$). There was no area free from fruit flies in Togo at the moment of the study. These results constitute an essential reference in the future evaluation of the effectiveness of control activities initiated in Togo against fruit flies.

Key-words: - Surveillance, fruit flies, *Bactrocera dorsalis*, *Ceratitis cosyra*, invasive exotic species, Togo

1 Introduction

The consumption of fruits and vegetables is at the core of a healthy diet [1, 2, 3]. 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 [1]. Because of their nutritional importance, the demand for healthy vegetable and fruit products is increasing in West Africa where consumers are increasingly purchasing expensive, good quality fruits and vegetables [4]. 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 [3, 5, 6]. 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 tonnes in 1980 to 32,668,682 tonnes in 2008, with average growth rates of 1% and 1.7% for fruits and vegetables, respectively [7]. In Togo, fruit and vegetable production is estimated at around 560,000 tonnes in 2017, 66% of which are mangoes [8]. Apart from their importance in food security, 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. Indeed, in 2017, the horticultural sector contributed an income of 4.5 billion FCFA to the national economy of Togo, with 30,265 tonnes exported [8]. Given its importance, the fruit and vegetable sector is one of the key agricultural sectors targeted for promotion in Togo's National Development Plan (PND). Unfortunately, horticultural production and trade are threatened by pests affecting the implementation of the horticultural sector's development policies. Among the fruit and vegetable pests noted are insects, especially fruit flies (Diptera: Tephritidae) that have the most economic importance. The losses attributed to fruit flies in sub-Saharan Africa have been increasing in recent years because, in addition to the indigenous species like *Ceratitis cosyra* (Walker) (Diptera: Tephritidae) which attack fruits and reduce their nutritional and trade values, a new species, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) first detected in Kenya in 2003, was introduced from Southeast Asia [9, 10]. In a few years, this species has spread throughout West Africa [11], as an invasive species. *B. dorsalis* is economically very important because it has found in West Africa, a favorable ecological niche for its development, in particular a suitable climate and other preferred host plants [12, 13, 14]. Being the main species associated with the mango, *B. dorsalis* and *C. cosyra* are the major constraints on mango production and trade today. Mango losses caused by these major pests are estimated at 17% at the beginning of the harvest period and can exceed 70% at the end of the period [15]. As fruit flies are classified as "quarantine insects", any container from Africa containing perforated fruits is intercepted, seized and destroyed by incineration at ports and airports in Europe, causing serious economic damage to African exporters [9, 16]. Between 2006 and 2007, interceptions associated with fruit flies increased by 23% and the annual economic losses were estimated at more than USD 42 million in Africa and more than one USD 1.0 billion worldwide [17]. For West Africa, interceptions related to fruit flies at the EU border, cost around € 9,000,000 in mango exports in 2006 [18].

In order to reduce the level of fruit fly infestations under Economic Injury Level (E.I.L.) in orchards and also, to avoid interceptions of fruits and vegetables in general and mangoes in particular (from ECOWAS countries) the European Union countries and eleven ECOWAS countries (Benin, Ivory Coast, Burkina Faso, Gambia, Ghana, Guinea Conakry, Mali, Nigeria, Senegal, Togo) have decided to combine their efforts to control fruit flies. ECOWAS has therefore initiated a sub-regional project entitled "Project to support the regional plan for the control of fruit flies in West Africa (PLMF)". Its general objective is to substantially increase fruit and vegetable producers' incomes (especially smallholders), to contribute to food security and poverty reduction in the sub-region. One of the most important components of this project is the accurate monitoring of fruit fly populations for early warning and adequate decision-making for controlling the pests in the interest of farmers.

The study aimed to: (i) present the state of diversity of fruit fly species in different mango production areas in Togo and (ii) point out the boundaries of the areas considered to be infested or free from fruit flies by assessing the prevalence of species at the beginning of the project. This was fundamental to developing accurate management methods, targeting the dominant fruit fly species in the agro-ecosystems or mango producing areas in Togo, and gathering a reference database to facilitate future assessment of the effectiveness of management activities implemented in the country.

2 Material and methods

2.1 Study area: geographic location, ecological characteristics and choice of the orchards

The study was carried out in mango orchards in Togo, West Africa. The study area extends from the South to the North of Togo, 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 (TG_1) or wet area and the other in the North (TG_2) or dry area. They are distributed in the five ecological zones of Togo described by Ern [19] and Brunel [20] as follows:

- the North-East, North-West, Center and South-East of ecological zone I (orchards TG_2V_4, TG_2V_5, TG_2V_7 and TG_2V_{10}) or the northern plains with Sudan-savannas, dry forests, meadows around ponds and agroforestry parks. The climate is Sudano-tropical type with a single rainy season (June-October) and a longer dry season dominated by the harmattan (November-May). The average 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 TG_1V_5, TG_1V_9, TG_1V_{10}, TG_2V_2, TG_2V_3, TG_2V_6, TG_2V_8, TG_2V_9) or part of the Northern mountains dominated by a mosaic of dry forests, mountain savannas 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 TG_1V_3, TG_1V_4, TG_2V_1,) or the central 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 TG_1V_7) 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 season (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 TG_1V_1, TG_1V_2, TG_1V_6, TG_1V_8) 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 seasons (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).

2.2 Design of the Fruit fly capture device

The fruit fly traps were made with the aid of monitoring traps using a dry bait or parapheromone specific to males: Tephri Trap of the McPhail type [21]. The parapheromones used have well known spectra [21, 22, 23] 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 *Dacus* and individuals of the *Zeugodacus cucurbitae* (Coquillett) species; (iii) Terpinyl Acetate (TA) and 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 [24]. The traps were installed in the orchards from May 3 to 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, Tridmedlure and Terpinyl 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 (May 3 to June 8, 2018). Trap surveys were carried out weekly from May 25, 2018. Individuals of the

Tephritidae species captured were kept per type of parapheromone and orchard in 70° ethanol and brought to the laboratory for identification.

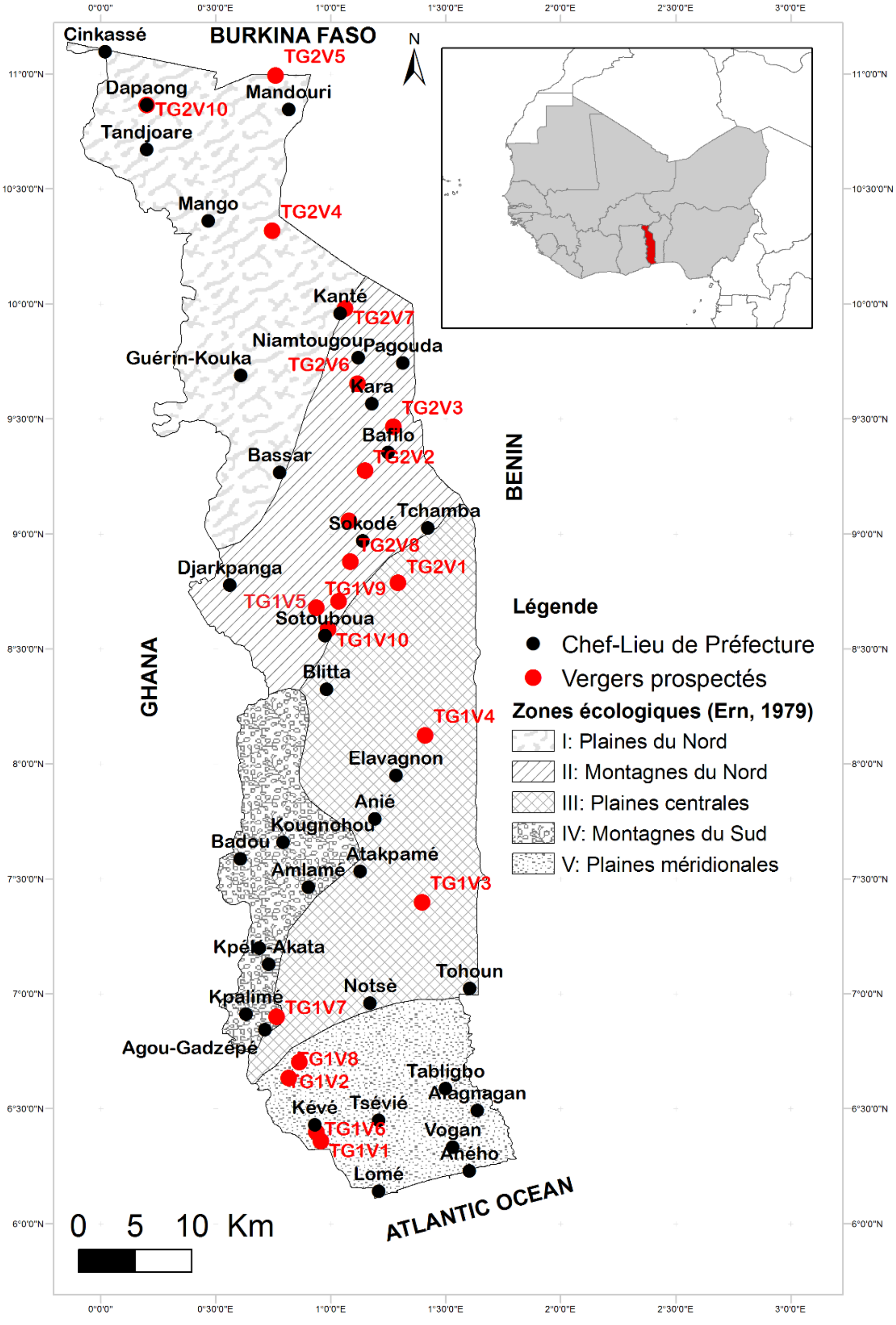

Fig. 1: Distribution of orchards under surveillance in ecological zones of Togo

Table 1**:** Description of orchards for surveillance of fruit flies in Togo

Orchard code*	Location (Village or Town)	Orchard Age (years)	Area (ha)	Mango varieties in the orchard
TG_1V_1	Folli Kopé (Badja)	10	2	Pistolet, Somnole, Gouverneur, Smith, Eldon
TG_1V_2	Agou Wudralé	5	36	Somnole, Kent, Gouverneur, Pistolet, Palmer
TG_1V_3	Sognokopé (Namgbéto)	15	2	Smith
TG_1V_4	Agan (Est-Mono)	15	4	Somnole, Eldon, Smith
TG_1V_5	Babadè (Sotouboua)	23	2,5	Somnole, Kent, Davis, Palmer
TG_1V_6	Fédémé (Badja)	10	2	Pistolet, Gouverneur, Papaye.
TG_1V_7	Agou Akplolo	40	3	Somnole, Palmer, Eldon, Smith, Kent, Hade, Bruce
TG_1V_8	Adjakpa (Amoussoukopé)	18	3	Somnole, Kent, Gouverneur, Pistolet, Palmer, sensation
TG_1V_9	Kériadè (Koumongou)	26	5	Eldon, Chinois
TG_1V_{10}	Watchalo (Sotouboua ville)	24	2	Smith, Eldon, Palmer, Somnole, Gouverneur, Valencia, Aden, Davis, Bruce, Kent
TG_2V_1	Sada (Tchaoudjo)	15	25	Eldon, Smith, Kent
TG_2V_2	Tagbadè (Assoli)	10	4,5	Eldon, Pistolet, Smith, Somnole
TG_2V_3	Kpanzindè (Kozah)	25	3,5	Smith, Bruce, Kent, Sensation
TG_2V_4	Gando (Oti)	10	4	Pistolet, Smith, Gouverneur, etc.
TG_2V_5	Samloaga (Kpendjal)	23	2	Smith, Bruce, Kent, Sensation
TG_2V_6	Pya (Akeyi)	40	3	Kent, Somnole
TG_2V_7	Kanté (Atè)	8	2	Pistolet, Gouverneur, Eldon, Kent, Palmer, Irwin
TG_2V_8	Kassena (Tchaoudjo)	18	2	Maloula, Francis, Somnole, Palmer, Pistolet, Sprint Field, Kent, Davis
TG_2V_9	Sagbadaï (Sokodé)	18	2,25	Pistolet, Eldon, Gouverneur, Rubi, Kent, Somnole
TG_2V_{10}	Dapaong	39	3	Gouverneur, Alphonse, Davis, Zaïre

*TG_1: Mango producing area 1; TG_2: Mango producing area 2; V_1-V_{10}: Orchard 1 to 10

2.3 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 [25, 26, 27, 28, 29] 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 refine the identification.

2.4 Data analysis

The trapped fruit flies were counted by species, date of collection and by orchard, averages and proportions were calculated using Microsoft Office Excel, version 2019. The diversity of Tephritidae in orchards was expressed in terms of alpha diversity (α) and beta diversity (β). The calculations were done in R [30] with the entropart package [31].

The α diversity is the number of species coexisting in a uniform habitat of fixed size [32, 33]. It was determined by the specific 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) [33] 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 specific 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 [34].
The prevalence of the dominant fruit fly species was determined by calculating the number of flies per trap per day (FTD) according to IAEA [21] and Rodríguez-Rodríguez et al. [35], applied in the case where no control measures were taken in the orchards considered. According to [21], 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 $0.1 \leq FDT \leq 1$, 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.

3 Results

3.1 Alpha diversity

3.1.1 Specific 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 parapheromone (Appendix 1). 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 have 25, 22 and 20 species respectively. The identified species belong to three subfamilies (Dacinae, Tephritinae and Trypetinae) and 7 genera (*Bactrocera* Macquart, *Ceratitis* McLeay, *Celidodacus* Hendel, *Dacus* Fabricius, *Elaphromyia* Bigot, *Trirhithrum* Bezzi and *Zeugodacus* Hendel). The subfamilies Tephritinae and Trypetinae appear to be absent from ecological zones I, III, IV and V. The genera *Ceratitis* and *Dacus* are the most diverse in species with 17 and 14 species respectively. The other genera are represented by one species only. Four Tephritidae remain to be identified precisely down to the generic and specific level.
The number of species caught per orchard varies from 4 (10% of the species) in the TG_2V_{10} orchard to 26 (65% of the species) in TG_2V_2. The relatively more species-rich orchards are found in ecological zones II, III and IV. The majority of orchards, relatively poor in species are located above latitude 09° 30’, in the north of Togo in ecological zone I (Fig. 1).

3.1.2 Specific diversity of Tephritidae

After the first month of capture, a total of 390,129 individuals of Tephritidae, all species combined, were captured in 320 parapheromone traps placed in 20 orchards in the study area. Of the 390,129 individuals, *B. dorsalis* and *C. cosyra* represented 89.95% (350,930 individuals) and 8.20% (31,979 individuals), respectively. The remaining 38 species represent only 1.85% (7280 individuals) of the population (Table 3). In all the mango orchards studied, *B. dorsalis* is the dominant species with a percentage varying from 41.4 to 97.6% compared to 1.9% to 15.9% for *C. cosyra*.

Analysis of the specific diversity of Tephritidae showed that the Simpson diversity indices 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 indices which are well below the maximum value (Hmax). The Pielou evenness index with relatively very low values correspond to orchards TG_1V_9, TG_1V_{10} and TG_2V_9 (Ecological Zone II) and TG_2V_5 (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.

Consideration of the Engen rarity variance allows to realise on the one hand that orchards TG_1V_2 and TG_1V_3 present the most homogeneous sample distribution and on the other hand, orchards TG_2V_5 (lower specific richness) and TG_2V_{10} show the greatest disparities marked by an unequal distribution of probabilities and low specific richness.

Table 3: Cumulative number and proportion of species of the most common and abundant Tephritidae caught in different mango producing areas.

Species	Number (% per zone)			% individuals
	Zone 1	Zone 2	Total	
B. dorsalis	210694(90,3)	140236 (89,4)	350930	89,95
C. cosyra	17666 (7,6)	14313 (9,13)	31979	8,20
D. armatus	1764 (0,76)	12 (0,01)	1776	0,46
D. humeralis	1134 (0,49)	631 (0,40)	1765	0,45
C. fasciventris	168 (0,07)	977 (0,62)	1145	0,29
C. capitata	453 (0,19)	69 (0,04)	522	0,13
D. bivittatus	387 (0,17)	92 (0,06)	479	0,12
D. theophratus	217 (0,09)	21 (0,01)	238	0,06
Z. cucurbitae	140 (0,06)	40 (0,03)	180	0,05
C. silvestrii	40 (0,02)	96 (0,06)	136	0,03
C. anonae	115 (0,5)	6 (0,00)	121	0,03
Ceratitis sp2.	117 (0,05)	0 (0,00)	117	0,03
C. quinaria	26 (0,01)	83 (0,05)	109	0,03
C. bremii	33 (0,01)	69 (0,04)	102	0,03
D. punctatifrons	85 (0,04)	10 (0,00)	95	0,02
D. diastatus	45 (0,02)	19 (0,01)	64	0,02
C. penicillata	55 (0,02)	3 (0,00)	58	0,01
D. mediovittatus	52 (0,02)	3 (0,00)	55	0,01
C. ditissima	15 (0,01)	32 (0,02)	47	0,01
Other species	113 (0,05)	98 (0,06)	211	0,05
Total	233319 (100)	156810 (100)	390129	100

Table 4: Alpha diversity index of Tephritidae in mango orchards studied

Orchardcode	Simpson diversity index (D)	Shannon Wiener diversity index (H')	Maximum diversity (Hmax)	Pielou evenness index (E)	Engen rarity variance (EVS)
TG_1V_1	0,122	0,503	3,584	0,140	2,596
TG_1V_2	0,158	0,690	4,169	0,165	3,661
TG_1V_3	0,183	0,761	4	0,190	3,630
TG_1V_4	0,382	0,882	4,247	0,216	1,092
TG_1V_5	0,104	0,342	4,087	0,084	1,337
TG_1V_6	0,215	0,844	4,169	0,206	3,628
TG_1V_7	0,131	0,502	4,459	0,113	2,344
TG_1V_8	0,100	0,439	4	0,112	2,536
TG_1V_9	0,089	0,349	4,392	0,079	1,776
TG_1V_{10}	0,070	0,269	4,392	0,061	1,399
TG_2V_1	0,202	0,572	4,584	0,125	1,550
TG_2V_2	0,182	0,599	4,7	0,127	2,244
TG_2V_3	0,448	1,135	4,392	0,258	1,642
TG_2V_4	0,396	1,133	2,321	0,488	2,036
TG_2V_5	0,047	0,179	2,584	0,069	0,882
TG_2V_6	0,284	0,806	3	0,269	1,958
TG_2V_7	0,546	1,366	3	0,455	1,560
TG_2V_8	0,171	0,513	4,459	0,115	1,642
TG_2V_9	0,092	0,328	4	0,082	1,478
TG_2V_{10}	0,207	0,540	2	0,270	1,079

3.2 Beta diversity

Species community analysis of the Tephritidae species showed that several orchards at the study site had shared similar species because, the Jaccard index was higher than 0,50 (Appendix 2). The highest similarity was observed between orchards TG_1V_5 and TG_2V_9; TG_1V_7 and TG_1V_9; TG_1V_2 and TG_1V_6, with Jaccard indices estimated at 0.94; 0.87 and 0.84, respectively. Orchards TG_1V_7 and TG_2V_4, TG_1V_9 and TG_2V_4 were those in which very low similar species were recorded, with a Jaccard index of 0.13 each.

B. dorsalis, *C. cosyra* and *C. fasciventris* were the three similar Tephritidae species in all the orchards studied (Fig. 3). They are followed by *C. capitata*, *D. humeralis* et *D. punctatifrons* similar for 16 orchards and *C. bremii*, *D. bivittatus* et *Z. cucurbitae* similar for 15 orhcards. Uncommon species that were present only in one orchard were *C. colae* (TG_1V_7), *C. flexuosa* (TG_1V_{10}), *Ceratitis* sp3 (TG_2V_2), *Dacus annulatus* Becker (TG_2V_1), *Dacus disjunctus* (Bezzi) (TG_1V_9), *Dacus seguyi* (Munro) (TG_2V_2) and unidentified Tephritidae 2, 3 et 4 present in orchards TG_2V_3, TG_2V_2, 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 the same similarities (Figure 3). Four main groups of orchards were identified:

- group 1 comprised orchards TG_1V_4, TG_1V_5, TG_2V_1, TG_2V_2, TG_2V_3, TG_2V_8 and TG_2V_9 which are similar because they have more than half of the species that are common;
- group 2 are orchards TG_1V_1, TG_1V_8, TG_1V_2, TG_1V_6, which also have more than half of the species that are common;
- group 3 includes orchards TG_1V_3, TG_1V_7 and TG_1V_9, are similar on the basis of the number of common species;
- group 4: orchards TG_2V_4, TG_2V_6 and TG_2V_7;

Orchards TG_2V_5, TG_2V_{10} and TG_1V_{10} are not well represented in the projection made.

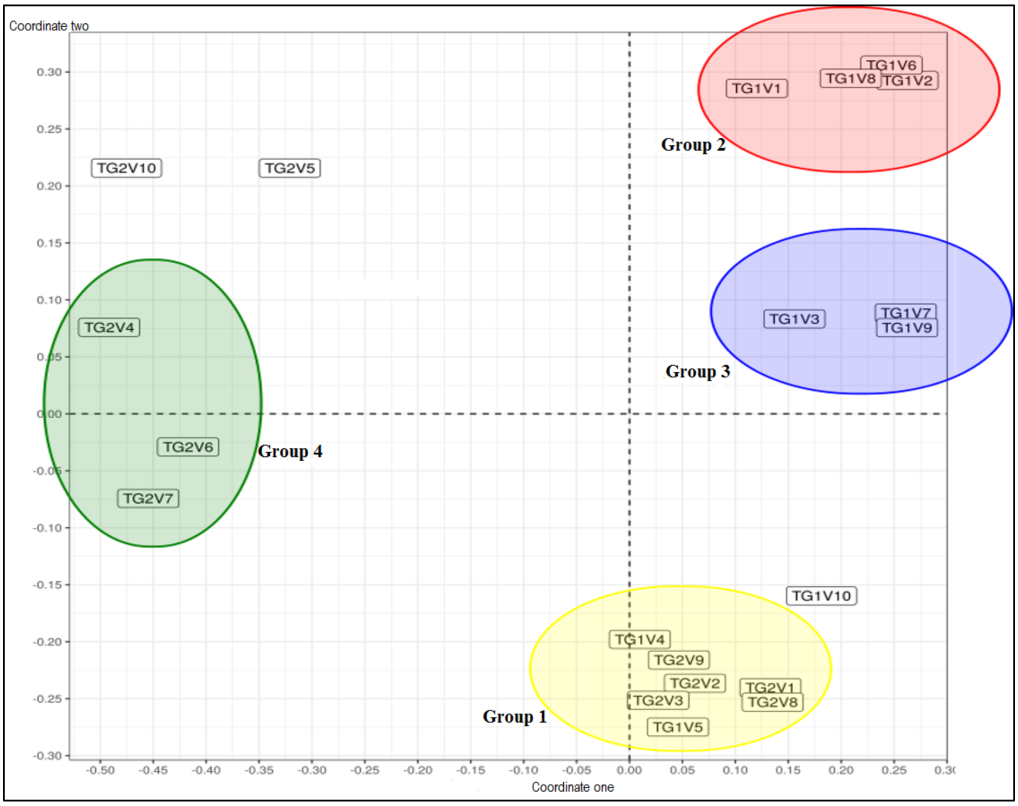

Fig. 3: Graphic representation groups of mango orchards in a principal coordinate analysis based on Jaccard distances between the number of fruit fly species

3.3 Species Prevalence

The species *B. dorsalis* and *C. cosyra* were considered in this analysis based on the specific diversity which proved that they 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* is the highest in all the orchards and varies from 2.12 (TG_2V_4) to 472.1 (TG_1V_7) (Fig. 4). The prevalence of *C. cosyra* is lower and lies between 0.34 (TG_2V_4) and 97.28 (TG_1V_4).

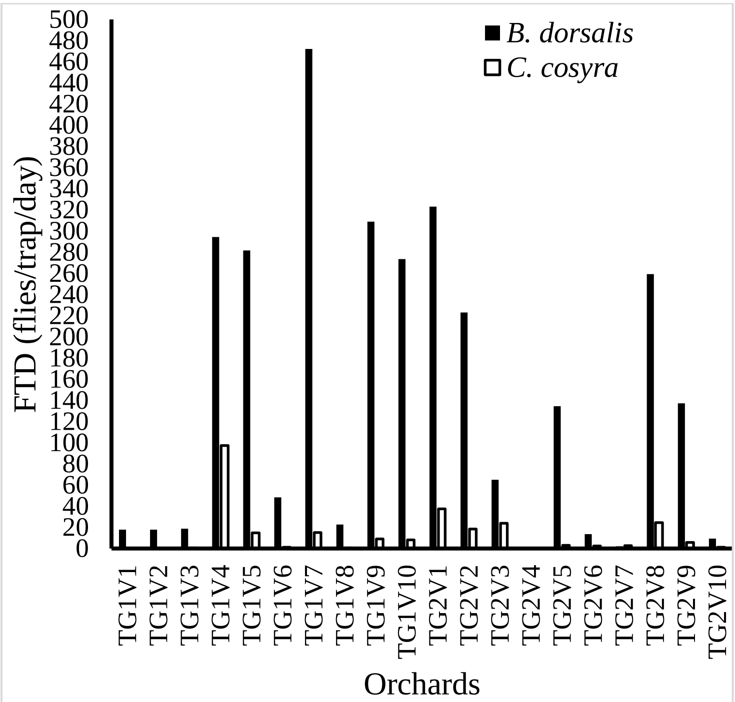

Fig. 4: Prevalence variation of the two major fruit fly species in the mango orchards during the first month of monitoring

4 Discussion

The trap-capture method with parapheromone used in this study from May to early June 2018 in Togo made it possible to record 40 species of Tephritidae, 11 of which could not be identified up to specific level. The Tephritidae identified in this study represent 77% of the species reported in Togo and 34.2% of those in West Africa [36, 37]. The species determined up to specific level are those of the Dacinae subfamily reported in Togo and other countries of the afrotropical region [24, 37, 38, 39, 40]. The relatively small specific richness obtained with a single study method applied over a period of one month (May corresponding to the start of maturation of mango) proves that during the capture period, the species are found in mango orchards and the surrounding vegetation, abiotic (temperature, relative humidity, precipitation, etc.) and biotic conditions, notably at resting sites and host plants favorable to their development, most of the recorded species are polyphagous [13, 41]. These reasons probably explain the diversification in species of the two main genera *Ceratitis* and *Dacus*. Indeed, Vayssières et al. [42] and Gomina [14] have noted the presence of host plants of several Tephritidae species identified in this study. The zones of high specific richness are observed in ecological zones II, III (at the level of the latitude of Sokodé and Bafilo) and IV. This can be explained by the diversification not only of wild host plants but especially of fruit trees cultivated in these environments. Note that these zones are recognized in Togo fruit producing regions, which is not the case for orchards located in the far North (zone I) of the country where the diversity of host plants seems lower probably because of less favorable ecological and climatic conditions. Among the species of Tephritidae identified in mango orchards are *B. dorsalis*, *C. cosyra*, *C. capitata*, *C. fasciventris*, *C. silvestrii*, *C. anonae*, *C. quinaria*, *C. ditissima* recognized as associated fruit plant pest species in Africa [22, 43, 44, 45, 46]. According to Vayssières et al. [46] the presence of a wide variety of fruit fly species on mango has today considerably attenuated 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 recognized as being more dependent on Cucurbitaceae, Passifloraceae and Apocynaceae [27, 41]. The observed species are generally native except *B. dorsalis* and *Z. cucurbitae* reported as exotic and invasive [13, 14, 37].

The very high proportions and prevalence of *B. dorsalis* in all the orchards in the study area suggest that this invasive species has settled in Togo and undoubtedly constitutes a scourge. These results do not seem to be explained solely by the effectiveness of the attractant used for this species but especially by its very good adaptation to the agro-ecological conditions of the study area. In addition to its polyphagia, Gomina [37] has shown that under the Guinea zone conditions in Togo, *B. dorsalis* was very prolific because a female could lay an average of 538 eggs during her life time with a short total developmental period of around 3 weeks and an offspring survival rate estimated at 67%. *C. cosyra* is the second species to which special attention must be paid in Togo and in West Africa [39]. While *C. cosyra* has been cited as subservient to the Sahelian and Sudanian zones but absent from the humid forest agro-ecological zones of West Africa [10], this species has been 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 specific richness of Tephritidae frugivores in Togo seems important but the different indices of diversity suggest a low specific diversity. This helps to deduce that the potential specific diversity in Tephritidae seems high. This result is in line with the work of De Meyer et al. [37]. 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 bring more species into Togo.

Analysis of the Tephritidae community from the catches shows that several species are common to the mango orchards studied. The representation of the orchards of the different zones in a principal analysis coordinate based on Jaccard distances showed that 4 groups of orchards are considered similar from the point of view of the common Tephritidae species. Orchards in the same ecological zone tend to be similar. This result probably suggests a 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 consistent with Ouedraogo et al. [37]. The most common and wide-ranging species in our study area are *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 [24, 37, 39, 46]. The species *C. colae*, *C. flexuosa*, *Ceratitis* sp and some species of *Dacus* not determined up to the specific level present only in a single orchard can probably be considered to be rare in the area but monitoring over a long period will make it possible specify their status.

The prevalence of the two species considered dominant in our study area during the month of May expressed 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*. *B. dorsalis* and *C. cosyra* thus remain the species of economic importance in Togo. Our study area is therefore infested with these two species which seem to be best adapted to the environmental conditions. According to the recommendations of IAEA [21], this result indicates that it is necessary to implement phytosanitary protection actions against these formidable species of fruit flies.

This study shows 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 during the month of May 2018, corresponding to the maturation period of mangoes. The diversity indices estimated in this study predict 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*. These species are numerically dominated by the invasive species *B. dorsalis* and the endogenous species *C. cosyra* which have very high prevalence. In the light of these results, it is essential to determine, in all agro-ecological zones, the economic thresholds of the most abundant fruit flies (*B. dorsalis* and *C. cosyra*) on important economic fruits and vegetables. This will constitute a basis for the establishment and application of a sustainable, efficient, economically profitable and healthy management program vis-à-vis the environment of the population of these pests in Togo.

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Appendix 1: Presence of the Tephritidae species in different mango orchards in Togo*

Species	TG_1V_1	TG_1V_2	TG_1V_3	TG_1V_4	TG_1V_5	TG_1V_6	TG_1V_7	TG_1V_8	TG_1V_9	TG_1V_{10}	TG_2V_1	TG_2V_2	TG_2V_3	TG_2V_4	TG_2V_5	TG_2V_6	TG_2V_7	TG_2V_8	TG_2V_9	TG_2V_{10}
Bactrocera dorsalis (Hendel)	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Celidodacus sp.												×						×		
Ceratitis anonae Graham		×	×			×	×	×	×	×	×	×	×					×		
Ceratitis bremii Guérin-Méneville			×	×	×		×		×	×	×	×	×		×	×	×	×	×	×
Ceratitis capitata (Wiedemann)	×	×	×	×	×	×	×	×	×	×	×	×	×			×		×	×	
Ceratitis colae Silvestri							×													
Ceratitis cosyra (Walker)	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Ceratitis ditissima (Muro)	×					×				×	×	×	×					×		
Ceratitis fasciventris (Bezzi)	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
Ceratitis flava Meyer & Freidberg		×	×	×	×	×	×	×	×	×	×	×						×	×	
Ceratitis flexuosa Walker										×										
Ceratitis penicillata Bigot		×				×	×		×	×		×								
Ceratitis punctata (Wiedemann)	×	×	×	×	×	×	×	×	×	×	×	×	×					×	×	
Ceratitis quinaria Bezzi				×	×					×	×	×	×	×		×	×	×	×	
Ceratitis silvestrii Bezzi			×	×	×						×	×	×	×		×	×	×	×	
Ceratitis sp1.		×					×													
Ceratitis sp2.		×				×														
Ceratitis sp3.												×								
Ceratitis sp4.											×	×	×							
Dacus armatus Fabricius	×	×	×	×	×	×	×	×	×	×	×							×	×	
Dacus bivittatus (Bigot)	×	×	×	×	×	×	×	×	×	×	×	×	×					×	×	
Dacus diastatus Munro				×	×		×		×	×	×	×	×					×	×	
Dacus fuscovittatus Graham	×	×				×	×	×	×											
Dacus humeralis (Bezzi)		×	×	×	×	×	×	×	×	×	×	×	×			×	×	×	×	
Dacus langi Curran		×	×			×	×	×	×	×		×						×		
Dacus mediovittatus White	×	×	×	×		×	×	×	×		×									
Dacus punctatifrons Karsch	×	×	×	×	×	×	×	×	×	×	×	×	×		×			×	×	
Dacus theophrastus Hering				×	×		×		×	×	×	×	×					×	×	
Dacus guineensis Hering				×			×		×		×									
Dacus vertebratus Bezzi				×	×					×	×	×	×				×	×		
Dacus annulatus Becker											×									
Dacus disjunctus (Bezzi)									×											
Dacus seguyi (Munro)												×								
Elaphromyia sp.												×	×							
Tephritidae1											×							×		
Tephritidae2													×							
Tephritidae3												×								
Tephritidae4												×								
Trirhithrum sp1.								×					×							
Zeugodacus cucurbitae (Coquillett)	×	×	×	×	×	×	×	×	×	×	×		×		×			×	×	
Specific richness	12	18	16	19	17	18	22	16	21	21	24	26	21	5	6	8	8	22	16	4

*TG_1 : Mango producing area 1 ; TG_2 : Mango producing area 2; V_1-V_{10} : Orchard 1 to 10 ;
× : presence of the species

Appendix 2: Jaccard indices from the different mango orchards in the study area

	TG_1V_{10}	TG_1V_2	TG_1V_3	TG_1V_4	TG_1V_5	TG_1V_6	TG_1V_7	TG_1V_8	TG_1V_9	TG_2V_1	TG_2V_{10}	TG_2V_2	TG_2V_3	TG_2V_4	TG_2V_5	TG_2V_6	TG_2V_7	TG_2V_8	TG_2V_9
TG_1V_1	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
TG_1V_{10}		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
TG_1V_2			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
TG_1V_3				0,57	0,65	0,65	0,65	0,72	0,68	0,60	0,25	0,45	0,48	0,24	0,38	0,41	0,33	0,65	0,68
TG_1V_4					0,79	0,42	0,56	0,45	0,58	0,71	0,24	0,43	0,58	0,29	0,35	0,47	0,47	0,63	0,74
TG_1V_5						0,42	0,56	0,45	0,58	0,71	0,24	0,54	0,65	0,29	0,35	0,47	0,47	0,77	0,94
TG_1V_6							0,63	0,78	0,65	0,46	0,17	0,39	0,41	0,16	0,28	0,25	0,19	0,50	0,43
TG_1V_7								0,61	0,87	0,59	0,18	0,45	0,43	0,13	0,27	0,25	0,20	0,57	0,58
TG_1V_8									0,64	0,44	0,19	0,32	0,44	0,18	0,31	0,28	0,21	0,48	0,48
TG_1V_9										0,61	0,19	0,47	0,45	0,13	0,29	0,26	0,21	0,59	0,61
TG_2V_1											0,17	0,56	0,67	0,21	0,25	0,33	0,33	0,77	0,67
TG_2V_{10}												0,15	0,19	0,50	0,67	0,50	0,50	0,18	0,25
TG_2V_2													0,62	0,19	0,19	0,31	0,31	0,66	0,50
TG_2V_3														0,24	0,29	0,38	0,38	0,65	0,61
TG_2V_4															0,38	0,63	0,63	0,23	0,31
TG_2V_5																0,40	0,40	0,27	0,38
TG_2V_6																	0,78	0,36	0,50
TG_2V_7																		0,36	0,41
TG_2V_8																			0,73

Index of the orchards hosting the greatest number of common species