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Research Article

Species Composition of Fruit Flies (Diptera: Tephritidae) on Selected Fruit Crops in Northeastern Ethiopia

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A study was conducted to characterize the species composition of fruit flies in South Wollo and North Wollo administrative zones of northeastern Ethiopia. Fruit flies were collected using two methods: rearing from infested mango, guava, and sweet orange fruits and trapping the adults with male lures and food-based attractants. Three fruit fly species were recovered from the fruits collected: *Bactrocera dorsalis, Ceratitis cosyra,* and *Ceratitis capitata*; in addition to these species, *Ceratitis fasciventris* was trapped. *Bactrocera dorsalis* was the most abundant species and accounted for 97.9 and 78.89% of the total trapped and emerged adults, respectively. The number of *B. dorsalis* and *C. capitata* showed a significant difference among trapping locations and attractants. The highest number of *B. dorsalis* was trapped with methyl eugenol at Kalu (722.2 flies per trap per week). Among the indigenous fruit fly species, *C. capitata* was higher at Habru which was guava and coffee-dominated habitat, whereas *C. cosyra* was relatively higher at Kobo which is mango dominated. More adults were trapped in male lure traps (97.03%) than in food-based attractants (2.97%). Hence, fruit fly management should focus on guava and mango crops which host all the fruit fly species, including the dominant *B. dorsalis*.

1. Introduction

Fruit flies (Diptera: Tephritidae) are one of the most diverse groups of insects, comprising over 4000 species in 481 genera [1]. They are considered by far the most important group of horticultural pests worldwide. Each continent is plagued by several fruit fly pests, both indigenous and invasive ones, causing tremendous economic losses (De Meyer et al. 2015). In addition to the direct losses through damage, they can negatively impact commodity trade through restrictions to market access [2].

Tephritidae are distributed worldwide in temperate, tropical, and subtropical regions [3]. The genus *Anastrepha* is restricted to the Western Hemisphere, with various species, while most of the *Bactrocera* are native to tropical South and Southeast Asia [4]). The genus *Ceratitis* is native to tropical Africa [5]. In most African countries, many indigenous fruit fly species belong to *Ceratitis*. However, *Bactrocera* spp. (mainly Asian origin) appear to dominate over *Ceratitis* populations [6]. A complex of fruit fly species commonly coexists in the fragmented fruit and vegetable production systems in Africa [7]. An important aspect of fruit fly management is accurate information on the species and their host spectrum [8].

Fruit flies, especially alien invasive species, constitute a major threat to horticulture in Africa [9]. Since the arrival of *Bactrocera dorsalis* (Hendel) on the African continent [10], direct yield losses in mango, depending on local conditions, cultivars, and seasons, have raised up to 90%, which is significantly higher than earlier losses attributed just to native fruit fly species [11].

In Ethiopia, different species of fruit flies have been reported to infest the berry and stone fruits in considerable extents [12–15]. However, most of the producers have not

recognized the fruit flies as a problem and did not associate fruit rotting with this pest [15]. Recently, the invasive species *B. dorsalis* is being reported as the most devastating mango fruit fly in eastern, southwestern, and central Ethiopia [14, 16, 17] even causing up to 100% loss on guava in central rift valley region after its entry [17], where *Ceratitis capitata* (Wiedemann) and *Ceratitis fasciventris* (Bezzi) were previously reported as a dominant species [18]. Recently, in the study area, up to 78% fruit infestation on guava and 28% on mango have been reported [19].

In northern Ethiopia especially northeastern part, having wide coverage of fruit crop production, the information about the species composition causing infestation on the major fruit crops of the area is not well studied, though this information primarily required to plan management options for the loss being caused. Hence, this research was conducted to characterize the species compositions in major fruit crop-producing areas in northeastern Ethiopia.

2. Materials and Methods

2.1. Study Areas

2.1.1. Fruit Collection Sites. The study was conducted in the South Wollo administrative zone (Kalu district), and North Wollo administrative zone (Habru and Kobo districts) of eastern Amhara, Ethiopia. A total of nine collection sites were selected in consultation with zone and district agricultural office experts, to represent the major mango, guava, and citrus fruit production areas of the respective districts. Three sites from each district were selected for the study. However, one fruit collection site from Kalu district (Degan) was omitted for guava fruit since there was no guava in the area during the study period. Table 1 presents the major areas surveyed and their approximate georeferenced positions.

Fruit crops are widely grown in the study area, being the most important mango, guava, orange, banana, and coffee. The districts were selected based on their fruit crop production potential purposively; Kalu and Kobo districts are well-organized fruit production areas, and Habru is a major guava production area besides mango, orange, and coffee in eastern Amhara.

2.1.2. Trap Sites. Three orchards were selected for adult trapping; the orchards were selected based on the availability of mango, guava, and citrus fruits, having an area of more than two hectares to accommodate the replicated attractant devices. The details of trapping sites are presented in Table 2.

2.2. Sampling Techniques. Two methods of sampling were employed to collect the species of fruit flies, rearing of larvae to the adult stage from infested mango, guava, and sweet orange fruits and trapping of adult fruit flies using food-based attractants and male lures.

2.3. Collection of Fruits. Samples of infested ripe fruit of 75.4 kg of mango, 212.6 kg of guava, and 8.27 kg of sweet orange were collected weekly for four consecutive weeks. Single samples ranged from 0.5 to 3.6 kg, 2.1 to 7.6 kg, and 0.01 to 1 kg for mango, guava, and sweet orange, respectively. Fruit collection was conducted during peak maturing periods of fruit crops, between July and December 2018: July and August for mango and October-November for guava and sweet orange. The sample size varies among crops and study areas due to the area coverage differences in the study area.

2.4. Rearing of Fruit Flies from Infested Fruits. The matured fruits collected purposively having confirmed oviposition puncture were weighed, counted, and placed in plastic containers with a net lid and sterilized sand at the bottom and then incubated for about six weeks. Fruits were placed in containers in groups of 5–20 depending on the fruit and container size.

The fruits in the containers were checked in the three-day interval for adult flies. Emerged adults were provided with honey into the roof of the cage and water (cotton wool soaked with water) on the floor of the cage for feeding. Emerged adults were left in the cage for 3–5 days for growth and full development of morphological development. The adult fruit flies that emerged from different fruits was counted and preserved in 70% alcohol for identification [7]. Identification was performed at the Laboratory of Entomology at the Sirinka Agricultural Research Center with the help of a guide book [7], and for confirmation, voucher specimens were sent to the International Center of Insect Physiology and Ecology (ICIPE), Addis Ababa, Ethiopia.

2.5. Collection of Fruit Flies Using Different Attractants. Three different male lures, namely, methyl eugenol (ME), trimedlure (TML), and terpinyl acetate (TA), and two food-based attractants, torula yeast and protein hydrolase, have been used to attract fruit flies, since different attractants can be combined to reach the possible higher number of fruit flies [20]. Finally, the specialized male lures were evaluated with food-based attractants. ME for *B. dorsalis* and TML and TA for *Ceratitis* species were evaluated along with torula yeast and protein hydrolase. For further details of the attractant's longevity and specificity, see Table 3.

Empty water bottles of one-liter capacity were used for making a modified trap by cutting the bottle at the 2/3 level; the cutoff neck served as an entry funnel into the rest of the bottle; then, the modified trap was hanged with a binding wire by penetrating at the bottom of the bottle. Baits with polymeric plug formulation were smeared in the inner side of the opened bottle, whereas liquid-formulated attractants were placed in the bottle using a piece of cotton wick. Locking from the opened side of the bottle with the binding wire by dipping in a mixture of carbaryl (Sevin 85% WP) in a 1 to 4 ratio with attractants was used to kill the fly in the bottle. The trap bottles with the male lures and food-based attractants were suspended with a binding wire on mango trees at a height of 1.5–2 meters from the ground for eight consecutive weeks (1 July to 26 August 2018). Each lure was replicated three times in each trap area with a minimum spacing of 20 meters among and 50 meters with attractant

Table 1: Fruit collection sites with their approximate latitudes, longitudes, and altitudes.

Zone	District	Kebele/collection site	Approximate latitude (N)	Approximate longitude (E)	Approximate altitude (masl)
North Wollo	Kobo	Aradum	12° 4′ 7″	39° 37′ 44″	1466
		Menjelo	12° 2′ 34″	39° 37′ 53″	1582
		Durlebes	11° 53′ 58″	39° 4′ 15″	1395
North Wollo	Habru	Girana	11° 34′ 13″	39° 42′ 59″	1437
		Anto	11° 41′ 2″	39° 38′ 5″	1705
		Wutie	11° 38′ 0″	39° 37′ 37″	1794
South Wollo	Kalu	Habru01	10°55′ 1″	39° 46′ 52″	1421
		Habru02	10° 55′ 34″	39° 43′ 29″	1594
		Degan	11° 7′ 52″	39° 52′ 42″	1485
		SARC			1850

*SARC = Sirinka Agricultural Research Center wherein the laboratory-based experiment was conducted, masl = meters above sea level, kebele = lower administrative structure in Ethiopia.

Table 2: Descriptions for the trap sites location, area, altitude, and cultivated fruit crops.

Location	Farm area (ha)	Altitude	Fruits cultivated (common and scientific name)	Remarks
Kalu	4	1421	Mango *Mangifera indica* L., different varieties, lemon *Citrus limon* (L.) burman f., sweet orange *Citrus sinensis* (L.), different varieties avocado *Persea americana* miller., guava *Psidium guajava* L., coffee *Coffea arabica,* papaya *Carica papaya* L	Habru01 nursery and semifruit production site
Habru	2.5	1705	Coffee (dominant), avocado, mango, guava, and geisho *Rhamnus prinoides* L'Herit	Anto farmer's field
Kobo	2.5	1395	Mango (dominant), avocado, sweet orange, different varieties	Durlebes *kebele* agricultural office's model fruit production farm

Table 3: Pheromone lures and food-based attractants and their formulation, field longevity, and specificity for fruit fly species [21].

Common name	Acronym	Chemical	Formulation	Field longevity (weeks)	Species
Trimedlure	TML	*Tert*-butyl 4 (and 5)-chloro-2-methylcyclohexane-1-carboxylate	Polymeric plug/panel	6	*Ceratitis* spp
Methyl eugenol	ME	Benzene, 1,2-dimethoxy-4-(2-propenyl)	Polymeric plug/panel	6	*Bactrocera* spp
Terpinyl acetate	TA		Polymeric plug/panel		*Ceratitis* spp
Torula yeast/borax	TY	Torula yeast/borax	Pellet	1-2	All
Protein derivatives	HP	Hydrolized protein	Liquid	1-2	All

types; there were three traps without any attractant with carbaryl (Sevin 85% WP) as control at each trap sites (totally, 18 traps per site including the control treatments); the trap sites were 60–180 kilometers apart from each other.

New water bottle traps were used to avoid contamination of the outer surface of the bottles with the baits, which may keep the flies to settle to the outer side of the bottle instead of getting in. The trap-holding wires were smeared with grease to prevent the entry of ants. Renewing of the attractants was employed in a weekly interval for food-based attractants (torula yeast and protein hydrolase) and monthly for male lures (ME, TA, and TML). After each inspection, there was a clockwise rotation of traps; inspection was employed in a 7 days interval [20]. The trapped flies were preserved in vials containing ethanol 70% for further identification. The samples were identified at the Laboratory of Entomology at the Sirinka Agricultural Research Center with the help of color print guide books [7, 22]; for confirmation, voucher specimens were sent to the International Center of Insect Physiology and Ecology (ICIPE), Addis Ababa, Ethiopia.

Meteorological parameters like maximum and minimum temperature, solar radiation, and rainfall data were taken from the MARKSIM DSSAT weather file generator.

The relative abundance of each fruit fly species was estimated as the proportion of the total adult of each fruit fly species and the total adult collected of all fruit fly species:

$$\text{relative abundance } (\%) = \frac{\mathbf{Isi}}{\sum \text{Nsi}} X\ 100, \quad (1)$$

where Isi is the total number of individual species and $\sum$ Nsi is the total number of the species population.

Flies per trap per week was estimated with the following daily formula by contextualizing to the week basis:

$$\text{FTD} = \frac{F}{T \times D}, \quad (2)$$

where F is the total number of fruit flies, T is the number of inspected traps, and D is the average number of days traps were exposed in the field [21].

2.6. Data Analysis. Data for all insect counts were converted to the number of flies per trap per week and were subjected to ANOVA using the generalized linear model (PROC GLM, SAS Institute). ANOVAs were performed on catch data for all species, considering locality and attractants as main factors. The data were transformed using procedure $\text{Log}_{10}(x+1)$ for *B. dorsalis* and $\sqrt{x+0.5}$ for *C. capitata* and *C. cosyra* species. Means were separated by the Student–Newman–Keuls Test when ANOVA was significant at $p < 0.05$.

3. Results

3.1. Fruit Fly Species and Their Abundance. A total of 7064 adult fruit flies have emerged from the collected three fruit hosts' species. Three fruit fly species were recovered, namely, *B. dorsalis*, *C. cosyra*, and *C. capitata. Bactrocera dorsalis* was the most abundant species and accounted for 78.89% of the total emerged adults; *C. capitata* contributed 17.19% of the emerged adult fruit flies, whereas *C. cosyra* had the lowest proportion of emerged adults from the infested fruits collected (3.92%) (Figure 1).

Bactrocera dorsalis was also the dominant species from the trapped adults that accounted for 97.9%; *Ceratitis fasciventris* was observed only from the trap with the lowest proportion of trapped adults (0.03%) (Figure 1).

All of the observed fruit fly species emerged from guava and mango; one fruit fly species (*B. dorsalis*) emerged from sweet orange. Only *B. dorsalis* emerged from all observed host fruits, indicating its polyphagous nature. *Ceratitis fasciventris* was not reared from the collected host fruits, but it was found only from the trap with the lowest proportion of trapped adults. However, this species was reported as dominant on mango in eastern Ethiopia [14].

Bactrocera dorsalis, C. cosyra, and *C. capitata* represented the 71.95%, 56.68%, and 83.36%, respectively, of emerged adults from guava fruits and 27.9, 43.32, and 16.64%, respectively, from mango fruits (Figure 2). On the other hand, sweet orange contributed 0.14% adult emergence only for *B. dorsalis*. The three evaluated hosts were observed to have a simultaneous occurrence of *B. dorsalis* and *Ceratitis* species. As shown in Figure 2, *B. dorsalis* shared mango and guava with *C. capitata* and *C. cosyra*; on sweet orange, *B. dorsalis* was the only species reared.

The invasive species *Bactrocera dorsalis* dominated the indigenous species of fruit flies in the current study which is supported by the earlier reports in different parts of Ethiopia, and it has established in some parts of eastern Ethiopia [14]. *Bactrocera dorsalis* is the dominant species reared from mango fruits, followed by *C. fasciventris* and *C. cosyra* in western Ethiopia [15]; also in southwestern Ethiopia, it was the predominant species, with 96% of captures and the only fruit fly species emerging from mango fruits incubated [16]. In other African countries, *B. dorsalis* was reported as the most prevalent species (98%) in Uganda on mango [23]. In Kenya, it displaced *C. cosyra* on mango within 4 years from invasion, constituting 98 and 88% of the total population in traps and mango fruit at Nguruman, respectively [24].

The polyphagous nature of the species had been reported in different countries out of its origin. In Tanzania, suitable hosts are available throughout the year for *B. dorsalis*. Mango appears to be the principal host in the period October to January, while guava is the principal host in the period February to August [6]. However, mango is an important host for *C. cosyra* during the Mango fruiting season [6]. In Kenya, before the arrival of *B. dorsalis*, the indigenous fruit fly species *C. cosyra* was the predominant fruit fly pest of mango [24]. *Bactrocera dorsalis* is also present in indigenous coastal forests in Kenya and is capable of reproducing in wild fruits; hence, a sufficient reproductive base exists even when mangoes are not fruiting [25]. From the survey conducted in Peninsular Malaysia to determine the infestation levels of fruit flies, *B. dorsalis* was recorded as the most abundant species (91%), compared to *Bactrocera carambolae* Drew and Hancock (9%) [26].

In this study, *C. capitata* was mostly (83.36%) reared from guava fruit, and a significantly small amount (16.64%) was reared from mango fruit (Figure 2). In addition, this species contributed a very small amount of the trapped adult fruit flies (1.2%) (Figure 1), whereas significantly more specimens were reared from fruits (17.19%) (Figure 2). This is probably due to the time of occurrence and trapping time difference, since the trap was left in the field during July and August, which is before the maturity of guava, whereas it is the time for the peak maturing of mango in the study areas, especially late-maturing improved varieties. It may be due to displacement of the indigenous species on mango, as Vargas et al. [27] reported that, when *B. dorsalis* became established in Hawaii, it displaced *C. capitata* in many hosts and lowland habitats.

A significantly higher proportion of *C. cosyra* (43.32%) were reared on mango fruit than *C. capitata* and *B. dorsalis* (Figure 2). This result is supported by Ekesi et al. [24], who stated that *C. cosyra* has not been completely displaced in mango orchards at Nguruman. There are probably some advantages this species allows for some level of coexistence with *B. dorsalis*. One advantage may be its more specialized host-searching abilities on mangoes have been linked more closely to this host plant over a long period in Africa. Also, the same author reported that *B. dorsalis* frequently shared the same fruits with the indigenous fruit fly species *C. cosyra* but often occurred at higher numbers than *C. cosyra* [28]. *Ceratitis cosyra* dominated in most wild fruits [8].

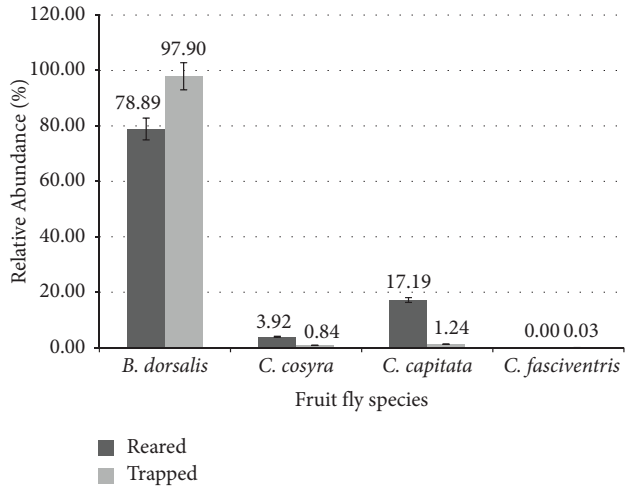

Figure 1: Relative abundance of fruit flies recovered from the host fruits and trapped through different attractants in eastern Amhara, Ethiopia, in 2018.

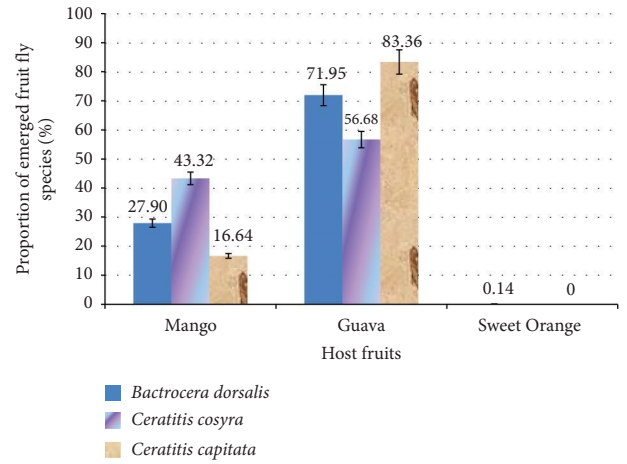

Figure 2: Contribution of each host fruit on the total number of emerged fruit flies in eastern Amhara, Ethiopia, in 2018.

The economic importance of *C. cosyra* has been growing since the widespread commercialization of mango and the introduction of exotic mango varieties. Late ripening mango varieties are the ones that suffer the most, due to *C. cosyra* infestation. *Ceratitis cosyra* is widespread in sub-Saharan Africa [2] and the dominant one in Abugubeiha area, Sudan [29]. This probably is the other reason for the rearing of a proportionally higher number of *C. cosyra* on mango fruits; i.e., the study covered the peak harvesting period of late-maturing improved mango varieties.

In the current study area, from sweet orange, the only emerged fly was *B. dorsalis*, meaning that it completely displaced other fruit flies, as previously reported in Tanzania, in the some host *C. sinensis* [6].

3.2. Fruit fly Species Collected through Traps. Overall, 27641 (27060 *B. dorsalis*, 231 *C. cosyra*, 342 *C. capitata*, and 8 *C. fasciventris*) specimens were collected. The total number of specimens was higher in male lure traps (97.03%) than in food-based attractants (2.97%) (Table 4). Methyl eugenol caught 97.5% *B. dorsalis*, and the remaining 1.54 and 0.91% of specimens were collected with protein hydrolase and torula yeast, respectively (Table 4). TML captured 78.35% of *C. cosyra*, followed by TA with 12.56%, and the remaining 5.63 and 3.46% were collected by torula yeast and protein hydrolase, respectively.

3.2.1. Bactrocera dorsalis. Analysis of variance showed that there is a significant difference between treatments (attractants) ($F = 265.04$; DF = 3; $p < 0.001$) for *B. dorsalis* (Table 5). The highest number of *B. dorsalis* per trap per week was trapped at Kalu with methyl eugenol (722.2 flies trapped per trap per week (FTW)) followed by the same attractant at Kobo (376.5) and Habru (90) (Table 5). Both food-based attractants, torula yeast and protein hydrolase, trapped much lower *B. dorsalis* than the male lure (ME), statistically in par each other (Table 5). According to the earlier reports, torula yeast would be a better monitoring tool than other attractants for *B. dorsalis* like biolure [30], even more effective than hydrolyzed proteins over time [21].

For *B. dorsalis*, the effects of attractants were consistent between locations, with ME attracting a significantly higher number of adults. Methyl eugenol is a natural phenylpropanoid highly attractive to *B. dorsalis* males [31]. Males of the *B. dorsalis* are strongly attracted to ME [32]. This research also confirmed its high attractiveness.

The number of *B. dorsalis* per trap per week was shown to be significantly different among trapping locations ($F = 59.27$; DF = 2; $p < 0.001$), where the overall mean of adult *B. dorsalis* per trap per week was significantly higher at Kalu (184.4) which is eight times as high as at Habru (23.6) and two times as high as at Kobo (96.2) (Table 5); this is probably due to the year round availability of diverse reservoir alternative host fruit species and varieties at and around the trap site at Kalu (Table 2). Also, since the Kalu trap site is a governmental nursery and semifruit production site, fruits set by mother plants of different varieties escaping from the purposive abortion of flowers for the preparation of scion may be left on the field; also, it is the most probable entry point of the exotic species (*B. dorsalis*) into the region, since they use seed sources for rootstock preparation from southern Ethiopia where the species was reported earlier [15, 16].

3.2.2. Ceratitis Species. There were significant differences in the number of *C. capitata* between attractants ($F = 53.62$; DF = 4; $p < 0.001$); the highest number of *C. capitata* was trapped by TML at Habru (4.83 adult flies per trap per week); this lure also trapped a significantly higher number of flies at Kalu (2.79) and Kobo (1.88), while the other male lure TA recorded par with the food-based attractants except at Habru (1.29) (Table 6). This result is analogous with some previous reports as trimedlure is an effective lure for surveying and monitoring activities of *C. capitata* males [33]. Also, other *Ceratitis* species are known to be attracted to it [34].

Table 4: Mean fruit fly counts attracted by the male lure and food-based attractants.

Species	Attractants										Total
	Male lures						Food-based				
	ME		TML		TA		Protein hydrolase		Torula yeast		
	Number	%	Number	%	Number	%	Number	%	Number	%	
B. dorsalis	26386	97.5	0		2	0.05	426	1.54	246	0.91	27060
								2.45			
C. capitata	0		120	35.1	102	29.8	71	20.8	49	14.3	342
				64.9				35.1			
C. cosyra	0		181	78.3	29	12.5	8	3.5	13	5.6	231
				90.8				9.1			
C. fasciventris	0			0			3	37.5	5	62.5	8
								100			
Overall			97.03%					2.97%			27641

Table 5: Mean *B. dorsalis* adults trapped per week at Kalu, Kobo, and Habru districts in eastern Amhara, Ethiopia, in 2018.

Sources of variations		*Bactrocera dorsalis* number/per trap per week
Location	Attractants	
Habru	Methyl eugenol	90 (1.91)c
	Protein hydrolase	2.7 (0.39)f
	Torula yeast	1.8 (0.32)f
	Control	0.0 (0)g
Mean		23.6
Kalu	Methyl eugenol	722.2 (2.81)a
	Protein hydrolase	9.4 (0.89)d
	Torula yeast	6.0 (0.67)e
	Control	0.0 (0)g
Mean		184.4
Kobo	Methyl eugenol	376.5 (2.56)b
	Protein hydrolase	5.7 (0.61)e
	Torula yeast	2.5 (0.43)f
	Control	0.0 (0)g
Mean		96.2
Grand mean		101.4
CV (%)		30.7
Location p value		<0.001
Attractant p value		<0.001

Note. Value in parenthesis shows $\text{Log}_{10}(x+1)$ transformed results of the data.

Table 6: Mean *Ceratitis* species adults trapped per week at Kalu, Kobo, and Habru districts in eastern Amhara, Ethiopia, in 2018.

Source of variations		*Ceratitis*	*Ceratitis*	*Ceratitis*
Location	Attractants	*capitata* number/trap/week	*fasciventris* number/trap/week	*cosyra* number/trap/week
Habru	Trimedlure	4.83 (2.16)a	0.00 (0.71)	0.00 (0.71)b
	Terpinyl acetate	1.29 (1.30)c	0.00 (0.71)	0.00 (0.71)b
	Protein hydrolase	0.71 (1.04)d	0.21 (0.79)	0.54 (0.90)b
	Torula yeast	0.42 (0.92)de	0.04 (0.73)	0.25 (0.82)b
	Control	0.00 (0.71)e	0.00 (0.71)	0.00 (0.71)b
Mean		1.45	0.05	0.16
Kalu	Trimedlure	2.79 (1.68)b	0.00 (0.71)	0.00 (0.71)b
	Terpinyl acetate	0.33 (0.87)de	0.00 (0.71)	0.00 (0.71)b
	Protein hydrolase	0.04 (0.73)e	0.54 (0.85)	0.29 (0.82)b
	Torula yeast	0.13 (0.77)e	0.08 (0.74)	0.38 (0.86)b
	Control	0.00 (0.71)e	0.00 (0.71)	0.00 (0.71)b
Mean		0.66	0.13	0.13
Kobo	Trimedlure	1.88 (1.50)b	0.00 (0.71)	0.00 (0.71)b
	Terpinyl acetate	0.17 (0.79)de	0.00 (0.71)	0.00 (0.71)b
	Protein hydrolase	0.00 (0.71)e	0.21 (0.79)	7.25 (2.23)a
	Torula yeast	0.04 (0.73)e	0.42 (0.86)	0.21 (0.81)b
	Control	0.00 (0.71)e	0.00 (0.71)	0.00 (0.71)b
Mean		0.42	0.13	1.49
Grand mean		0.84	0.10	0.59
CV (%)		33.5	28.7	56.6
Location p value		<0.001	0.63	0.004
Attractant p value		<0.001	0.06	<0.001

Note. Value in parenthesis shows square root transformed results of the data.

There was also a significant difference for *C. capitata* among the trap sites ($F = 15.04$; DF = 2; $p < 0.001$). The highest number of *C. capitata* was trapped at Habru (1.45) followed by Kalu (0.66) and Kobo (0.42) (Table 6). The study was conducted in the area where *C. capitata* and *C. fasciventris* were previously reported as dominant species [18]. The current result showed the displacement of the indigenous *Ceratitis* species by the invasive ones

(*B. dorsalis*), especially from the lowland habitats, since the Habru site was relatively at higher altitude. This finding is in line with analogous results reported by Ekesi et al. [28], who reported a significant inverse relationship between numbers of flies and elevation. On the other hand, *C. capitata* persists from the displacement by the invasive species (*B. dorsalis*) in lowlands on coffee [24]. This is probably the other reason for the relatively higher *C. capitata* catches at Habru, which is a known coffee production area in the region, and may explain the coexistence of *C. capitata* with the dominant species *B. dorsalis*.

The number of *C. fasciventris* is shown to be non-significant among trapping sites ($F = 0.46$; DF = 2; $p = 0.63$) and attractants ($F = 3.69$; DF = 4; $p = 0.06$) (Table 6). Even the overall number of *C. fasciventris* is shown to be negligible, from 0.05 flies per trap per week at Habru to 0.13 flies at Kalu and Kobo. The limited number of *C. fasciventris* was trapped with torula yeast and protein hydrolase-baited traps in all sites. Unlike other fruit fly species trapped during this study, *C. fasciventris* was not found in collected fruits; however, this species was reported as a dominant species especially on citrus (Fardu et al. 2009).

The weekly trapped *C. cosyra* showed a significant difference for both attractants ($F = 7.90$; DF = 4; $p < 0.001$) and trapping sites ($F = 5.71$; DF = 2; $p = 0.004$) (Table 6). The highest number of *C. cosyra* was trapped by protein hydrolase at Kobo (7.25 flies per trap per week), followed by the same attractant at Habru (0.54) and torula yeast at Kalu (0.38). However, most of the attractants were not statistically significant even with the control traps, except protein hydrolase at Kobo (Table 5). Among the trap sites, *C. cosyra* was higher at Kobo (1.49). This site was mango dominated, as the whole Kobo district, following the Kobo-Girana valley irrigation scheme, is a major mango producer. *Ceratitis cosyra,* widespread in sub-Saharan Africa [2], has been linked more closely to mango over a long period in Africa and has more specialized host-searching abilities on mangoes [24].

Food lures are generic by nature, and besides the target fruit fly species, traps tend to catch a wide range of other tephritid and nontephritid flies [21]. Both PH and TY had trapped the species detected in all trapping sites through male lures in a comparative amount for *Ceratitis* species, and this may also be considered as an additional advantage for the survey and monitoring purposes.

4. Conclusion

Monitoring of Tephritidae fruit flies in eastern Amhara revealed the existence of four fruit fly species under the genera *Ceratitis* and *Bactrocera*. These are *C. capitata, C. cosyra*, *C. fasciventris,* and *B. dorsalis*. The last one is the dominant species from the trapped and emerged adults in the study area. From the indigenous species, *C. capitata* was commonly trapped by TML-baited traps at Habru, which is a guava and coffee dominated and relatively higher altitude trap site. The higher proportion of *C. cosyra* was reared on mango and trapped at Kobo, which is a mango-dominated site, mainly with protein hydrolase-baited traps. *Ceratitis fasciventris* was observed only from the traps with the lowest proportion. All the observed fruit fly species emerged from guava and mango, from sweet orange *B. dorsalis* only. More adults were trapped in male lure traps (97.03%) than food-based attractants (2.97%); hence, fruit fly management should focus on guava and mango crops which host all the fruit fly species, including the dominant *B. dorsalis*.

Data Availability

The data for this paper are available from the corresponding author upon request.

Disclosure

This paper is part of MSc thesis presented at Bahir Dar University.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

A.M. and Y.W. were responsible for conceptualization. A.M., M.A., and Y.W. were responsible for methodology. A.M. was responsible for formal analysis. A.M. and M.A. were responsible for investigation. A.M. was responsible for writing the original draft. A.M., M.A., and Y.W. were responsible for writing, reviewing, and editing.

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References

[1] S. Jaipal, K. Asha, S. M. Bikash Das, and S. Kumar, "Diversity and population dynamic of fruit flies species in methyl eugenol based parapheromone traps in Jharkhand region of India," *An International Quarterly Journal of Environmental Sciences*, vol. 1, pp. 57–60, 2012.

[2] I. R. Tanga, "Fruit fly research and development in Africa-Towards a sustainable management strategy to improve horticulture," in *Fruit Fly Research and Development in Africa- towards a Sustainable Management Strategy to Improve Horticulture*, S. Ekesi, S. A. Mohamed, and M. De Meyer, Eds., pp. 71–106, Springer International Publishing, Switzerland, 2016.

[3] Ippc (International Plant Protection Convention), *ISPM 27 Diagnostic Protocols for Regulated Pests DP 9: Genus Anastrepha Schiner*, Ippc, Rome, Italy, 2015.

[4] Iaea (International Atomic Energy Agency), *The South American Frut Fly Anastrepha Fraterculus (Wied) Advances in*

Artificial Rearing, Taxonomic Status and Biological Studies, Iaea, Vienna, Austria, 1996.

[5] I. M. White and M. Elson-Harris, *Fruit Flies of Economic Significance: Their Identification and Bionomics*, International Institute of Entomology, London, UK, 1992.

[6] M. W. Mwatawala, M. De Meyer, R. H. Makundi, and A. P. Maerere, "Host range and distribution of fruit-infesting pestiferous fruit flies (Diptera, Tephritidae) in selected areas of Central Tanzania," *Bulletin of Entomological Research*, vol. 99, no. 6, pp. 629–641, 2009.

[7] S. Ekesi, K. Billah, and D. Osogo, *A Field Guide to the Management of Economically Important Tephritid Fruit Flies in Africa*, Icipe Science Press, Nairobi, Kenya, 2nd edition, 2007.

[8] K. Badii, M. Billah, K. Afreh-Nuamah, and D. Obeng-Ofori, "Species composition and host range of fruit-infesting flies (Diptera: Tephritidae) in northern Ghana," *International Journal of Tropical Insect Science*, vol. 35, no. 03, pp. 137–151, 2015.

[9] S. Ekesi, M. De Meyer, S. A. Mohamed, M. Virgilio, and C. Borgemeister, "Taxonomy, ecology, and management of native and exotic fruit fly species in Africa," *Annual Review of Entomology*, vol. 61, no. 1, pp. 219–238, 2016.

[10] R. A. I. Drew, K. Tsuruta, and I. W. White, "A new species of pest fruit fly (Diptera: Tephritidae: Dacinae) from Sri Lanka and Africa," *African Entomology*, vol. 13, no. 1, pp. 149–154, 2005.

[11] M. De Meyer and S. Ekesi, *Fruit Fly Research and Development in Africa- towards a Sustainable Management Strategy to Improve Horticulture*, Springer International Publishing, Switzerland, 2016.

[12] A. Dagnew, D. Belew, B. Admassu, and M. Yesuf, "Citrus production, constraints and management practices in Ethiopia: the case of <i>Pseudocercospora<i> leaf and fruit spot disease," *Science, Technology and Arts Research Journal*, vol. 3, no. 2, pp. 4–18, 2014.

[13] A. Chemeda, G. Emana, S. Emiru, and H. Hindorf, "Coffee berry insect pests and their parasitoids in the Afromontane rainforests of southwestern Ethiopia," *East African Journal of Sciences*, vol. 5, no. 1, pp. 41–50, 2011.

[14] G. Dawit, A. Firdu, and B. Yibrah, "Species composition of fruit flies (Diptera: Tephritidae) and extent of damage on mango fruit in eastern Ethiopia," *International Journal of Innovation and Scientific Research*, vol. 19, no. 1, pp. 95–102, 2015.

[15] W. Fikru, A. Firdu, and B. Yibrah, "Species composition of fruit flies (Diptera: Tephritidae) and extent of infestations on mango (*Mangifera indica* L.) in Western Ethiopia," *Journal of Natural Sciences Research*, vol. 8, no. 11, pp. 104–112, 2018.

[16] M. Fekadu and T. Zenebe, "Status of *Bactrocera invadens* (Diptera: Tephritidae) in mango-producing areas of arba minch," *Journal of Insect Science: Short Communication*, vol. 3, no. 3, pp. 1–3, 2015.

[17] D. Tibebe, *The Chemical Ecology of the oriental Fruit Fly Bactrocera Dorsalis and the Potential for Novel Odor-Based Management Tools*, Swedish University of Agricultural Sciences, Alnarp, Sweden, 2017.

[18] A. Ferdu, D. Mohammed, and B. Difabachew, "Review of research on fruit crop diseases in Ethiopia," in *Increasing Crop Production through Improved Plant Protection Volume II*, A. Tadesse, Ed., pp. 69–92, plant protection society of Ethiopia and EIAR, Addis Ababa, Ethiopia, 2009.

[19] A. Mihretie, M. Abera, and Y. Weldehawariat, "Fruit flies damage on selected fruit crops in northeastern Ethiopia," *Indian Journal of Entomology*, vol. 82, no. 4, pp. 599–605, 2020.

[20] Ippc (International Plant Protection Convention), *International Standards for Phytosanitary Measures, Draft Appendix to ISPM 26:2006 Fruit Fly Trapping*, Ippc, Rome, Italy, 2010.

[21] Iaea, *Trapping Guidelines for Area Wide Fruit Fly Programmes (No. TG/FFP-2003)*, International Atomic Energy Agency, Vienna, Austria, 2003.

[22] J. S. Choudhary, N. Naaz, and C. S. Prabhakar, *Field Guide For Identification Of Fruit Fly Species Of Genus Bactrocera Prevalent In and Around Mango (No.: R-43/)*, ICAR Research Complex for Eastern Region Research Centre, Ranchi, India, 2014.

[23] C. M. Nankinga, B. E. Isabirye, H. Muyinza, I. Rwomushana, P. C. Stevenson, and A. Mayamba, "Fruit fly infestation in mango: a threat to the horticultural sector in Uganda," *Uganda Journal of Agricultural Sciences*, vol. 15, no. 1, pp. 1–14, 2014.

[24] S. Ekesi, M. K. Billah, P. W. Nderitu, S. A. Lux, and I. Rwomushana, "Evidence for competitive displacement of *Ceratitis cosyra* by the invasive fruit fly *Bactrocera invadens* (Diptera: Tephritidae) on mango and mechanisms contributing to the displacement," *Journal of Economic Entomology*, vol. 102, no. 3, pp. 981–991, 2009.

[25] S. A. Lux, R. S. Copeland, I. M. White, A. Manrakhan, and M. K. Billah, "A new invasive fruit fly species from the *Bactrocera dorsalis* (Hendel) Group Detected in East Africa," *International Journal of Tropical Insect Science*, vol. 23, no. 04, pp. 355–361, 2003.

[26] M. Salmah, N. A. Adam, R. Muhamad, W. H. Lau, and H. Ahmad, "Infestation of fruit fly, *Bactrocera* (Diptera: Tephritidae) on mango (*Mangifera indica* L.) in peninsular Malaysia," *Journal of Fundamental and Applied Sciences*, vol. 9, no. 2S, pp. 799–812, 2018.

[27] R. I. Vargas, L. Leblanc, R. Putoa, and A. Eitam, "Impact of introduction of *Bactrocera dorsalis* (Diptera: Tephritidae) and classical biological control releases of *Fopius arisanus* (Hymenoptera: *braconidae*) on economically important fruit flies in French Polynesia," *Journal of Economic Entomology*, vol. 100, no. 3, pp. 670–679, 2007.

[28] S. Ekesi, P. W. Nderitu, and I. Rwomushana, "Field infestation, life history and demographic parameters of the fruit fly*Bactrocera invadens*(Diptera: Tephritidae) in Africa," *Bulletin of Entomological Research*, vol. 96, no. 4, pp. 379–386, 2006.

[29] Maisoon Mohammed Eltahir Ali, *Studies on the Distribution and Integrated Management of Fruit Flies in Sudan*, PhD Dissertation at Sudan University of Science and Technology, Sudan, 2019.

[30] S. Ekesi, S. Mohamed, and C. M. Tanga, "Comparison of food-based attractants for *Bactrocera invadens* (Diptera: *Tephritidae*) and evaluation of mazoferm-spinosad bait spray for field suppression in Mango," *Journal of Economic Entomology*, vol. 107, no. 1, pp. 299–309, 2014.

[31] A. Khrimian, E. B. Jang, J. Nagata, and L. Carvalho, "Consumption and metabolism of 1, 2-dimethoxy-4-(3-fluoro-2-propenyl) benzene, a fluorine analog of methyl eugenol, in the oriental fruit fly *Bactrocera dorsalis* (hendel)," *Journal of Chemical Ecology*, vol. 32, no. 7, pp. 1513–1526, 2006.

[32] T. E. Shelly, J. Edu, and D. Mcinnis, "Pre-Release consumption of methyl eugenol increases the mating competitiveness of sterile males of the oriental fruit fly, *Bactrocera*

dorsalis, in large field enclosures," *Journal of Insect Science*, vol. 10, no. 8, pp. 1–16, 2010.

[33] T. G. Grout, J. H. Daneel, A. B. Ware, and R. R. Beck, "A comparison of monitoring systems used for *Ceratitis* species (Diptera: Tephritidae) in South Africa," *Crop Protection*, vol. 30, no. 6, pp. 617–622, 2011.

[34] M. Virgilio, T. Backeljau, N. Barr, and M. D. Meyer, "Molecular evaluation of nominal species in the *Ceratitis fasciventris, C. anonae, C. rosa* complex (Diptera: Tephritidae)," *Molecular Phylogenetics and Evolution*, vol. 48, no. 1, pp. 270–280, 2008.