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Research Article

NATIVE HYMENOPTERAN PARASITOIDS ASSOCIATED WITH FRUIT FLIES (DIPTERA: TEPHRITIDAE) IN FRUITS AND VEGETABLES IN THREE ECOLOGICAL ZONES OF TOGO

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ABSTRACT

Fruit flies (Diptera: Tephritidae) are major pests associated with fruit and vegetable production in West Africa in general and in Togo in particular. The use of parasitoid wasps to significantly reduce their populations in agroecosystems is a significant component of the integrated management of these pests (IPM-package). To do this, it is important to know their diversity, distribution and potential in controlling fruit flies. In this perspective, the incubation of 28 species of fruits and vegetables sampled in 2009 in ecological zones III, IV and V in Togo allowed to identify five species of native braconid parasitoids: *Fopius caudatus* Szepligeti, *Diachasmimorpha fullawayi* Silvestri, *Bracon* sp., *Fopius* sp. and *Psyttalia* sp. *F. caudatus* was the most abundant making 98.6% of parasitoids recovered. These parasitoids were associated with 4 species of fruit flies, the most abundant being the native species, *Ceratitis cosyra* (Walker). The parasitism rate in the three ecological zones depended on the locality, the incubated fruit and the fruit fly species. It was relatively low and ranged from 0 to 42.31%, with the highest average rate recorded in the wild fruit, *Sarcocephalus latifolius* (Sm.) E.A.Bruce, associated exclusively with *C. cosyra*. Pupae recorded from *S. latifolius* frequently yielded *F. caudatus* which was the most abundant. Assessment of the demographic parameters of *F. caudatus*, a potential candidate for augmentative biological control of *C. cosyra* in Togo, should be considered under controlled and natural conditions.

Keywords: Braconidae, *Ceratitis cosyra, Fopius caudatus,* Augmentative biological control, Parasitism rate.

INTRODUCTION

Fruit flies (Diptera: Tephritidae) are of great economic importance in sub-Saharan Africa because they attack (punctures) and cause severe damage to fruits and vegetables which they use as support for the development of their offspring (Ekesi *et al*., 2016; Mutamiswa *et al*., 2021). In West Africa, fruit fly species of economic importance belong to genera *Bactrocera*, *Ceratitis*, *Dacus* and *Zeugodacus* (De Meyer *et al*., 2013, 2016; Vayssières *et al*., 2007, 2014; Zida *et al*., 2020). Among these species, *Dacus ciliates* Loew and *Zeugodacus cucurbitae* (Coquillett) associated with Cucurbitaceae; *Ceratitis capitata* (Wiedemann) associated with citrus; *Ceratitis cosyra* (Walker) and *Bactrocera dorsalis* (Hendel) associated with citrus, cashew, shea, guava and especially mango are the most economically important in this region (Vayssières *et al*., 2014; Zida *et al*., 2020; Amevoin *et al*., 2021; Mutamiswa *et al*., 2021). Furthermore, *B. dorsalis*, an invasive species, native to Asia and identified for the first time in Africa in 2003, and currently found in all West African countries, is the major pest associated with fruit production (De Meyer *et al*., 2010; Vayssières *et al*., 2014).

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The infestation rate of fruits and vegetables according to agro-ecological zone and season varies between 5 and 100% (Lux *et al*., 2003). As a result, the yield and especially the market value of these fruits and vegetables are constantly decreasing. Punctures on these foodstuffs sometimes go unnoticed at harvest. Upon exportation, they are intercepted and destroyed in European ports and airports resulting in substantial economic losses (Vayssières *et al*., 2014; Europhyt, 2023). To significantly reduce the levels of infestation of fruits and vegetables by these pests in orchards and market gardening areas, research programs focusing on their biology, ecology, and ethology have emphasized integrated pest management which consists in combining efficient, compatible, cost-effective, and easily applicable methods for producers to adopt (Ekesi *et al*., 2016; Zida *et al*., 2023). In the context of integrated management of Tephritidae, biological control is favored over chemical control to preserve the environmental, producer, and consumer health (Ovruski *et al*., 2000; Vayssières *et al*., 2002). Among these biological methods is the use of parasitoid wasps through the mastery of the interactions between them and their hosts (Mohamed *et al*., 2010; Quilici and Rousse, 2012; Appiah *et al*., 2014; Sanou *et al*., 2019; Garcia *et al*., 2020). However, for a reasoned and long-term management of native and alien fruit flies in sub-Saharan Africa, it is important to have an adequate database on the parasitoid fauna associated with these pests so as to better understand their bio-ecology (Badii *et al*., 2016).

In Togo, to our knowledge, apart from the studies by Steck *et al*. (1986) on a few parasitoid species of *Ceratitis capitata* Wiedemann in ecological zone IV, only the preliminary work of Gomina *et al*. (2020) assessed the diversity of native parasitoid wasps in a few localities (13 in total) in the south of the country (ecological zones IV and V) based on sampling carried out between 2009 and 2011. Therefore, very few studies are conducted on the diversity and distribution of native parasitoid wasps and their potential in controlling fruit flies. However, to contribute to the implementation of the integrated management of fruit fly populations of economic importance in Togo, it is essential to continue to study the bio-ecology of these natural enemies in order to master the tritrophic relationships « Host-Plants-Tephritidae-Parasitoids ». To do this, surveys initiated by the above-mentioned authors must continue in the south and extended to the center and north of the country in order to draw up an exhaustive list of native parasitoid wasps. The objectives of this study were to (i) assess the diversity and distribution of native parasitoid wasp species in ecological zones III, IV, V; (ii) assess their overall parasitism rates (based on the fruits and vegetables sampled) and biological control potential against fruit flies in Togo.

MATERIALS AND METHODS

Study zone

Surveys were carried out in ecological zones III, IV and V (Figure 1) defined by Ern (1979) and Brunel *et al.* (1984). Ecological zone III is characterized by vegetation consisting of Guinean savannahs interspersed with vast expanses of dry forests. Its climate is of the Guinean type, with a rainy season from April to October and a dry season from November to March. Monthly average temperatures range between 26 and 30°C, and annual average precipitation levels hover around 1200 mm. Ecological zone IV is a forest zone with a subequatorial climate characterized by a rainy season (March-November) and a dry season (December-February). Monthly average temperatures range from 21 to 26°C. Annual average precipitation is around 1800 mm. In comparison with zones III and IV, the savannah and highly anthropized ecological zone V, includes forested patches. It has a tropical Guinean climate characterized by two rainy seasons (April-July and September-October) and two dry seasons (August and November-March). Monthly average temperatures range from 26 to 30°C. Annual average precipitation is around 932 mm. The choice of these three zones is based on their agro-ecological contrasts and the presence of a diversity of potential host plants for fruit flies. Fifty-three (53) localities were surveyed during fruit and vegetable sampling. These fruits and vegetables were collected from 14, 12 and 27 localities respectively in ecological zones III, IV and V (Figure 1).

Sampling of fruits and vegetables

Fruits and vegetables (at the stage of prematurity and maturity) were sampled (according to their availability) in fields, within and around mango orchards, around dwellings, in vegetable gardens, along roadsides, every two weeks during the period from May to July 2019 (Table 1). Mangoes were sampled from May to June, while the rest of the fruits and vegetables were collected in the month of July. These fruits and vegetables were picked directly from trees, shrubs, lianas, herbaceous plants or from the ground.

Incubation of fruits and vegetables

The species of fruit flies and parasitoids collected were recovered in the laboratory (27.5 ± 1°C and 79.5 ± 3% relative humidity) through the incubation of the sampled fruits and vegetables taking into account the work done by Gomina *et al*. (2023). Adult fruit flies and emerged parasitoids were collected and stored in vials containing 70° alcohol for identification.

Identification of tephritid fruit fly species and their parasitoids

The species of fruit flies and parasitoids recovered during incubation of fruits and vegetables were sorted and identified in the Laboratory of Applied Entomology (LEA) of the University of Lomé. The identification of fruit flies was conducted using the reference works for Africa (White, 2006) and the identification keys established by Virgilio *et al*. (2014) and De Meyer and White (2016). Similarly, the parasitoids were identified by referring to the work of Bokonon-Ganta *et al*. (2019) and the identification key developed by Wharton and Yoder (2005).

Data analysis

The diversity of parasitoids in the study areas was assessed by calculating species richness, Shannon and Simpson diversity indexes, equitability and dominance using Past4.03 software.The infestation rate of a fruit sample by fruit flies was expressed as the number of pupae per kg of incubated fruit (Vayssières *et al*., 2011; Badii *et al*., 2016). Fruit fly/parasitoid associations took into account the assumptions that parasitoid species recovered from a fruit sample were attacking only the preimaginal stages of fruit fly species that were emerged also from the same sample (Badii *et al*., 2016). The parasitism rate (P_r) of fruit flies by parasitoids in incubated fruits was calculated using the formula: $P_r = a/(a+b) \times 100$; where a = total number of parasitoids emerged from the sample and b = total number of adult flies emerged from the sample (Steck *et al*., 1986). To assess the level of interaction among the host plants (incubated fruits), the species of Tephritidae and those of parasitoids emerged from these fruits, the density of each species of fruit fly (expressed in number of fruit flies/kg of fruit considered) and that of each species of parasitoid recovered from each fruit (expressed in number of parasitoids/kg of the fruit considered) were calculated. These calculated values were standardized and subjected to principal component analysis (PCA) using the XLSTAT 2022 software. Because the data relating to parasitism rate of the fruit samples and density of the various species of parasitoids in the fruits were not normally distributed, the Kruskal-Wallis test (non-parametric test) was done using the SPSS 20 software to compare these data.

RESULTS AND DISCUSSION

A total of 116 fruit and vegetable samples (corresponding to 9,150 fruits and vegetables) belonging to 28 plant species were sampled in the three zones combined. Of the 116 fruit samples incubated, 39 (33.62%) corresponding to 2,750 fruits and vegetables allowed to recover 613 parasitoid wasps belonging to the Braconidae family and associated with 3,275 fruit flies (emerged from 4,039 pupae) all species combined (Table 1 and Figure 2). These fruits and vegetables belonged to 4 species of plants: *S. latifolius*, *S. mombin*, *U. chamae* and *C. frutescens*. The fruit flies recovered belonged to 2 genera and 4 species: *C. cosyra* (3,031 individuals, or 92.55%), *B. dorsalis* (231 individuals, or 7.05%), *C. capitata* (12 individuals, or 0.37%) and *Ceratitis anonae* (Graham) (1 individual, or 0.03%). Similarly, parasitoids belonged to 2 subfamilies (of the Braconidae family), 4 genera and 5 species. The Opiinae subfamily was the most represented with 99.83% (612 individuals) of all parasitoids recovered. In this subfamily, *Fopius caudatus* Szepligeti was the most abundant with 605 individuals (98.69%). *Diachasmimorpha fullawayi* Silvestri, *Psyttalia* sp. and *Fopius* sp. represented 0.49% (3 individuals), 0.33% (2 individuals) and 0.33% (2 individuals) respectively (Figure 2). The Braconinae subfamily is represented by the species, *Bracon* sp. (1 individual, or 0.16%) only. The braconid parasitoid species *F. caudatus* and *D. fullawayi* have already been reported in other West African countries, notably Nigeria (Gilstrap and Hart, 1987), Mali (Vayssières *et al*., 2002; 2004), Ivory Coast (Kadio *et al*., 2011), Senegal (Vayssières *et al*., 2012; Ndiaye *et al*., 2015),

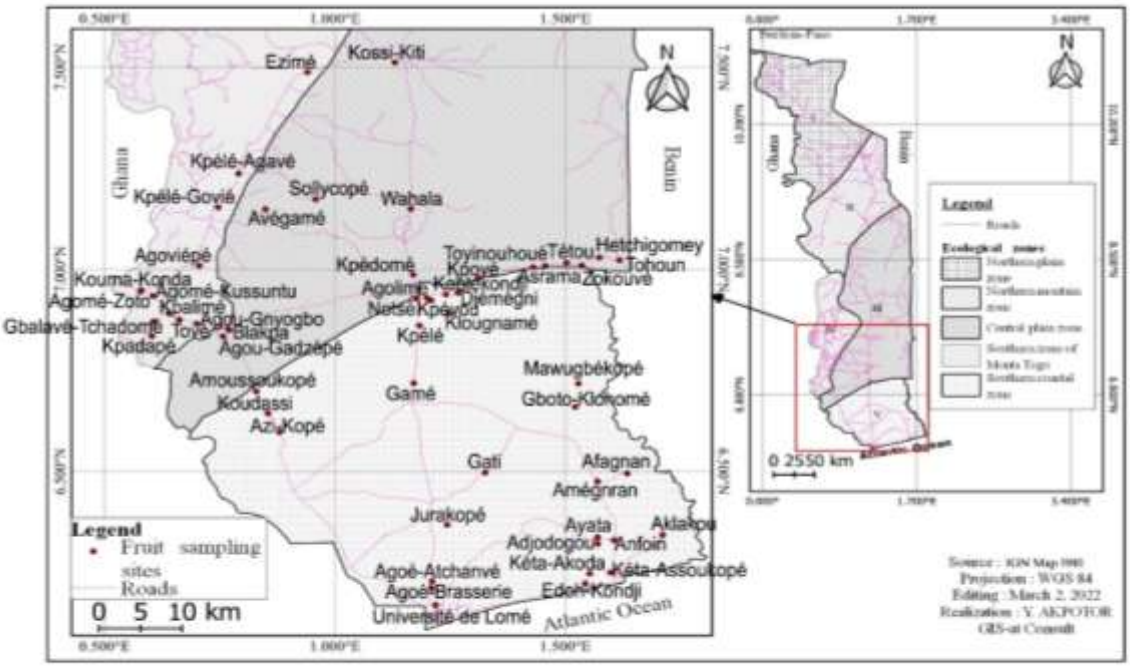

Figure 1. Study area with the different fruit and vegetable sampling localities.

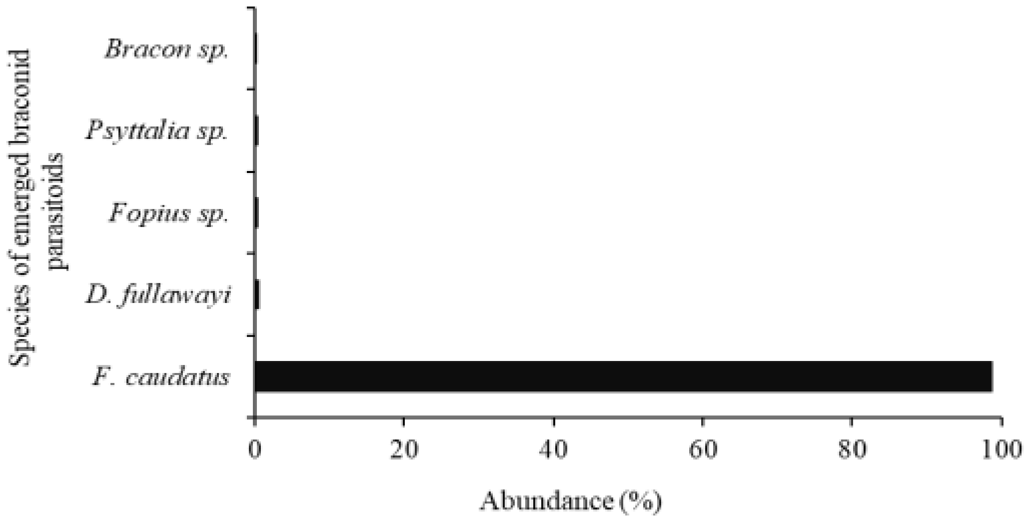

Figure 2. Proportions of braconid parasitoid species emerged from all the fruits and vegetables sampled in ecological zones III, IV and V.

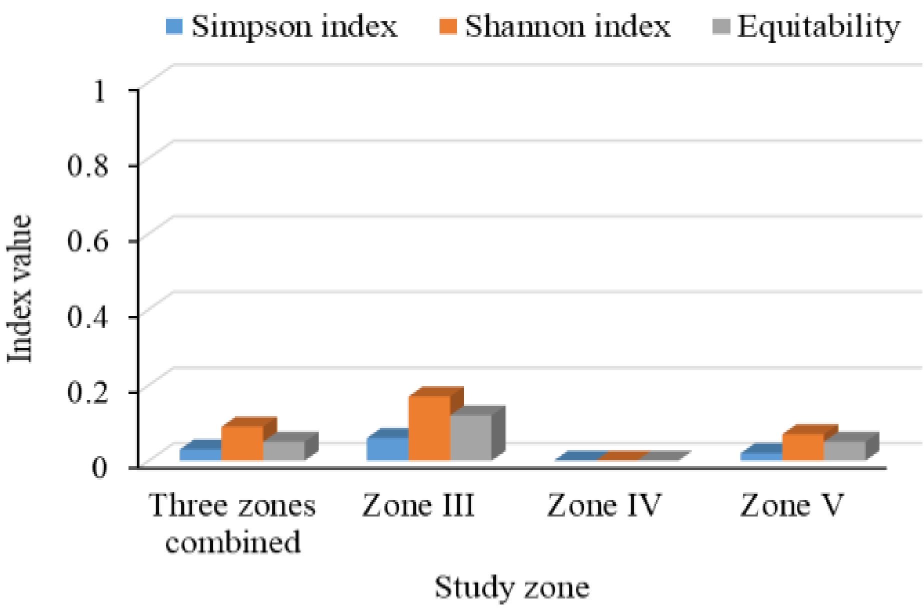

Figure 3. Equitability, Simpson and Shannon diversity indexes calculated in different ecological zones.

Ghana (Badii *et al*., 2016), Benin (Vayssières *et al*., 2011; Sambo *et al*., 2019), Burkina Faso (Zida *et al*., 2022) and even Togo (Steck *et al*., 1986; Gomina *et al*., 2020). To our knowledge, it is the first time that the genus *Bracon* has been reported in Togo. The 5 species of braconid parasitoids identified during this survey are all koinobiont endoparasitoids, except for the species of the genus *Bracon*, which is an idiobiont ectoparasitoid (Vayssières *et al*., 2002; Wharton and Yoder, 2005).

In the conditions of this study, the Shannon diversity index in different ecological zones was low. Likewise, the Simpson diversity index and eqitability were close to 0. These indicate that the diversity of parasitoids in the various study zones was low (Figure 3).

In ecological zone III, 783 incubated fruits (belonging to *C. frutescens* and *S. latifolius*) allowed to recover 102 parasitoids associated with 384 fruit flies, all species combined. Fruit flies associated with parasitoids in this ecological zone belonged to 2 species: *C. cosyra* (97.92%), *C. capitata* (2.08%). The 4 species of parasitoids identified in this zone belonged to the Opiinae and Braconinae subfamilies. In the Opiinae subfamily, *F. caudatus* was the most abundant species with 97.06% (99 individuals) of all parasitoids recovered during fruit incubation in this area. *D. fullawayi* and *Psyttalia* sp. each represented 0.98% (1 individual) of the total number of parasitoids recovered. *Bracon* sp. was the sole representative of the Braconinae subfamily with 0.98% (1 individual) of the total number of parasitoids recovered. In ecological zone IV, only 37 incubated fruits of *S. latifolius* allowed the recovery of 6 parasitoids associated with 275 individuals of *C. cosyra*. *F. caudatus* was the only parasitoid species recovered during fruit incubation in this area.

In ecological zone V, 1,889 incubated fruits (belonging to *S. latifolius*, *S. mombion* and *U. chamae*) yielded 505 parasitoids associated with 2,183 flies, all species combined. Fruit flies associated with parasitoids in this ecological zone belonged to 4 species: *C. cosyra* (1,974 individuals, or 90.43%), *B. dorsalis* (204 individuals, or 9.34%), *C. capitata* (4 individuals, or 0.18%) and *C. anonae* (1 individual, or 0.05%). The parasitoids obtained belong to 4 species and Opiinae subfamily.

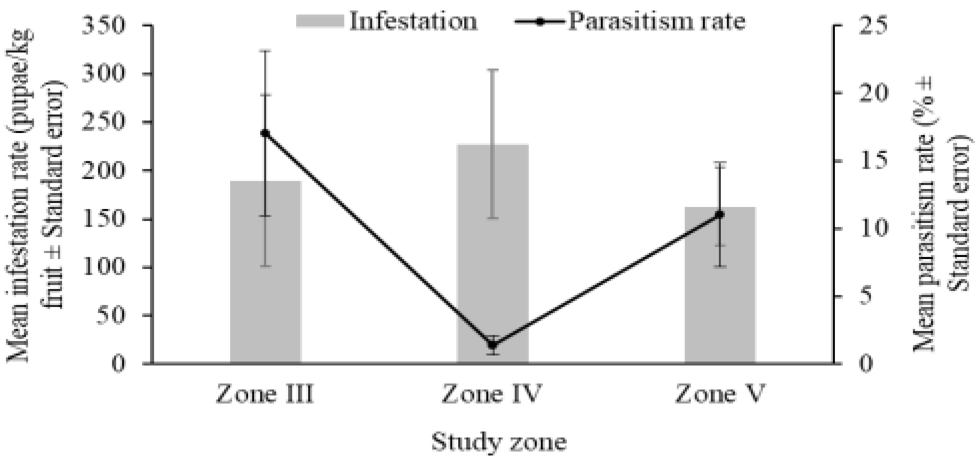

Figure 4. Fruit and vegetable infestation and parasitism rate of fruit fly species according to ecological zones III, IV and V.

F. caudatus was the most abundant with 99.01% (500 individuals). *D. fullawayi*, *Fopius* sp. and *Psyttalia* sp. represented respectively 0.40% (2 individuals), 0.40 (2 individuals) and 0.20% (1 individual).

The infestation rate of fruits incubated in ecological zones III, IV and V varied respectively between 5.38 and 540, 142.5 and 380, 18.21 and 340 pupae/kg of fruit with average rates of 189.53 ± 88.49 (Zone III), 226.83 ± 76.71 (Zone IV) and 162.73 ± 40.65 (Zone V) pupae/kg of fruit (Figure 4). Similarly, the parasitism rates in ecological zones III, IV and V varied respectively between 0 and 42.31, 0 and 2.19, 0 and 24.81% with mean rates of 17.03 ± 6.09 (Zone III), 1.36 ± 0.69 (Zone IV) and 11.02 ± 3.84% (Zone V) (Figure 4).

The diversity of parasitoids and the parasitism rate of fruit depended on locality, incubated fruit and fruit fly species (Figures 5 and 6; Tables 2 and 3). Among the 4 species of plants whose fruits allowed to recover parasitoids, the wild plant, *S. latifolius* (associated only with *C. cosyra*) recorded the high specific richness (the 5 species of braconid parasitoids identified throughout the study area were associated with it).

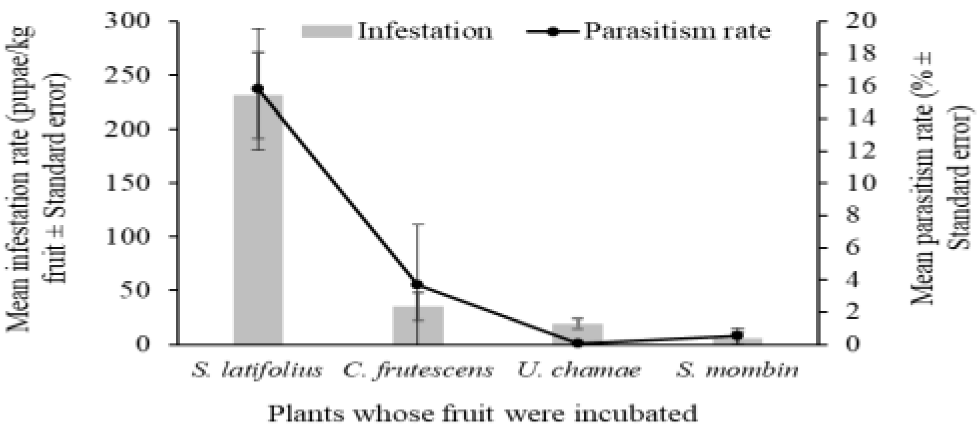

Figure 5. Infestation and parasitism rate of fruit fly species in relation to fruits and vegetables in the study area.

The infestation rate of *S. latifolius* fruits by *C. cosyra* varied from 30 to 540 pupae/kg of fruit with an average rate of 231.36 ± 39.58 pupae/kg of fruit (Figure 5 and Table 2). Ninety-nine point fifty-one percent (99.51%, or 610 individuals) of all parasitoids, all species combined (613 individuals) were recovered from the incubation of *S. latifolius* fruits (Tables 2 and 3). There was a significant difference between the parasitism rate of fruit flies by parasitoids of the various fruits belonging to the 4 plant species (Kruskal-Wallis: Chi-square = 21.648; df = 3; P = 0.0000). Therefore, the parasitism rate (15.79 ± 3.75%) of *C. cosyra* by braconid parasitoid species in *S. Latifolius* was the highest (Figure 5). In the fruits of *S. latifolius*, Simpson and Shannon indexes were low and showed that the diversity of parasitoids associated with *C. cosyra* was low regardless of the study zone (Figure 7). Among the 5 braconid parasitoid species associated with *C. cosyra* in *S. latifolius*, *F. caudatus* was the most abundant and frequent (Tables 3). Similarly, regardless of the study zone, the very low equitability and dominance close to 1 showed that *F. caudatus* dominated in this fruit (*S. latifolius*) (Figure 7). Consequently the density of *F. caudate* in *S. Latifolius* was the highest (Kruskal-Wallis: Chi-square = 40.427; df = 4; P = 0.000) and varied between 2 and 71.85 parasitoids/kg with an average of 46.86 ± 19.96 parasitoids/kg of fruit (Figure 8).

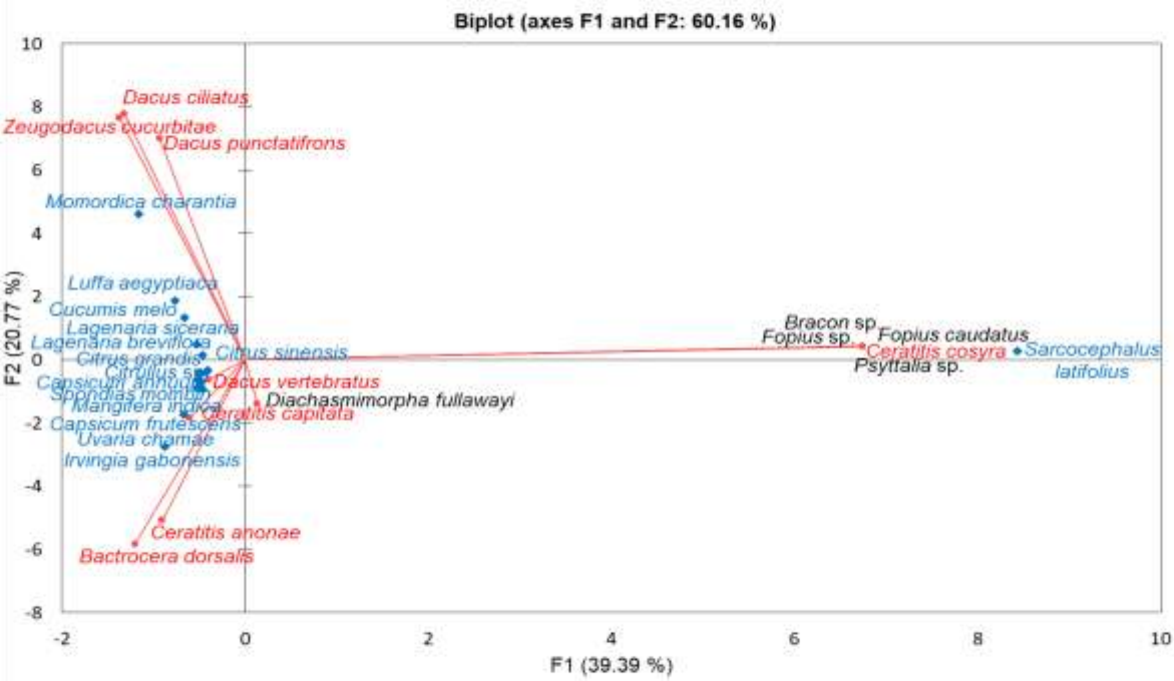

Figure 6. Interaction among host plants (in blue), fruit flies (in red) and parasitoids (in black) in the study area.

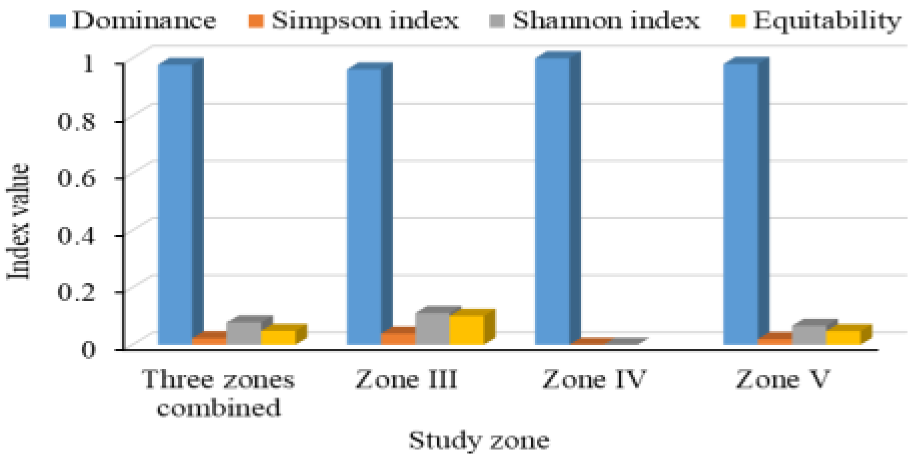

Figure 7. Dominance, equitability and Simpson and Shannon diversity indexes calculated for *S. latifolius* in the different ecological zones.

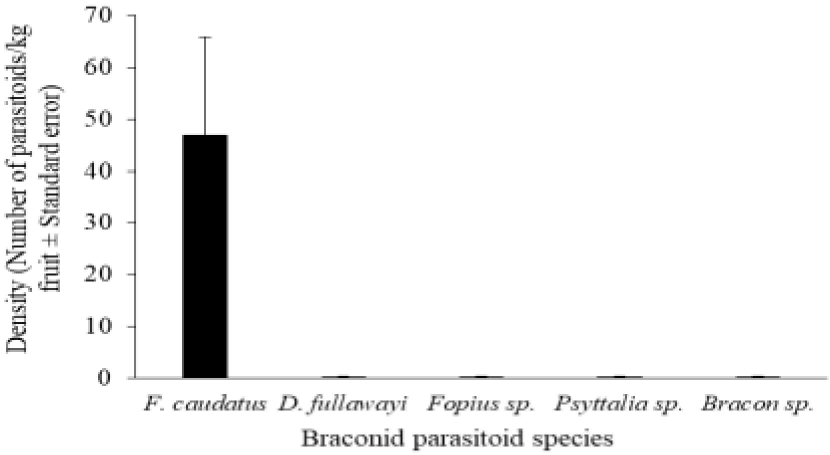

Figure 8. Density of different species of native braconid parasitoids associated with *C. cosyra* in *S. latifolius* in the study area.

Table 1. Number of fruits and samples per plant species sampled in the study zone.

Plant family	Scientific name	Ecological zone	Number of samples	Number of fruits per sample	Total number of fruits	Total weight of fruits (kg)
Anacardiaceae	*Mangifera indica* L.	III, IV, V	31	4-30	401	282.2
	**Spondias mombin* Jacq.	III, IV, V	7	54-1015	2070	18.2
Annonaceae	*Annona muricata* L.	IV	4	4-9	24	9.7
	Annona senegalensis Pers.	V	1	6	6	0.1
	Annona squamosa L.	IV	1	6	6	0.7
	**Uvaria chamae P. Beauv.*	V	12	84-179	1614	12.3
Cucurbitaceae	*Citrullus lanatus* (Thunb.) Mansf.	V	1	3	3	3.1
	Citrullus sp.	III	1	29	29	0.25
	Cucumis melo L.	III	1	19	19	2.3
	Cucumis sativus L.	V	2	19-20	39	15.5
	Luffa aegyptiaca Mill.	III, V	4	2-21	44	3.3
	Lagenaria siceraria (Molina) Standl.	III, IV, V	4	6-21	54	6.3
	Lagenaria breviflora (Benth.) Roberty	V	1	1	4	0.5
	Momordica charantia L.	IV, V	5	15-81	209	0.8
Euphorbiaceae	*Jatropha curcas* L.	V	1	16	16	0.25
Irvingiaceae	*Irvingia gabonensis* (Aubry-Lecomte ex O'Rorke) Baill.	IV, V	3	12-14	40	6.1
Lamiaceae	*Vitex doniana* Sweet	III, IV	2	168-192	360	2.5
Moraceae	*Artocarpus altilis* (Parkinson) Fosberg	IV	1	3	3	3.1
	Ficus sp.	V	1	59	59	1.3
Passifloraceae	*Passiflora edulis* Sims	IV, V	2	6-59	65	3.9
Piperaceae	*Piper guineense* Schum. & Thonn.	IV	3	496-679	1711	0.3
Rubiaceae	**Sarcocephalus latifolius* (Sm.) E.A.Bruce.	III, IV, V	16	4-104	419	24.31
Rutaceae	*Citrus sinensis* (L.) Osbeck	III, IV	2	5-31	36	6.5
	Citrus grandis (L.) Osbeck	IV	1	14	14	4.2
Solanaceae	*Capsicum annuum* L.	IV, V	3	78-289	543	1.05

**Capsicum frutescens* L.	III, IV, V	4	86-721	1293	1.45
Solanum lycopersicum L.	III	1	37	37	0.3
Solanum melongena L.	V	1	32	32	1.3
Total		**116**		**9150**	**411.81**

*Plants whose fruits allowed the recovery of parasitoid wasps

Table 2. Infestation and parasitism rate according to fruits and vegetables sampled in the different localities in ecological zones III, IV and V.

Ecological zone	Locality	Incubated fruit	Pupae/ kg fruit	Number of emerged parasitoids	Parasitism rate (%)	Fruit fly species emerged (%)	Braconid parasitoid species emerged
Zone III	Asrama	*S. latifolius*	354.29	40	17.37	*C. cosyra* (100)	*Bracon* sp., *F. caudatus*
	Kpédomé	*S. latifolius*	177.50	49	24.26	*C. cosyra* (100)	*F. caudatus*, *Psyttalia* sp.
	Kpové	*C. frutescens*	30.00	1	11.11	*C. capitata* (100)	*D. fullawayi*
	Wahala	*S. latifolius*	30.00	1	7.14	*C. cosyra* (100)	*F. caudatus*
	Zokouvé	*S. latifolius*	540.00	11	42.31	*C. cosyra* (100)	*F. caudatus*
Zone IV	Agoviépé	*S. latifolius*	158.00	5	2.19	*C. cosyra* (100)	*F. caudatus*
	Tové	*S. latifolius*	142.50	1	1.89	*C. cosyra* (100)	*F. caudatus*
Zone V	Agolime	*S. latifolius*	295.00	125	24.81	*C. cosyra* (100)	*F. caudatus*
	Davié	*S. mombin*	40.00	1	3.57	*B. dorsalis* (100)	*F. caudatus*
	Djéménin	*S. latifolius*	224.17	41	16.14	*C. cosyra* (100)	*D. fullawayi*, *F. caudatus*, *Fopius* sp., *Psyttalia* sp.
	Gamé	*S. latifolius*	232.22	194	31.49	*C. cosyra* (100)	*F. caudatus*
	Mawugbékopé	*S. latifolius*	79.79	52	14.33	*C. cosyra* (100)	*F. caudatus*
		U. chamae	18.21	1	0.48	*B. dorsalis* (97.61), *C. capitata* (1.91), *C. colae* (0.48)	*F. caudatus*
	Notsè	*S. latifolius*	202.91	91	8.33	*C. cosyra* (100)	*F. caudatus*

Table 3. Number and percentage (%) of the different braconid parasitoid species identified in the different localities in ecological zones III, IV and V.

Ecological zone	Locality	Incubated fruit	Species									
			Bracon sp.		*D. fullawayi*		*F. caudatus*		*Fopius* sp.		*Psyttalia* sp.	
			Number	%	Number	%	Number	%	Number	%	Number	%
Zone III	Asrama	*S. latifolius*	1	2.5	0	0	39	97.5	0	0	0	0
	Kpédomé	*S. latifolius*	0	0	0	0	48	97.96	0	0	1	2.04
	Kpové	*C. frutescens*	0	0	1	100	0	0	0	0	0	0
	Wahala	*S. latifolius*	0	0	0	0	1	100	0	0	0	0
	Zokouvé	*S. latifolius*	0	0	0	0	11	100	0	0	0	0
Zone IV	Agoviépé	*S. latifolius*	0	0	0	0	5	100	0	0	0	0
	Tové	*S. latifolius*	0	0	0	0	1	100	0	0	0	0
Zone V	Agolime	*S. latifolius*	0	0	0	0	125	100	0	0	0	0

	Davié	*S. mombin*	0	0	0	0	1	100	0	0	0	0
	Djéménin	*S. latifolius*	0	0	2	4.88	36	87.8	2	4.88	1	2.44
	Gamé	*S. latifolius*	0	0	0	0	194	100	0	0	0	0
	Mawugbékopé	*S. latifolius*	0	0	0	0	52	100	0	0	0	0
		U. chamae	0	0	0	0	1	100	0	0	0	0
	Notsè	*S. latifolius*	0	0	0	0	91	100	0	0	0	0
Total			1	−	3	−	605	−	2	−	2	−

In the conditions of the current study, the abundance and frequency of the braconid parasitoid, *F. caudatus*, which was mainly associated with *C. cosyra* in the fruits of *S. latifolius*, was probably related to the fact that *F. caudatus* is more (i) specific (preference and performance) to *C. cosyra* on these fruits than the other braconid parasitoids recovered and (ii) competitive on this same host (*C. cosyra*) associated with the same host plant. Indeed, Vayssières *et al*. (2011, 2012), Badii *et al*. (2016), Sambo *et al*. (2019), Zida *et al*. (2022) have shown that in *S. latifolius* associated mainly with *C. cosyra*, *F. caudatus* was the most abundant and frequent native parasitoid than other native species such as *D. fullawayi*, *Fopius silvestrii* (Wharton), *Fopius desideratus* (Bridwell), *Psyttalia concolor* (Szépligeti), *Psyttalia cosyrae* (Wilkinson). In addition, as shown by the work of Gripenberg *et al*. (2010), Quilici and Rousse (2012), Cusumano *et al*.(2016), Ayelo *et al*. (2017), Das *et al*. (2017) in other parasitoids, females of *F. caudatus* are probably able to more easily identify (locate) the fruits of the *S. latifolius* plant containing the host (pre-imaginal stages of *C. cosyra*) and to choose (preference) among several species of Tephritidae developing in this fruit, the one (i.e. *C. cosyra*) whose pre-imaginal stages are the most apt to ensure a harmonious development (performance) of their progeny. All of the aforementioned information probably explains the high density of *F. caudatus* (compared to other braconid parasitoid species) observed in *S. latifolius* fruits during this study. However, the parasitism rates of *F. caudatus* in this fruit in the different surveyed zones were low (15.79 ± 3.75%). Therefore, for a possible use of *F. caudatus* against *C. cosyra* associated with fruits of economic importance such as mango (Salum *et al*., 2014; Vayssières *et al*., 2014; Zida *et al*., 2022), it is desirable to promote augmentative biological control. As a prelude to this control, it is necessary to maintain this natural enemy in its natural habitat (conservation biological control) and assess its demographic parameters in controlled and natural conditions for mass rearing and releases of individuals able to significantly reduce populations of the target fruit fly in agroecosystems.

Moreover, among the cultivated plants, only the pepper (vegetable) allowed the recovery of the parasitoid, *D. fullawayi* (1 individual) associated with the fruit fly, *C. capitata* (Tables 2 and 3). Figure 6 (Axis F1 mainly explained the contributions of fruit fly *C. cosyra*, braconid species *Bracon* sp., *F. caudatus*, *Fopius* sp., *Psyttalia* sp. and host plant *S. latifolius*; however, the fruit flies *Z. cucurbitae*, *D. ciliatus*, *Dacus punctatifrons* Karsch and the host plant *M. charantia* contributed to axis F2) and Table 1 showed that no parasitoid wasps emerged from the pupae obtained from the incubation of cucurbit fruits which allowed to rear *Z. cucurbitae*, *D. ciliatus* and *D. punctatifrons*. Likewise, no parasitoid wasps emerged from the pupae obtained from the incubation of the mangoes which allowed to rear *B. dorsalis* exclusively (Figure 6 and Table 1). However, previous studies have shown that in mango, *B. dorsalis* was associated with *Pachycrepoideus vindemmiae* (Rondani) in Benin (Vayssières *et al*., 2011). Similarly, *B. dorsalis* pupae obtained from mango and cashew allowed to recoverthe native braconid parasitoids *D. fullawayi*, *F. caudatus* and *P. concolour* in Ghana with low parasitism rates (Badii *et al*., 2016).

During this work, only 1 individual of *F. caudatus* was recovered from fruits of the *S. mombin* plant (wild fruit) associated exclusively with *B. dorsalis*. This sufficiently demonstrates that native parasitoid wasps, unable to significantly reduce the populations of *B. dorsalis* below the economic thresholds in orchards, consequently lead to considerable yield losses. It is for this reason that the koinobiont, solitary, ovo-pupal and exotic (native to Asia) endoparasitoid *Fopius arisanus* (Sonan) (Braconidae: Opinae) was introduced into West Africa via ICIPE (International Centre of Insect Physiology and Ecology). Releases of this parasitoid were done in Benin and Senegal and showed a significant reduction of *B. dorsalis* populations in mango orchards (Ndiaye *et al*., 2015; Gnanvossou *et al*., 2016). In addition, releases have also been done in Togo (Ekesi *et al*., 2016). However, to our knowledge, no database from these releases is available to date. In addition, during this study, *F. arisanus* was not found in the samples. Also, Karlsson *et al*. (2018) showed that the exotic parasitoid, *F. arisanus* was more competitive than the native parasitoid, *F. caudatus* in *C. cosyra*. It is therefore important to continue sampling and incubating cultivated and wild fruits in the different ecological zones over a long period of time to verify whether *F. arisanus* has successfully established itself in Togo after the releases. This will allow to set up an effective and long-term biological control against indigenous and exotic fruit flies of economic importance in Togo.

CONCLUSION

The incubation of fruits and vegetables from ecological zones III, IV and V allowed identifying 5 native braconid parasitoid species. Among these parasitoids, *F. caudatus* found in the three ecological zones was the most abundant, the most frequent and was associated with *C. cosyra* in *S. latifolius*. In *S. latifolius*, *F. caudatus* showed very high densities compared to other braconid species associated with *C. cosyra*. However, the parasitism rates of *C. cosyra* by these braconid species in *S. latifolius* were variable and relatively low. Considering these results, *F. caudatus* constitutes a potential candidate for augmentative biological control against *C. cosyra* in agro-ecosystems in Togo. As a prelude to this control, in-depth studies on the bio-ecology of *F. caudatus* should be considered in determing its demographic parameters in controlled and natural conditions.

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